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**Universal Communication Model and  
Evaluation with the Elderly Society**

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## ABSTRACT

Telecommunication uses today various devices, operating systems, network technologies and applications. The multiplicity and diversity of these items are expected to increase due to the development of new technologies. As a result communication becomes a challenge. Communication is according to the World Health Organization a basic requirement for participation of elderly people in the society. In this thesis the architecture model "Universal Communication Model" (UCM) for the unified application of these items is developed and investigated. The future society will merely be 60+ and lowered physical abilities for communication need to be compensated. Two hypotheses that represent challenges of the UCM are provided and investigated: First, "Elderlies have difficulties in stress and ad-hoc situations to cope with ICT solutions" (H 1), and second "Elderlies have problems to reach destinations" (H 2). Both hypotheses are divided into sub-hypotheses without and with UCM support.

Two use cases are applied to the UCM: Elderly father at home called by his daughter from her car, and disoriented grandma walking to her appointment at the medical clinic using the public transportation system.

The two use cases are detailed with scenarios and corresponding prototypes. 24 tasks for elderly probands are developed and executed in a laboratory setting with 30 elderlies (including a questionnaire): Half of the tasks, namely twelve, are designed without the UCM and the other half with the application of the UCM. The time measurements to solve the tasks are evaluated using two statistical methods: The Euclidean distance and the Kullback-Leibler divergence of the measured data distributions and the corresponding Gaussian distributions are computed.

The experiments demonstrate that the task execution durations were reduced by a factor of up to six due to the application of the UCM (compared to the situation without UCM). And the (qualitative) satisfaction factor of the probands increased by a factor of up to four for all tasks due to the seamless and multimodal UCM. These results show that the UCM supports communication for the elderly society in a seamless and intuitive way.

Keywords: Universal Communication Model, Architecture Model, Future Media Technologies, Ubiquitous / Pervasive Communication, Communication Scenario for Elderly.



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**LIST OF ACRONYMS AND ABBREVIATIONS**

2G.....	Second Generation
3d.....	Three dimensional
3G.....	Third Generation
3GPP.....	3 <sup>rd</sup> Generation Partnership Project
4G.....	Fourth Generation
5G.....	Fifth Generation
6G.....	Sixth Generation
7G.....	Seventh Generation
AAA.....	Authentication, Authorization, and Accounting
AAAH.....	AAA Home
AAL.....	Ambient Assisted Living
ABS.....	Anti-Lock System of the Brakes
A-GPS.....	Assisted GPS
AMC.....	Architecture for Ubiquitous Mobile Communications
AmI.....	Ambient Intelligence
AR.....	Augmented Reality
AR (only in Section 3.3.5).....	Access Router
AV.....	Augmented Virtuality
Car-UCM.....	Universal Communication Model for Automotive
CDMA2000.....	Code Division Multiple Access 2000
CLI.....	Command-Line Interface
CM.....	Communication Model(s)
CRT.....	Cathode Ray Tube
CV.....	Cross Validation
DFKI.....	Deutsches Forschungszentrum für Künstliche Intelligenz (German Artificial Intelligence Research Institute)
D-Gen.....	Digital Generation
ECU.....	Electronic Control Units
FDD.....	Frequency Division Duplex
Gbit/s.....	Gigabit per second
GGSN.....	GPRS Gateway Support Node
GHz.....	Giga Hertz
GPRS.....	General Packet Radio Service
GPS.....	Global Positioning System
GS.....	Gateway Station
GSM.....	Global System for Mobile Communications

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GUI .....	Graphical User Interface
H2H .....	Human to Human
H2M .....	Human to Machine
HCI .....	Human Computer Interaction
HD .....	High Definition
HTML5 .....	Hypertext Markup Language version 5
Hw .....	Hardware
Hz .....	Hertz
ICT .....	Information and Communication Technology
IEEE .....	Institute of Electrical and Electronics Engineers
IG .....	Interworking Gateway
IoT .....	Internet of Things
IPv6 .....	Internet Protocol version 6
ISO .....	International Organization for Standardization
IT .....	Information Technology
ITU .....	International Telecommunication Union
KB .....	Kilo Byte
KLD .....	Kullback-Leibler divergence
LBS .....	Location-Based Services
LCD .....	Liquid Crystal Display
LTE .....	Long Term Evolution
M2H .....	Machine to Human
M2M .....	Machine to Machine
MB .....	Mega Byte
METIS....	Mobile and wireless communications Enablers for the Twenty-twenty Information Society
MHz .....	Mega Hertz
MIMO .....	Multiple Input Multiple Output
MoCCA .....	Mobile Communication and Computing Architecture
MR .....	Mixed Reality
MS-DOS .....	Microsoft Disk Operating System
MTC .....	Mathematical Theory of Communication
NFC .....	Near Field Communication
N-Gen .....	Net Generation
NGWS .....	Next Generation Wireless Systems
NIA .....	Network Interoperating Agent
NUI .....	Natural User Interface
OS .....	Operating System
PC .....	Personal Computer

---

PDSN.....	Packet Data Serving Node
Phablet.....	Mixture of a Smartphone and a Tablet
PSTN.....	Public Switched Telephone Network
QoS.....	Quality of Service
RFID.....	Radio-Frequency IDentification
SMCR.....	Source, Message, Channel, Receiver
SOC.....	Selective Optimization with Compensation
STT.....	Speech To Text
Sw.....	Software
TCP/IP.....	Transmission Control Protocol/Internet Protocol
TDD.....	Time Division Duplex
TtFF.....	Time to First Fix
TTS.....	Text To Speech
UCD.....	User-Centered Design
UCM.....	Universal Communication Model
UCM-S1.....	UCM-Scenario 1 - Media Rich Communication
UCM-S2.....	UCM-Scenario 2 - Mobility
UI.....	User Interface
UMTS.....	Universal Mobile Telecommunications System
UX.....	User eXperience
VC.....	Virtual Continuum
WHO.....	World Health Organization
WWW.....	World Wide Web
WYSIWYG.....	What You See Is What You Get





## 1 INTRODUCTION

Over the next years and decades the demographic change will permanently alter population structures. This poses challenges with a massive impact on political and social levels as, e.g., a shrinking working-age population generates a lower amount of taxes for the social security system, and an increasing aging society rises costs of social medical and care services. Technology can be a pillar for the elderly society to solve some of the future challenges. Many of today's pensioners encounter technology barriers which future generation 60+ will not have to face to the same extent, because they learned the usage of Information and Communication Technology (ICT) in their later working life. User-centered communication services help to participate in the society and supports elderly to be active and life healthy which afford successful aging.

Mass telephone communication became mobile with the first handheld mobile phone call in the early 70s (Motorola Inc., 2014; Kumar, 2004). Today cellular phones are used all over the globe for voice calls and data transfer like messaging (Qureshi, 2014; Pepper, Solomon and Williams, 2012). Cellular phones are ubiquitous in the sense, that their usage is limited by network coverage which nearly fully exists in well-developed areas like Europe, America, and Asia. Cellular network technology is enhancing quickly: Currently the 4<sup>th</sup> generation is being rolled out world-wide (3GPP, 2014b) and the subsequent generations will allow to transfer big data everywhere (NGMN, 2014). This technology boost will enable the support and amelioration of communication by data demanding services like fusion and fission of mimic and gestures, video, multi-displays, and text synthesis in the cloud, to name a few important. Machine to Machine (M2M) communication requires less bandwidth per device but a huge amount of connection is expected (50 Billiards of devices) and future cellular network technology provides the basis for the Internet of Things (IoT) (Taleb and Kunz, 2012; Holler et al., 2014).

Today a multiplicity and diversity of devices, operating systems (OS), and network technologies exist including different protocols. Additionally, the user interfaces are differing for devices from varying manufacturers and for OS. The

challenge for the usage of communication devices is obvious and increasing by the application of the above described amelioration of communication. Especially the aging society can profit from these supportive applications for communication, since physical disabilities that are needed for communication can be compensated.

In this thesis an architecture model is presented for a unified usage of different devices, network technologies, and applications for communication. This model is called Universal Communication Model (UCM) and is divided into three domains for communicators with gesture and mimic, devices with supportive applications and functionalities, and media for big data transmission. The architecture model follows Weiser's vision that technology for communication may become seamless, if ubiquitous real world objects appear "smart" and provide user experience (UX) without using complex computer user interfaces or obvious controlling devices (Weiser, 1991).

Communication is a challenge for elderlies (60+ with frequently limited movement capability and hebetude senses), and thus, technology can be a barrier (Charness, 2001). The number of elderlies is growing fast in post-industrial countries, and the portion of people 60+ will raise up to 1.2 billion worldwide in 2025 (WHO, 2002). Therefore, two use cases for the UCM with focus on elderly people are described: First, a daughter is calling from her car her elderly father at home. Second, grandma has an appointment at her doctor and during her trip to the clinic she is receiving information about her public transportation route. The use cases are investigated with focus on the required technologies and how elderlies with physical limitations are supported for a natural communication in their environment.

## 1.1 CHALLENGE AND REQUIREMENTS FOR COMMUNICATION MODELS

The thesis investigates how elderly people can be supported to communicate in scenarios where the participants are geographically distributed, i.e., they are having no direct eye contact. Focus is on communication models (CM) as they are known from the field of communication theory: Shannon's CM (Shannon, 1948) to connect an information source and a receiver via a transmitter and a receiver, and

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Berlo's extension (Berlo, 1960) by adding specific properties like communication skills to the CM.

CM have comprehensive requirements which are described in the following:

- 1) Technological requirements demand a connectivity of a CM to a variety of networks (any media: fixed-line, wireless, and ad-hoc to name a few important types) in order to make information beaming possible (cf. *Pervasive Principles*, Section 3.2.2).
- 2) Devices like smartphones, tablets, wearables, and all their derivatives (any device) should be enabled to act as communication assistance. Especially wearables allow the users to access information anywhere and anytime, since they are being traversed in the environment by their user (Barfield and Caudell, 2001).
- 3) Usability requirements in order to enable multimodal usage, since users may have different cultural background, varying age and education (anybody). Furthermore, the development of successful future communication end-user services must cope with the challenge of systems' capabilities and the human (in)ability to manage new emerging, complex technology.

Until today the materialization of CM remains a challenge, since either the CM are abstract and lack in application to the real world, or they can only be implemented for specific use cases (Demmeler and Giusto, 2001; Wahlster, Reithinger and Blocher, 2006). In the core of this thesis a CM (named UCM) based on the principal elements of Shannon and Berlo is developed and evaluated. Main features of this model are modularity (i.e., device-independence) and domain-independency. Furthermore, the applied technology is expected to become seamless in the sense of Weiser's vision for Ubiquitous Computing (Weiser, 1991).

Communication is a basic need of humans and especially for elderly people in order to participate in the society (WHO, 2002): The World Health Organization (WHO) states (2002) that communication is one of three basic pillars for social life. Technology-assisted communication like phone calls or computer chats lack in real-time mimic or they are difficult to use, especially for people that are unfamiliar with computer systems. The latter property holds especially for elderly people (Fisk et al., 2009; Ketcham and Stelmach, 2005), who will represent 50% of the population

in post-industrial countries in a couple of years (United Nation Press Release, 2011; Eurostat - European Commission, 2012). The architecture of the UCM is designed to overcome these hindrances by enabling a real-time, intuitive, and multimodal communication.

Why does the UCM solve the communication challenge? The UCM has a flexible architecture that allows to apply any device using any media for data transmission. Hence, personal preferences and habits can be incorporated. Furthermore, the domain-independence allows anyone to apply the UCM in any situation and context.

Two hypotheses that represent challenges of the UCM are provided and investigated: First, “Elderlies have difficulties in stress and ad-hoc situations to cope with ICT solutions” (H 1), and second “Elderlies have problems to reach destinations” (H 2). Both hypotheses are divided into sub-hypotheses without and with UCM support.

The generic property of the UCM is demonstrated by two different use cases, where a daughter calls her elderly father (he has reduced senses and motion abilities), and a grandma needs to travel to a medical clinic. For these two scenarios prototypes are implemented in order to demonstrate the feasibility of the UCM. Within these scenarios the UCM is applied twelve times to solve tasks like “accept a call using a gesture” or “after leaving the bus, decide to go to the right or to the left in order to reach the medical clinic”.

Experiments with real probands (in total 30) show the quality of the implemented UCM solution, where nearly all probands were able to solve the tasks up to six times faster due to the application of the UCM (compared to the situation without UCM). In parallel, the (qualitative) satisfaction factor of the probands increased by a factor of approximately four for all tasks due to the seamless and multimodal UCM. These requirements hold especially for a UCM for the future society as is proposed and investigated in this thesis.

## 1.2 THESIS STRUCTURE

The thesis is structured as follows: The target group for the UCM is described subsequently to the introduction in Chapter 2. The elderly society and their increase is depicted in the demographic development (Section 2.1). In Section 2.2

theories of aging are discussed and a focus is set onto Active Aging according to the WHO in Section 2.3 (WHO, 2002). Aging has consequences like reduced cognition or communication hurdles (Section 2.4). Especially, the latter can be supported by the UCM enabling the participation in the society (Section 2.5).

Related work for CM is described in Chapter 3. First, basic CM from Shannon (1948), Berlo's extension (1960), and from Bateson (1972) and Watzlawick et al. (1967) are described (Section 3.1). Then, in Section 3.2 several concepts for the integration of technology into daily life are considered, which leads to the discussion of related work for communication architectures and systems (Section 3.3).

The UCM is detailed in Chapter 4. Core of the UCM architecture are the three domains "Anybody", "Any Device", and "Any Media" (Section 4.1). They are described in detail including examples. Main idea of the UCM is to be domain-independent, modular, and technology-independent. Domain-independency allows the usage of the UCM in any context and situation, and the latter both features, modularity and technology-independence, ensure that any device and any media including wireless technologies for data transmission can be applied (Section 4.2).

Goal of the next chapters is to evaluate the UCM. Chapter 5 contains aspects for elderly communication services. First, human computer interaction is described in Section 5.1, especially for the elderlies' life. Elderlies have a heterogeneous lifestyle, and thus, social typologies are introduced in order to focus on technology-aware elderlies (Section 5.2). Technology acceptance and ICT usage of the target groups are depicted in Section 5.3.

The experimental settings and the experiments executions are described in Chapter 6. Starting with two use cases "Daughter and Father" and "Grandma" (Section 6.1), two hypotheses are investigated: First "Elderlies have difficulties in stress and ad-hoc situations to cope with ICT solutions" (H 1), and second "Elderlies have problems to reach destinations" (H 2). Both hypotheses are divided into sub-hypotheses without and with UCM support in (Section 6.2).

Corresponding to the use cases and the hypotheses two scenarios "Media Rich Communication" and "Mobility" with the prototypes "UCM-S1" and "UCM-S2" are detailed in Section 6.2. Then, in Section 6.3 the proband user groups and

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the laboratory setups for the 24 tasks are provided (six for UCM-S1 without UCM, six for UCM-S1 with UCM, six for UCM-S2 without UCM, and six for UCM-S2 with UCM).

Chapter 7 contains the measurements of the experiments and the statistical evaluation. The mathematical framework is provided in Section 7.1 including the data preparation (normalization and representation as statistical distribution) for the statistical evaluation. Section 7.2 describes the applied statistical method for the Euclidean metric, and Kullback-Leibler divergence (Hayes, 1969) computations of the measured data distributions, and the corresponding Gaussian distributions. The measurements and their evaluations are described and discussed including a comparison of the experiments (Section 7.3).

A conclusion and an outlook including a description of open aspects are provided in Chapter 8.

Figure 3 summarizes the thesis structure. After the introduction follows the theoretical background (yellow frame, Chapters 2 and 3). Then, the depiction of the UCM and the investigation of ICT usage is provided (blue frame, Chapters 4 and 5). Prototypes, experiments and the statistical evaluation is presented (red frame, Chapters 6 and 7). The thesis is completed with the conclusion and a discussion of open aspects (Chapter 8).

The following conventions are applied for the writing: Scientific theories and names of research fields are written with upper letters, e.g., Universal Communication Model and Augmented Reality. After their first occurrence they are abbreviated, e.g., UCM and AR.

Graphics and figures are printed in b/w or UCAM colors, except cited graphics and figures. Numbers up to twelve are written in words, from 13 they are written using digits. Copyrights and Trademarks are contained in the corresponding citations.

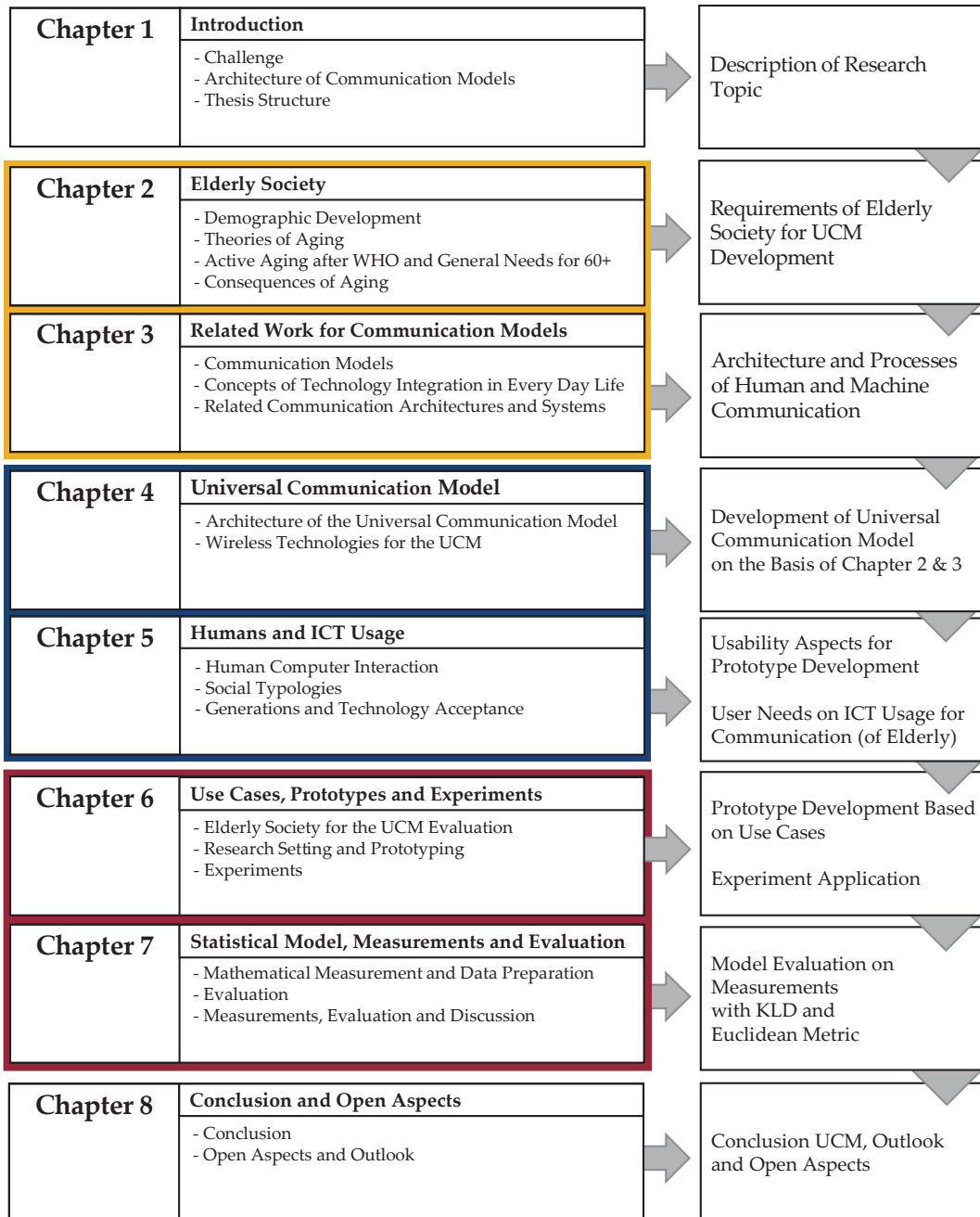


Figure 1: Thesis Structure Overview





## 2 ELDERLY SOCIETY

An enormous increase of the future generation 60+ will occur within the next decades for the post-industrial countries as described in Section 2.1. This development motivates to determine the needs for the future society. Aging theories depict the consequences of aging and how to compensate them (Section 2.2). The goal is to enable the so-called “Active Aging”, where elderlies can participate in the society (Section 2.3). This enabler requires new media technologies and will lead to an increased demand for technology in the elder age (Eurostat - European Commission, 2012). The consequences of aging are depicted in Section 2.4 and the decreasing sensual, physical and cognitive capabilities are derived from the consequences. Finally, in Section 2.5 the properties of Active Aging and the need for the universal communication architecture are summarized.

### 2.1 DEMOGRAPHIC DEVELOPMENT

Today more than 7 billion people inhabit the globe and this number will increase to an estimated 9.1 billion over the next 40 years (United Nation Department of Economic and Social Affairs, 2011). Collaterally, a demographic change is expected to occur: The fraction of people with an age of up to 40 years will drop to 25%, while the number of people of an age around 80 years will increase by a total of 180% (United Nation Press Release, 2011). This development is elementary for post-industrial countries (Eurostat - European Commission, 2012).

As an example see Figure 2 showing the numbers of the German male and female population in 2008 and the forecast for 2030: In 2008 19% (15.6%) of the German population are females (males) with an age of up to 20 years. For 2030 only 17% (12.9%) females (males) are expected, which is a reduction of  $(19-17)/19*100\% = 10.5\%$  (17.3%). In contrast to this population group, the elderly group above 65 years will change more dramatically: from 20% females (16.7% males) in 2008 are expected 29% females (22.3% males) in 2030, which is an expansion of  $(29-20)/29*100\% = 31\%$  of females above 65 years old and of 25.1% of males above the

age of 65. As a result fewer younger people and more elderlies will provide the basis for the future society (Federal Statistical Office, 2009).



**Figure 2: Distribution of the German Population, 2008 and Forecast for 2030**

Source: Eurostat - European Commission (2012), (English Translation by the Author)

German legislative aims to adjust the retirement age from 65 to 67 years. This adjustment will be gradually adapted between 2012 and 2029, to counteract the challenges of the demographic change (Federal Ministry of Labour and Social Affairs, 2011).

In the following section a closer look to different aging theories, that are explaining the effects of aging, is described in order to understand the physical, sensual, and cognitive situation of elderlies.

## 2.2 THEORIES OF AGING

Successful aging depends on various factors like physical, mental and social well-being (WHO, 2002). Gerontology research is investigating these factors for theories of aging (Charness and Boot, 2009): It differs between biological (anatomic and physiologic changes) and psycho-social (thought processes and behaviors). In the past, gerontology was focused on the negative aspects of aging to cope with the arising limitations (Rowe and Kahn, 1997). Levenson and Aldwin (1994, p.47) state:

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*“The biggest development in gerontology, or aging research, has been the recognition that the aging process is not simply senescence – most people over the age of 65 are not senile, bedridden, isolated, or suicidal.”*

Gerontology research changed from a “deficit perspective” of aging to a “success-oriented” strategy for a successful aging. Optimism, effective coping styles, and social participation support the subjective quality of life, which is part of a positive aging process (Pfeiffer, 1974). Rowe and Kahn (1987) define successful aging by the following three criteria:

- 1) Freedom from disease and disability,
- 2) high cognitive and physical functioning and
- 3) social and productive engagement.

Baltes and Baltes (1990; 1997) describe successful aging as a successful adaptation to the biological, social, and psychological situation. Additionally, the minimization of losses which are caused by aging should be compensated and the maximization of gains is on the focus of the aging person.

The process of aging differs from person to person depending on the physical and mental occurrences in the “Early” and “Adult Life” phases, which are depicted in Figure 3. Thus, considering the absolute age is not sufficient to evaluate and compare the range of functional skills of elderlies. Figure 3 shows the functional capacity of humans in relation to the live course (Kalache and Kickbusch, 1997; Kinsella and Phillips, 2005):

- In “Early Life” (approximately up to 25 years), the highest level of possible functions is achieved.
- Then, in the subsequent phase “Adult Life” (up to ~60 years) is the functional capacity slightly decreasing.
- And in the final phase “Older Age”, a constant decrease of the functional capacity is ongoing.

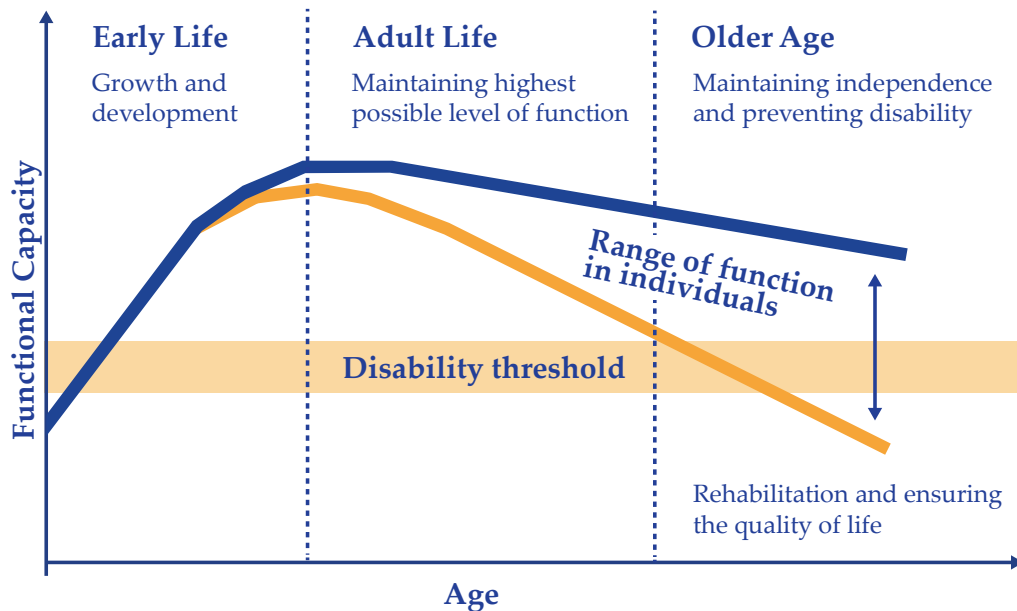


Figure 3: Maintaining Functional Capacity over the Live Course

Source: Kalache and Kickbusch (1997)

### 2.2.1 Disengagement Theory

The Disengagement Theory is developed by Cummings and Henry (1961, p.227). They describe that this theory is based on the assumption that,

*"...aging is an inevitable, mutual withdrawal or disengagement, resulting in decreased interaction between the aging person and others in the social system he/she belongs to".*

The theory points out that it is natural and acceptable for elderlies to withdraw from society. As a consequence they have to accept their own restrictions in old age to offer the younger generation possibilities to fill their roles. Aging is described as the desire and ability of elderlies to disengage from active life.

The main thrust of criticism on this theory is based on the missing evaluation with empirical data and that disengagement is enforced as inevitable, functional and universal in this theory (Havighurst, 1963; Roadburg, 1989; McPherson, 1998). Summarizing, the Disengagement Theory is one of the major psycho-social theories that describe the development of aging, although it is controversial to the Activity Theory and to the Continuity Theory. The latter are depicted in the following both sections.

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### 2.2.2 Activity Theory

Simultaneously to the Disengagement Theory, the Activity Theory has been invented by Havighurst (1961; 1963) who interpreted “successful aging” as a continued adherence to activities and attitudes of adult life and the substitution of roles lost by changes. In this theory aging is associated with a positive sense to cope the different changes in aging successful (Howe, 1987). Havighurst depicts in this theory that successful aging corresponds to regular activities, roles and social interaction in order to achieve happiness and satisfaction with the past and current life. Activity in elder life relies on a positive approach of aging and is the main difference to the Disengagement Theory. The Activity Theory points out that activity is a physiological basic need of humans and a key to participate in the society providing successful aging. Those people who were active in their younger years would (as much as they can) continue to be so in their old age (Neugarten, Havighurst and Tobin, 1968).

Criticisms on the Activity Theory are the disregarded inequalities in health and economics that limits the possibility for elderlies to participate in such activities, or alternatively, they may have no desire to engage in new challenges (Bengtson, 2009; Roadburg, 1989; McPherson, 1998).

### 2.2.3 Continuity Theory

Maddox (1968) founded the Continuity Theory with the empirical description “Persistence of life style among the elderly: A longitudinal study of patterns of social activity in relation to life satisfaction”. Atchley (1971; 1999) refined the Continuity Theory with the extension that elderlies preserve the same activities, behaviors, beliefs, and social relationships as they did in their “Early Life” (Figure 3). Continuity in their lifestyle is provided by adapting strategies that are connected to the past environments. The theory takes a life course perspective in which the aging process considers history, culture, and social constructs. Continuity in aging is described as a dynamic and evolutionary developmental process which refers how the individuals grow up, adapt, and change over the life course. Activity is the significant component of the person’s self-identity, which has to be preserved. Atchley (1989) described that, the individuals vary in their identities based on the priority the activities have in each persons’ elder life. The

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substitution of one activity with another comparable activity that is adjusted to the upcoming limitations, helps to cope with the age related restrictions.

The theory differs between Internal and External Continuity in the elder life: Internal Continuity refers to the own experience supporting the individual behavior, beliefs, and relating self-identity, which remain constant all over the life course. Future decisions and the behavior are based on the experience of the past. External Continuity mentions the activities and social roles in elder life, to provide stable relationships in the society.

The criticisms on this theory are the missing relevance of persons with chronic illness, and the missing influence of social institutions on the aging of individuals (Bond, Coleman and Peace, 1993).

With the approach of internal and external continuity and the process of adaptation of limitations this theory is situated between the complementing Disengagement Theory and the Activity Theory. The Continuity Theory is providing the basis for the SOC Theory that is described in the following.

#### **2.2.4 SOC Theory**

The Selective Optimization with Compensation (SOC) Theory of Baltes and Baltes (1987) is one of the leading models in gerontology research. It posits three fundamental processes to be important for successful aging:

- 1) Selection restricts the variety of functions and behavior to focus on the available potentials and resources to reach the subjective important aims;
- 2) Optimization ensures or enhances the competences in specific functional areas which are selected by individual and subjective preferences, and
- 3) Compensation adjusts the decreasing physical and psychological potentials and resources with a selective compensation and resources to maintain the subjective important and individual functions and behaviors.

These processes extend the previous described theories with an approach of adjustment and regulation with the upcoming limitations in elderly lives. Baltes

and Baltes (1990; 1997) point out that people select the needs in their life domains, optimize the resources and aids that assist in the domains, and compensate abandoned skills with biological, psychological, and environmental changes.

The concept of the SOC Theory is considered as a changing balance with a positive mental attitude between gains and losses during the aging process (Freund and Baltes, 2002). As an example over 50% of people worldwide aged 60+ have some degree of hearing loss (WHO, 2008), which can cause difficulties in communication (and lead to frustration), low self-esteem, withdrawal, and social isolation (Wilson et al., 1999). Using a hearing aid, the hearing loss can be compensated in many cases. The SOC Theory is considered as a flexible mechanism which can be adapted to the individual requirements that vary from person to person and the life span (Baltes, 1987).

Emotional well-being, satisfaction with aging and life satisfaction are fundamentally important for successful aging (Baltes, 1995). Empirical data from the representative Berlin Aging Study<sup>1</sup> offer valuable knowledge for well-being in the "Older Age" (cf. Figure 3, p.36) and the relevance of the SOC Theory (Baltes and Mayer, 1999). Additionally, these data provide also insights in the general needs for people 60+.

### 2.3 ACTIVE AGING AFTER WHO AND GENERAL NEEDS FOR 60+

The Active Aging Framework of the WHO is based on the following three pillars (WHO, 2002):

- a) Participation,
- b) Health, and
- c) Security,

which will be detailed in this section.

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<sup>1</sup> The Berlin Aging Study (Berlin Aging Study #313) is a multidisciplinary investigation of elder people aged 70 to over 100 years living in former West Berlin. In the main study, with a sample of 516 individuals was examined in 14 sessions covering mental and physical health, psychological functioning, and the social and economic situation. Since then, the study has been continued as a longitudinal study, and participants have been reexamined seven times.

Active Aging intends strategies for living longer, with better health and refers to the gerontology research term of “successful aging”. It is a key part in the global strategy of the WHO for the management of aging populations to cope with the challenge of the demographic change. Several programs to evaluate solutions for healthier and better life of future aging society are supported by the European Union (European Union, 2014) and the associated countries (Federal Ministry of Education and Research, 2013). The integration of the aging society is a cross-sectional task, that recognizes multiple factors and has to be oriented on realistic lifestyles, typologies and segmentations to cover the needs, desires and capacities for successful aging (Walker, 2002b; Walker, 2006).

According to the WHO (WHO, 2002, p.12),

*“Active Aging is the process of optimizing opportunities for health, participation and security in order to enhance quality of life as people age.”*

Active Aging enables the potential of elderly people for physical, social and mental well-being to participate in the society throughout the life course. The term “aging” refers to the entire life of human society and “active” involves the social, economic and cultural activities of daily living (WHO, 2002). The fundamental aspects of Active Aging are autonomy and independence to provide each elderly the individual quality of life, in order to decide how day-to-day routine can be arranged (Harper and Power, 1998). Autonomy is the ability to control and make personal decisions according to the own rules and preferences. Whereas, independence enables the ability to perform functions of daily living with no or little help from other persons, and maintains in addition to autonomy a high quality of life (WHO, 2002).

Aging occurs in the context of work, neighborhood, friendship, and family and this makes Active Aging to a multidimensional approach (Bruine, 2007). Social participation and social support refers to good health and well-being to participate in leisure, social, and cultural activities.

### **2.3.1 Participation**

Participation offers opportunities for civic, cultural, educational and voluntary engagement to the aging society (WHO, 2002). Lövdén, Ghisletta and Lindenberger (2005) founded on the basis of the Berlin Aging Study (Baltes and



Mayer, 1999) an attenuation of the decline in perceptual speed of elderly people with an engaged and active lifestyle. In this analysis the indicators perceptual speed and social participation are correlated to evaluate the relation of underlying cognitive aging (cf. Lövdén, Ghisletta and Lindenberger, 2005). Lövdén, Ghisletta and Lindenberger concludes that social participation helps to prevent elderly people from aged-related declines.

Being active, and participate in the society improves good physical health and the well-being of the individual (Walker, 2002a; Avramov and Maskova, 2003). The framework of the WHO (2002) claims to provide an infrastructure which supports elderly people to participate comfortably in the society. Private or public transportation enables mobility which is essential to participate in family, friendship or employment activities (Eurostat - European Commission, 2012). Social isolation, and the risk of mental health problems like depression, isolation and decreasing functional capacity can be prevented by providing opportunities for elderly people to interchange with their families, communities and friends (Stein and Moritz, 1999; Chan, 2012; Rosow, 1967).

### 2.3.2 Health

The WHO (WHO, 2002) defines the main goal of health to prevent and reduce the burden of disabilities, chronic disease, and premature mortality. Health refers to the physical, mental and social well-being and enables participation by joining social activities in the community and economy. Chronic diseases and functional decline limit the quantity and quality of life for the aging society. Preventive strategies for healthy aging enables a wide range of managing own lives as long as possible and reduce the needs of medical treatment and care services (WHO, 2002; Mynatt and Rogers, 2001).

The similarities between age-related deterioration and the accompanying physical and mental inactivity are evaluated in several studies like “Effects of Social Integration on Preserving Memory Function in a Nationally Representative US Elderly Population” (Ertel, Glymour and Berkman, 2008) and the “Berlin Aging Study” (Baltes and Mayer, 1999). Mental and physical activity support the preventive approach of Active Aging to avoid age related diseases. Getting access

to appropriate health services is as important as places and programs for socializing to enable Active Aging.

Technical devices like hearing aids reduce the burden of diseases and can help to compensate physical limitations, which can cause social exclusion. Concepts of barrier-free living provide an architecture that enables access to buildings, products, and environments that are accessible to older persons, people with and without disabilities (WHO, 2002).E.g.

- the avoidance of stairs,
- high color-contrast of digital displays, and
- websites that provide alternative text to describe images.

The use of technology in the context of “Ambient Assisted Living”<sup>2</sup> (AAL JP, 2013) can also support healthy aging as policies, programs, and services enabling elderly people to remain at their own homes as long as possible.

### 2.3.3 Security

Elderly needs are common to the needs of all people. Additionally, they have also special requirements due to the fact that they are elder people (Havighurst, 1952). Security and trust are important in elderly lives and ensure their active role in the society. The needs of security by older people address social, financial and physical security rights (WHO, 2002) in order to compensate physical limitations like lowered physical strengths (Mynatt and Rogers, 2001).

Age related restrictions minimize the self-confidence of elderlies and therefore they lose their courage to cope with new influences. A social aspect of security needs in old age is the requirement of safe and secure accommodation of a familiar environment at home. This supports the aspect of well-being and prevents unsteadiness and accidents. Technical systems that provide support in an emergency case or cope with aspects of dementia and disorientation convey

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<sup>2</sup> Ambient Assisted Living (AAL) is an approach that encompasses technical environments with needs-oriented services to cope with physical and mental illness. Ambience Intelligence technology provides proactive and situation-aware assistance to sustain the autonomy of elderly to live longer in their preferred environment (Kleinberger et al., 2007).

security and support the independency of the elderlies. Physical security refers to the safety from abuse and criminal victimization and also to an access to medical and health care systems. A steady and adequate stream of income and policy programs by the government relate to security in "Old Age" (Figure 3, p.36) (WHO, 2002).

## 2.4 CONSEQUENCES OF AGING

The process of aging varies from person to person, and is additionally influenced, by factors like profession, income, lifestyle or quality of live - all of them affect the level of aging (Eurostat - European Commission, 2012). The loss of autonomy and decreasing independency of assistance and care request physical, economic, social, and psychological demands (Baltes, 1995). The subjective well-being over the human life span depends on emotional, cognitive, and psychological aspects (Diener, 2000).

Functional limitations such as the decline of psychomotor performance, cognitive and perceptual abilities, hinder older adults to use technology in the same way as younger ones (Lee, Chen and Hewitt, 2011; Mynatt and Rogers, 2001). Despite objective sufficient capacities, the negative attitudes and beliefs towards ICT deters elder people from the successful use of technology (Charness and Boot, 2009; Charness, 2001).

Table 1 shows the three categories for the aging of humans that hold for both life courses, namely the "Adult Life" and the "Older Age" (see also Figure 3, p.36):

- 1) Sensual (left column): this category is addressing the human senses like vision, audition, haptic, and taste and smell. Sensual information provides knowledge that supports the perception of the environment. The senses taste and smell are put into bracelets, since they are not incorporated into the UCM.
- 2) Physical (middle column): movability and strength are main factors of the physical capacity. Furthermore, dexterity, i.e., motor skills of hands and fingers, is also an important factor. Physical reactions are based upon cognitive conclusions and sensual information.
- 3) Cognitive (right column): properties of cognition are memorization, attention and spatial cognition. A further basic property is the

understanding of language. Cognitive processing of information that is based on these properties enables interaction with the environment, e.g., decide to go to the right or to the left at a crossing for pedestrians.

Sensual	Physical	Cognitive
vision	movability	memory
audition	strength	attention
haptic	dexterity	spatial cognition
(taste and smell)		understanding language

**Table 1: Description of Aging Categories**

In the following sections the development of aging is depicted in the categories sensual, physical, and cognitive aging.

### 2.4.1 Sensual Aging

Sensual aging is an important factor in the interaction and use with technical items and the environment. Sensation is the awareness of simple properties of stimuli allowing the human to combine and recognize several complex characteristics of things in the environment, e.g., recognizing a red object as an apple or determining that a sound is an alarm (Fisk et al., 2009). Especially, visual and auditory limitations can restrict elderly in their daily life (Wilson et al., 1999). The taste begins to decrease in the “Adult Life” already and results in the disability to distinguish sweet, sour, bitter, and salt. The sense of smell declines in the “Older Age” due to the loss of nerves in the nose (Fisk et al., 2009). The latter factors are out of scope of this work, since they are lacking relevance in the development of ICT.

The properties of sensual aging (Table 1) are discussed in the following.

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#### 2.4.1.1 *Vision*

Visual impairments affect humans in the case of chronic conditions but in old-age nearly everybody suffers with vision problems. Visual acuity is a summary index to evaluate the range of visual limitations. About 80% of people over 60 need glasses for vision correction (Fisk et al., 2009). Another age-related limitation is the ability to adapt to darkness: The adaptation capability from a dark to a bright environment decreases due to the diminution of the pupil diameter. Furthermore, the advancing dehydration of the eyes results in glare sensitivity.

#### 2.4.1.2 *Audition*

Hearing is an affecting ability in human life and is thus essential for maintaining communication in a comfortable way as it enables the ability of successful and effective interaction between humans and the environment (Wahl and Tesch-Römer, 2001). Over 30% of women and 50% of men suffer of decreasing hearing capabilities (Fisk et al., 2009). Referring to the “Early” and “Adult Life” course, pure tones in frequencies up to 15,000 Hertz (Hz) can be heard and after the age of 65 or 70 sounds above 4,000 Hz may be inaudible. In comparison to this, low-range tones (below 1,000 Hz) are not affected of age-related changes in hearing (Presbycusis).

Volume and loudness are common criteria for rating the hearing impairment (Hofer, Berg and Era, 2003). In a usual range, sounds about eight decibels (human breathing or rustling a sheet) can be heard and a normal conversation can be classified in the range of 50 to 60 decibels. Sounds between 120 and 130 decibels can cause further physical injury (Fisk et al., 2009). Age-related hearing impairment differs between 30 and 60 decibels, and occurs with the limited ability to hear high-frequencies. These limitations are based to a deterioration of the receptor hair cells, neurons, and vascular changes in the inner ear or membranes.

Developing solutions with audio in- and output, the changes in hearing capabilities of elderlies have to be considered in order to provide the ability of detecting sounds and tones, and also to support the comprehension of speech.

### 2.4.1.3 *Haptic*

Haptic relates to the sense of touch. Thus, it is important to the design of modern devices as smartphones and tablets with touch- and gesture-controlled user interfaces. Haptic control also provides information about temperature or feedback as vibration perception. Another aspect of haptic information is kinesthetic, that provides automatic integration of movement-related sensation by vestibular cues to maintain balance and avoiding injury through falling. This disability depends on individual physical aging factors (Fisk et al., 2009).

## 2.4.2 **Physical Aging**

The coordination of muscles and strength is important for the precision of motion and the physical movement. Examples are the tasks “double click a mouse button” and “grab an object from a shelf” (Fisk et al., 2009). Increasing age leads to decreasing movability and strength. Additionally, limitations of the motoric skills of hands and fingers can occur, which is known as dexterity (Aldwin, Park and Spiro, 2007).

### 2.4.2.1 *Movability*

With increasing age similar movements take more time and are less precise (Ketcham and Stelmach, 2005). This impact can be recognized by positioning a cursor on a computer or driving a car. The age-related decreasing performance can be declined as a combination of (Fisk et al., 2009)

- a) poorer perceptual feedback,
- b) increased noise in the motor pathway, and
- c) (strategic) differences in approaching the task.

For the development of solutions for the group 60+ strategies are required to cope with less precise and slower movement, e.g., easy adoptable gain and acceleration profiles for interactions with a system (Lim, 2010).

### 2.4.2.2 *Strength*

Skeletal muscles are required to control and execute movements. At the age of approximately 75 years the muscle mass has a lost at a rate of 0.64-0.70% per year in women and 0.80-0.98% per year in men. The strength has a lost with a rate of 2.5-

3% per year in women and 3-4% per year in men (Mitchell et al., 2012). Since the strength of skeletal muscles is proportional to the muscle size, wasting of muscles makes it harder to move, climbing stairs or to carry things (University of Nottingham, 2008). Additionally, in order to maintain the size of the muscles requires a continuous practice, which might be difficult to perform for many elderly, since further physical limitations may hinder them to practice.

#### 2.4.2.3 *Dexterity*

Small muscle movements are necessary to fulfill precise gestures, writing, or pressing a button. Fine motoric skills are decreasing with increasing age, and as a consequence elderly people are losing the ability of precise motoric movement (Olafsdottir, Zatsiorsky and Latash, 2008). Especially precise tasks, like pressing a button twice or sliding a button, appears to be a challenge for elderly (Laux, 2001). Analogously, precise gestures are more difficult to perform and should not be used for sensitive tasks like authentication. As an example consider the mobile OS system Android (Google Inc., 2014b), that allows users to unlock the screen by wiping a pattern on the mobile screen.

### 2.4.3 **Cognitive Aging**

Cognition combines all the processes of the brain that take sensory input of eyes, ears, and other senses. Fisk et al. state (2009) that cognition

*“...transforms, reduces, elaborates, stores, recovers to use that input for further processing, e.g., thinking, problem solving and decision making”.*

Elderly still have the ability to learn new things if the training is adequate: Willis et al. (2006) argue that persons over 60 years have the ability to transfer new knowledge to comparable tasks after a period of five years.

#### 2.4.3.1 *Memory*

The working memory, also called short-term memory, is responsible for all active aspects in the memory, what has recently happened and currently being thought or working on (Kemper and Mitzner, 2005; Lewis, Langdon and Clarkson, 2007). It provides a storage, to coordinate and update the information coming into short-term memory both from the environment and from the long-term memory

during the execution of a tasks. For example, consider a menu system at a telephone hotline which requires the working memory, since users can only listen to the telephone and need to imagine the menu. It consists of new information and knowledge that has recently been retrieved from long-term memory. The capacity of the working memory is limited and degrades rapidly if it is not exercised. It is one of the most relevant factors on age-related limitations. Additionally, age-related differences in speech, language comprehension, reasoning, and problem solving are deeply attributed to the age-related differences in working memory of elderlies ( Craik and Salthouse, 2008).

Long-term memory is a more permanent storage of knowledge and contains concepts as vocabulary words, historical facts, cultural norms, rules of language. The semantic memory is part of the long-term memory and shows only a minimal decline with aging (Fisk et al., 2009). It is being composed through the lifetime of learning. Access time to stored information slows down in advanced age. Hence, the semantic memory is useful for supporting solutions in order to compensate cognitive limitations (Norman, 1988).

Remembering to perform an action in the future is part of the time-based prospective memory, e.g., taking pills at 2:00 pm. The event-based prospective memory refers to an event which relates to another action, e.g., leaving the apartment, to remember closing the door and turn off the light. The age-related declines of time-based prospective memory are much higher than the event-based tasks and result in the demand of special supportive solutions on time assisting items.

#### 2.4.3.2 Attention

Attention is the process that controls awareness of events in the environment (Fisk et al., 2009). Through selective attention it is possible to focus on information details. The range of attention is limited and operates selectively on stimuli in the environment. Another aspect of cognition is the dynamic visual attention that relates to successful interaction with the environments (Jastrzembski and Charness, 2007). Thus, the development of user interfaces requires a well-structured interface.



### 2.4.3.3 *Spatial Cognition*

The ability to manipulate images or patterns mentally and to accurately represent spatial relationships among components are investigated by the spatial cognition. For example, consider the task “rotate mentally a cube on an image” (Fisk et al., 2009). Age-related differences can be observed by tasks that require memory for object locations and also for the development of a sequence of locations.

### 2.4.3.4 *Understanding Language*

Language and the meaning of words and sentences are essential for communication, and thus, for the participation in the society. It is relevant to interpret verbal information in written and spoken words to understand the meaning of sentences and paragraphs. The decreasing working memory (capability) is responsible for problems on various linguistic tasks that are more complex for elderlies than for younger people (Craik and Salthouse, 2008), e.g., understanding natural language, and processing and producing syntactically complex speech. Relying on the semantic memory helps to improve understanding, and therefore, familiar terms should be used to make communication easier understandable and to avoid misunderstandings (Fisk et al., 2009).

## 2.5 COMMUNICATION AS PARTICIPATION

Becoming older, most elderlies prefer to live as long as possible at home, even alone (Bayer, Harper and Greenwald, 2000; Iwarsson et al., 2007; Mynatt and Rogers, 2001; Fisk et al., 2009). Additionally, less mobility restricts their social participation. Communication technology can aid elderlies in active and successful aging (Mollenkopf and Fozard, 2004). Future communication devices will be able to recognize the loss of abilities, e.g. hearing impairment, low vision or less prestidigitation.

Social participation is a focal point of Active Aging as Walker (2007, p.86) points out that

*“Active Aging should be a comprehensive strategy to maximize participation and well-being as people age. It should operate simultaneously at the individual (lifestyle), organizational (management) and societal (policy) levels and at all stages of the life course.”*

Additionally, social participation and social support, both, refer to health and well-being in order to take part in leisure, social, and cultural activities. The new research field gerontechnology is defined by Charness and Boot (2009, p.253) as

*“... the predictors of technology use in older adults, understanding how normative changes with age affect interactions with technology, and determining how to design better technology products.”*

Charness (2001) compared several attributes of technical communication channels (i.e., PSTN, telefax, e-mail, chat, video conference,) to a personal meeting and claims for a video conference the same high “socializing value” as for a face to face meeting. Additionally to an audio signal like a telephone call the transmission of information based on body language (gesture and mimic) is provided, which is important for nonverbal Human to Human (H2H) communication.

Bicchieri and Lev-On (2007) denote the “communication effect”, which states that communication has a positive effect on cooperation, information sharing, and participation. They perform experiments to show that communication is necessary for cooperation. These experiments are based on computer-mediated communication (audio / video conference) on the one hand, and on a stable network connection on the other hand. As main result video-based communication with a stable connection is similar effective as face-to-face communication.

The UCM has the goal to enable social participation for successful aging. In the following chapter CM are discussed and related architectures are depicted.

### 3 RELATED WORK FOR COMMUNICATION MODELS

Human communication is the exchange of meanings between individuals and the several aspects of communication are depicted by the CM in Section 3.1. Concepts of technology integration into everyday life with a focus on ubiquitous approaches are introduced in Section 3.2 with a focus on the requirements of H2H and M2M communication. The Architecture of communication systems is detailed in Section 3.3 to form the basis of the UCM.

#### 3.1 COMMUNICATION MODELS

Communication modeling started with Shannon's cutting through article "Mathematical Theory of Communication" (MTC) in 1948. The theory contains the significant communication model MTC that defines information transmission from an information source to a destination based on entropy (Section 3.1.1). Weaver (1949) extended the MTC in by a feedback loop for the receiver to the sender enabling a first step towards a meaningful, and thus, successful communication. Then, in Section 3.1.2 Berlo's (1960) successful CM through additional features of communication based on the five human senses is detailed. Finally, Bateson and Watzlawik defined five basic axioms for human communication without misunderstandings. These axioms are described and discussed in Section 3.1.3.

In contrast to human communication the so-called agent communication emerged in the 90s (Farjami, Görg and Bell, 2000; ACTS, 1999). Agents are software pieces that traverse network nodes. At each node actions can be performed. The agents are standardized through a communication language, a fixed pre-defined set of performatives representing possible actions, and an ontology to describe items (Finin, Labrou and Peng, 1998). Agent communication enables today's M2M (Finin, Labrou and Peng, 1998). In this thesis the focus of CM is on H2H communication based on communication networks. These networks are fixed line or wireless and they connect devices like tablets, wearables, or smartphones. Today's fast development of network and computer technology expands the possibilities of a simple, flexible, and feature-rich communication.

### 3.1.1 Shannon's Communication Model and Weaver's Feedback Component

The communication model MTC of Shannon (1948) incorporates the channel capacity, i.e., an upper bound for the amount of transferable information for a given channel, and noise, i.e., loss of information during the transfer. The model can be described symbolically (Figure 4): The information source (left part) contains a message that may consist of written or spoken words, or of pictures, music, and movies. Then, the transmitter converts the message into signals that are sent over the communication channel (center part) to the receiver which converts the message to the origin format (right part).

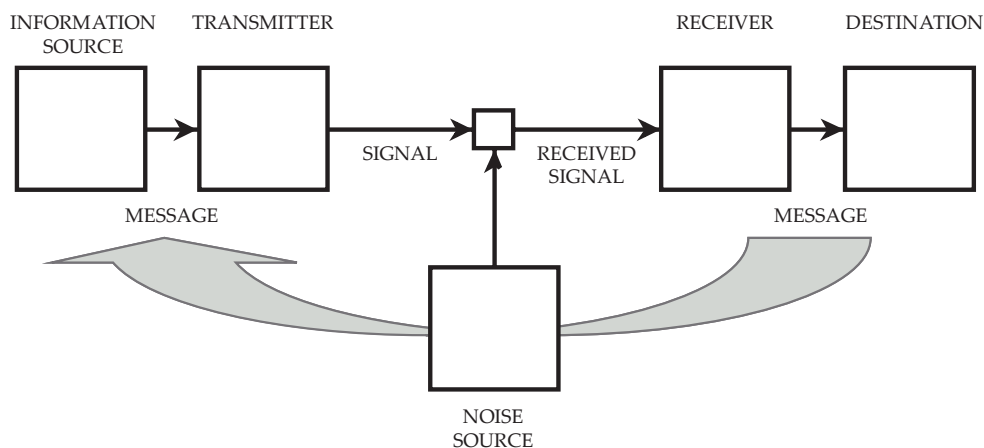


Figure 4: Schematic Diagram of Shannon's General Communication System

Source: Shannon (1948) (upper part)

Source: Weaver (1949) (bottom arrow)

The noise source is related to the environment, e.g., background noise when someone is communicating in a public transport system. As an example consider fixed-line telephony, whereas

- the information source and destination are humans,
- the transmitter and receiver are devices which change the sound pressure of the voice into varying electrical signals and vice versa,
- and finally, the communication channel is a (copper) wire network, and the electrical signal is varying currently on this wire, which may incorporate noise due to damping of the electrical signal.

In this theory the word "information" does not relate to its usual meaning of a word: Here it refers to the meaning of a whole situation, e.g., the communication

environment where someone is located at home or travelling in a train. This model is also applicable to the transmission of information (Floridi, 2010; Gleick, 2011), even though it is an abstract approach without considering human needs. Communication using the MTC has three challenges (Weaver, 1949):

- Technically, how accurately can the symbols of communication be transmitted?
- Semantically, how precisely the symbols represent the intended meaning?
- Effectively, does the received meaning affect / conduct in the desired way?

These challenges have wide ramifications for communication. To alleviate these challenges, Weaver (1949) added a feedback component to Shannon's model (Figure 4, bottom arrow): the destination must provide immediate feedback to the sender (information source), in order to provide a successful communication that fulfills the above challenges. Without feedback, the source would never know if the message was transmitted to the receiver and the communication process is successful. Berlo (1960) detailed in the meaning of successful communication as described in the following.

### 3.1.2 Berlo's SMCR Communication Model

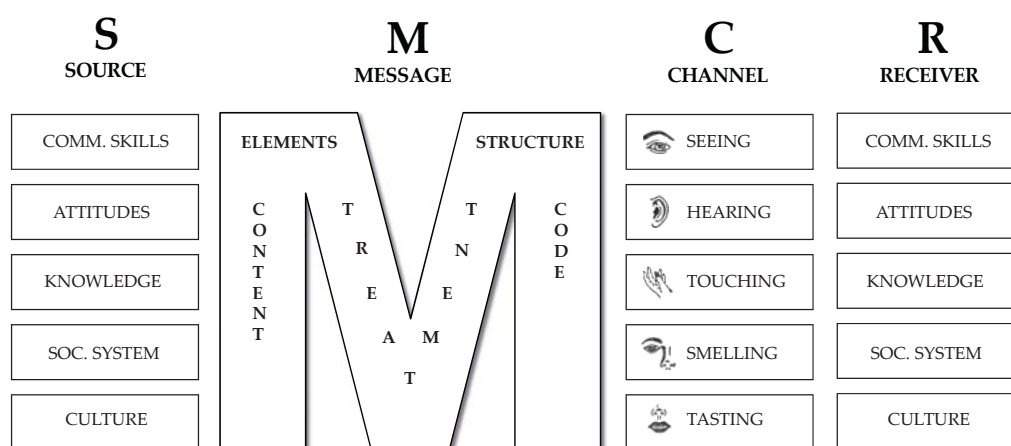
Berlo (1960) extended the MTC postulating that,

*"In any communication situation, the source and the receiver are interdependent."*

The interdependence may be based on an action of the sender and a reaction of the receiver onto the interpreted message. Or more refined, on empathy that generates expectations, when the sender is anticipating the receiver's interpretation and vice versa. Therefore, he added specific properties to the four communication elements of the MTC, namely the Source, the Message, the Channel, and the Receiver (SMCR) (Figure 5):

- 1) Source: The source is influenced by the five factors communication skills, attitudes, knowledge level, social system, and the culture of the sender. The message is encoded by the source and contains these influences.

- 2) Message: The message itself consists of the content, additional elements, treatment, and a structure including code. This comprehensive message is being transferred via the channel.
- 3) Channel: The channel is “how the message will be transmitted”, offering the utilization of the most appropriate senses to the receiver, so that s/he has the best opportunity to accurately interpret the message. The senses are hearing, seeing, touching, smelling, and tasting. Finally, the channel needs to decode the message based on the appropriate senses.
- 4) Receiver: The receiver is symmetric to the sender, and thus, s/he is influenced by the same five communication factors as the sender.



**Figure 5: Berlo's SMCR Model of Communication**

Source: Berlo (1960)

In case of an empathy-interdependent communication the sender and receiver are aligned in their expectations, and having as a consequence of the alignment a successful communication. These four elements gave the CM the name SMCR, i.e., sender, message, channel, receiver CM. Berlo's SMCR model includes the important non-verbal as well as verbal communication.

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### 3.1.3 Bateson's and Watzlawick's Communication Axioms

In the early 70s Bateson (1972) defined the basis for five axioms for human communication without misunderstandings. Philosophers like Watzlawick, Bavelas and Jackson (1967) supported these axioms in order to enable proper human communication without misunderstandings. They describe five axioms as basic features of verbal and non-verbal communication in the "Pragmatics of Human Communication" (cited from Watzlawick, Bavelas and Jackson, 1967):

- 1) Axiom (cannot not): "One Cannot Not Communicate." Every behavior is a kind of communication. It is impossible to not communicate, even with the absence of action. The interpretation of spoken or non-spoken words is equal to the non-/behavior of persons in a communication process.
- 2) Axiom (content & relationship): "Every communication has a content and relationship aspect such that the latter classifies the former and is therefore a metacommunication." Communication contains beside the pure meaning of words, further information about how the sender wants to be understood. This means that the context defines the content and the relationship of the communicators is important for the interpretation of the message. E.g. a familiar or foreign relation (context) between two persons alters the understanding of a message (content).
- 3) Axiom (punctuation): "The nature of a relationship is dependent on the punctuation of the partners' communication procedures." Human communication is based on a circular process between sender and receiver. The interpretation of each behavior can affect and alter the meaning of the message and result in further changes of the communication flow.
- 4) Axiom (digital & analogic): "Human communication involves both digital and analogic modalities." Digital modalities refer to discrete, defined elements of communication with a complex and logical syntax to transfer pure information with words. Analog modalities have a semantic meaning and support the level of relationship meaning with intonation, gesture and mimic. The combination of digital (verbal) and

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analog (non-verbal) elements are necessary for a successful communication process. Ambiguous and wrong interpretation will cause misunderstandings.

- 5) Axiom (symmetric or complementary): "Interhuman communication procedures are either symmetric or complementary, depending on whether the relationship of the partners is based on differences or parity." Differences can be established on e.g. strong-weak or good-bad attitudes and relate to an asymmetrical relationship. Symmetry between communication partners requires an acceptance of equality and results on an equal power of the communication partners. Successful communication can be established in a complementary and symmetric relationship and depends on the situation and individuality of the communication partners.

Watzlawick et al. (1967) provide intuitively the idea that communication might fail, if at least one of these axioms is violated. Interferences in the communication chain result from, e.g., unconscious behavior, gesture and mimic, the personal relations between sender and receiver, or misinterpretations of information.

### 3.2 CONCEPTS OF TECHNOLOGY INTEGRATION INTO EVERYDAY LIFE

In this section the development of the main concepts of Ubiquitous and Pervasive Computing are described. Furthermore, the concepts of the IoT, Ambient Intelligence (AmI), Wearable Computing and Augmented Reality (AR) complement the theoretical background of omnipresent technology in the upcoming everyday live.

In the early 1980s personal computers (PC) getting popular as workstations; since the 1990s it is no longer possible to imagine information and communication technologies without them (Petty and Meulen, 2008). Ubiquitous Computing, the vision of Weiser (1991) is depicted in Section 3.2.1 as a concept of technology use with omnipresent, multitude, tiny, wireless sensors that are implemented in everyday objects and environments. Weiser criticizes the use of the PC and describes (oppositional) how technology can be used and also disappears in the background. In Section 3.2.2 the applied view of "everywhere" and "anytime"



technology use is specified as Pervasive Computing. Additionally, the IoT enables “M2M Communication” with wireless access (Section 3.2.3). The IoT supports in combination with Pervasive Computing the vision of Weiser that “everyday things” are intelligent and maintains users’ needs. In Section 3.2.4 Ambient Intelligence is described as an ICT assistance with a human approach of technology application. Wearable Computing (Section 3.2.5) extends the usage of ICT with small, body- worn, hands-free to use devices and provides e.g., AR. Finally, Augmented Reality is envisioned in Section 3.2.6. AR systems enhance the real world with digital, contextual information for user assistance in real-time.

### 3.2.1 Ubiquitous Computing

The term Ubiquitous Computing, defined by Weiser (1991), is based on the omnipresence of computer services and information technology (IT). At the end of 1987, a group of scientists at Xerox PARC<sup>3</sup>, led by Weiser, developed an idea to produce wall-sized, flat computer displays which serve as input and output media. Based on this idea, devices and usage ideas were developed at PARC which split more and more off from the original concepts of personal computing (Want et al., 1995). Weiser (1993a) claims that, PC and workstations will be obsolete in the future because computing access will be provided everywhere and every time as needed, e.g. in the walls, on the wrist, and lying around (like paper). The focus of the vision for the use of ICT had been on handy laptops, electronic field notebooks, and dictionaries. As a consequence the technology is expected to become seamless (Weiser, 1991).

The vision

*“The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.”*

was postulated by Weiser (1991, p.94).

Weiser and Brown (1997) describe how omnipresent, multitude, tiny, wireless sensors are implemented in everyday objects and environments. As a result the technology disappears (calm technology). Weiser (1991) also depicts how they

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<sup>3</sup> PARC (Palo Alto Research Center Incorporated), formerly Xerox PARC, is a research and co-development company in Palo Alto, California.

interact with each other and that they disappear physically and mentally into the background. Everyday objects offer information on anything, anytime and anywhere to operate and react in a context-sensitive way (Weiser, Gold and Brown, 1999). This ease of use with ubiquitous devices is described by Weiser (1991, p.104) as:

*“Ubiquitous computers, in contrast, reside in the human world and pose no barrier to personal interactions.”*

Ubiquitous real-world objects will appear “smart” providing UX without using complex human-computer interfaces and obvious controlling devices. Ubiquitous Computing is a framework which relates to hardware components, network protocols, interaction substrates, applications, privacy, and computational methods (Weiser, 1993b). Weiser (1991) proposed three basic devices for using ubiquitous technology: Tabs (wearable, centimeter-sized devices), pads (hand-held, decimeter-sized devices), and boards (interactive display devices, meter-sized).

New ideas about the use of ICT are rising: The most striking aspect is that users consume information on several individual devices and that several users may work in parallel on one sole device (Want et al., 1995). Nowadays, everyday objects can use sensors and computing power to perform position determination, measure characteristics, record a history, and combine it with program logic. This offers important local and situation-related information to execute commands in a context sensitive way (Norman, 1998).

The vision of Ubiquitous Computing has begun to enter the everyday lives of society over the last years (Weiser, 1993a). Today, ubiquitous solutions have to fulfill, apart from usability aspects, the requirements of legally and socially compatible technology design. Emphasizing trust helps users to accept and integrate technology in everyday life (Hoffmann et al., 2011).

New devices and technologies allow completely new usage scenarios which had been postulated in similar form by Weiser already at the beginning of the 1990s. An example for this is the recent trend in smartphone and tablet computing with mobile data usage (Harrison, Wiese and Dey, 2010). Weiser’s vision of Ubiquitous Computing describes the change of human-computer-interaction and the invisibility of a wide range of computer systems in a user environment.

### 3.2.2 Pervasive Computing

Pervasive Computing was defined in the mid of the 1990s. It is based on a more pragmatic applicable vision of technology integration than the concept by Weiser. Pervasive Computing has its origin in a project of IBM which dealt with the trend of increasing and fundamental linking of information technology and mobile phones. Hansmann et al. (2001, p.1) state:

*“A billion people interacting with a million e-businesses through a trillion interconnected intelligent devices.”*

Hansmann et al. (2001) defined the principles of Pervasive Computing by the following four dimensions: decentralization, diversification, connectivity and simplicity.

Decentralization	Diversification	Connectivity	Simplicity
<ul style="list-style-type: none"> <li>• Distributed systems</li> <li>• Synchronize information</li> <li>• Managing application</li> </ul>	<ul style="list-style-type: none"> <li>• Universality vs. specialty</li> <li>• Managing diversity</li> </ul>	<ul style="list-style-type: none"> <li>• Information beaming</li> <li>• Wide range of technology standards</li> </ul>	<ul style="list-style-type: none"> <li>• Convenient intuitive Access</li> <li>• Usability</li> <li>• Availability</li> </ul>

**Table 2: Principles of Pervasive Computing**

Source: Hansmann et al. (2001)

The principles are pointed out in Table 2: the 1<sup>st</sup> principle “decentralization” enables devices to take over specific tasks and functions on distributed systems. Synchronization provides the same information for the user on a wide range of devices. Applications can be managed by central administration to enable the same functions on the dedicated user profile and device.

The 2<sup>nd</sup> principle “diversification” describes the challenge of universality and specialty. A multitude of devices of different types will co-exist and will have an overlapping functionality, but they are designed for a specific task which matches best the accompanying usage purpose. As an example consider tablet computers (tabs) for convenient information consume or notebook computers for mobile data input.

The 3<sup>rd</sup> principle “connectivity” allows global and convenient access to communication networks, regardless of time and location. The variety of infrastructure specifications and communication protocols without boundaries enable information transmission and delivery (so called, information beaming) to manifold devices that are integrated seamlessly in a wireless infrastructure like Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System (UMTS), Long Term Evolution (LTE), Wireless Networks (Wi-Fi) (Wi-Fi Alliance, 2014a) or Bluetooth Networks.

Finally, the 4<sup>th</sup> principle “simplicity” relates to the need of an intuitive and convenient access to information with an ease of use through multimodal user interaction, e.g. voice, touch or handwriting.

The concept of Pervasive Computing deals with an anytime and anywhere access via distributed networks with different user devices. Here, information processing is emphasized with the goal to use technology that is already in place or is expected to be developed in the short-term (Satyanarayanan, 2001). The focus is on e-commerce scenarios and web-based business processes, accessed via mobile terminals and wireless transmission protocols (Hansmann et al., 2001).

Context-sensitivity is enabled by Location-Based Services (LBS) which is provided by location technology as Global Positioning System (GPS) (Mattern and Floerkemeier, 2010; Bajaj, Ranaweera and Agrawal, 2002). Assisted GPS (A-GPS) eliminates the delay for position finding with a “First Fix” (Time to First Fix-(TtFF)) by radio cell location and additional adjustment with reference data provided by internet services (van Diggelen, 2009).

New integration effects are supported by standardized interface technologies for the exchange of data between a diversity of electronic devices by Near Field Communication (NFC) (NFC Forum, 2014). The easy integration of video and audio resources supported by new web standards as Hypertext Markup Language version 5 (HTML5) (Berjon et al., 2013), offer new impulses to the concept of Pervasive Computing (Bohn et al., 2004).

### 3.2.3 Internet of Things

The concept of the IoT is an industrial approach identifying things with Radio-Frequency IDentification (RFID) developed in the late 1990s. Uniquely identifiable objects, labeled with tags (optical or radio) correspond information to internet services (Gershenfeld, Krikorian and Cohen, 2004; Fine et al., 2006). This technology relates to the principle of M2M communication, e.g., a car is sending a message to an internet server with a request of an inspection and the user gets the acknowledgement via an automatic generated e-mail information.

Haller, Karnouskos and Schroth (2009, p.2) define the IoT as:

*“A world where physical objects are seamlessly integrated into the information network, and where the physical objects can become active participants in business processes. Services are available to interact with these “smart objects” over the Internet, query their state and any information associated with them, taking into account security and privacy issues.”*

In a broadly penetrated scenario, sensors and actors communicate via autonomous wireless techniques, and therefore react and act towards each other in the real world (Biggs and Srivastava, 2005). Enabler of the IoT are wireless protocols like Wi-Fi, Bluetooth, RFID, NFC and also UMTS and LTE as cellular protocols for a pervasive data transfer.

Sensor and actuator networks (wired and wireless) enhance the information gathering of smart objects, supported by LBS to enable context-sensitive information. Location technologies with NFC, GPS, Wi-Fi or GSM enable LBS with a precision of 5 centimeters by NFC and up to 300 meters via GSM. Depending on the range of use the requirements on the precision of localization-information can vary, e.g. in a logistic indoor scenario a positioning information is required in a centimeter range about whereas on a global perspective a GSM cell location is sufficient. Precise localization in an indoor environment can be realized with a short distance NFC solution, whereas Wi-Fi technology enables indoor localization with triangulation and trilateration with a precision about 5 meters (Liu et al., 2007). The accuracy with outdoor GPS positioning depends on factors as signal strength and available satellites, with an exactness up to 5 to 10 meter with perfect conditions.

Communication exchange over web-services (W3C, 2004) and the implementation of the Internet Protocol version 6 (IPv6) (Internet Engineering Task

Force, 1998) enable a universal and extendable infrastructure with heterogeneous M2M (Broll et al., 2009), machine to human (M2H) and human to machine (H2M) interaction.

The focus of the concept of the IoT is on the integration of intelligent, autonomously communication systems, that are equipped with a unique identity and which connect the virtual with the real world. Here, RFID technology has a key role in enabling wireless communication and identification (Welbourne et al., 2009). Whilst the concept of Ambient Intelligence (Section 3.2.4) supports the user with her/his requirements in the environment, the concept of the IoT has a clear technical approach, to enhance and fasten the processes in logistics and industry by improved information value (Hribernik et al., 2010).

### **3.2.4 Ambient Intelligence**

AmI represents an extended integration concept of technology use and user requirements with electronic environments that are sensitive and responsive to the presence of humans (Shadbolt, 2003). The concept was developed in the late 1990s with the approach of assistance information technology, combined with human-to-machine communication and Artificial Intelligence for an AmI world in the future up to 2020. The focus of AmI is on the assistance of private citizens, in their private environment and healthcare (Fellbaum, 2008).

Everyday objects turn into communicating intelligent and user-friendly things (Mattern and Floerkemeier, 2010; Emiliani and Stephanidis, 2005). An AmI environment understands human's speech and gestures to act and react in the user's sense, including to make decisions (Fellbaum, 2008). AmI systems also aims to enable multimodality (Nijholt, 2004) with fusion and fission (see also Section 3.3.2) of in/output of sensors or external data, e.g., Internet Web Services or M2M communication (Section 3.2.3).

The technology in the background, is not noticeable for the user and actions are partially performed by intelligent systems.

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AmI is based on the following (Denning, 2002):

- A wide range of embedded network devices are integrated into the environment.
- Context awareness helps the devices to recognize the person and the situational context.
- Personalized systems are tailored to the user needs.
- Adaptive systems can change in response to the user.
- AmI systems anticipate the users' desire without conscious mediation.

The vision of Weiser's ubiquitous computing (Section 3.2.1) and the anytime, anywhere and anything technology use of the pervasive computing (Section 3.2.2) are the basis for the user centered approach of smart technology assistance of AmI. It also includes technology disciplines as wearable devices, computational intelligence and semantic relations (Section 3.3.2) for helpful and efficient technology integration in everyday things, resulting in the fact that the user has less to worry about it (Miori, Russo and Aliberti, 2010).

The aim of AmI is to provide people with omnipresent support to improve the quality of life by using technology based, and reactive items (Fellbaum, 2008; Dewsbury et al., 2003). AmI includes a change from the technology-driven information push mechanism to application-based user or scenario-oriented approaches, so that the user can access ambient technology through his behavior and through environment influences. Today, smart home environment and European research programs as AAL Joint Program (AAL JP, 2013) envisage the future potential of intelligent environments.

### 3.2.5 Wearable Computing

Wearable computing extends the usage of ICT with small, body-worn, hands-free to use devices (Dey, Abowdm and Futakawa, 1999). They are proactive and supported by sensors to provide context-sensitivity (Rhodes, 1997). They interact synchronously driven by external devices or independent to execute operations. Mann (1998) described three modes how wearable devices conduct. The constant mode provides a permanent and stable interaction with the user. The augmentation mode offers interchange with the user, the device, and the environment without distraction of the real world. Capsulation between human and the device is

supported by the mediation mode which filters information in the solitude mode and provides security of the individual in privacy mode.

The six attributes of wearable computing (Mann, 1998) depict the human-machine synergy of wearable computing from a human's point of view:

- 1) Unrestrictive (by the user), supports the user while s/he exercises other activities.
- 2) Un-monopolizing (of the users intention), the focus is on the real world and the users is not cut off. Wearable computing is only the second activity, with the intention to enhance sensory capabilities.
- 3) Observable (by the user), the output medium is constantly perceptible as far it is desired by the wearer.
- 4) Controllable (by the user), with an automatic and responsive behavior, with possibilities to manual override the interaction.
- 5) Attentive (to the environment), provides environmentally aware, multimodal, multisensory situational awareness.
- 6) Communicative (to others), allows the usage of the device as a direct or indirect communication medium.

Wearable computing enables new possibilities of mobile, context-sensitive technology use with the extension of the human senses enhanced by sensor integration in the devices (Mann, 2013). The devices can interact autonomously or in addition to other devices, e.g. smartphones or embedded systems in cars.

Wearable Devices as "Google Glass", (Google Inc., 2014c), "Oculus Rift", (Oculus VR, 2014) or "Smartwatches" (Samsung, 2014b) embodies the potential of this approach. Wearable Computing provides the basis for AR.

### 3.2.6 Augmented Reality

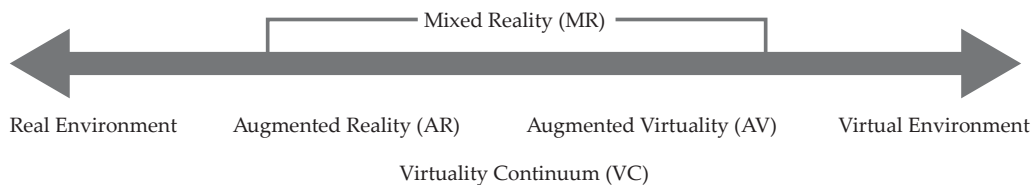
Caudell and Mizell (1992) defined the term AR as overlaying computer-presented material on top of the real world. Azuma (1997, p.356) states that,

*"AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world."*

Azuma characterized that AR systems combine and overlay the real world with virtual objects and are interactive in real-time. The real and virtual objects relate to each other in a three-dimensional manner (Azuma, 1997). Two years later,



Milgram and Kishino (1994) created the term Virtual Continuum (VC) including the approach Mixed Reality (MR), Augmented Reality (AR) and AR, as it is depicted in Figure 6.



**Figure 6: Simplified Representation of a "Virtual Continuum"**

**Source: Milgram and Kishino (1994)**

Mixed reality is placed between the real and the virtual environment, where the real environment is supported with digital added information layered over the real world from AR and a virtual environment is merged with objects of the real world from AV (Milgram et al., 1994). Azuma et al. (2001) depict that AR can be applied to enhance all senses as hearing, touching, and smelling. Wearable Devices as "Google Glass" (Google Inc., 2014c) emerge as a concrete example for an AR scenario, with contextual digital information layered on the real environment. Second Life (Linden Research Inc.) is a virtual reality platform where an avatar in a Virtual Environment can be enhanced with real world objects, e.g. a picture of the face from the user.

Mixed reality systems enhance the five human senses in a communication process, providing multimodal, and media-rich information transmission (Schreer et al., 2008). Positive UX of AR assistance can be achieved in combination of with an Ambient Intelligent environment for user centered technical assistance services. Research topics as "Augmented Reality in a Contact Lens" (Parviz, 2009) demonstrate the future potential of the AR approach and move computation from the desktop to the user.

### 3.3 RELATED COMMUNICATION ARCHITECTURES AND SYSTEMS

In this section several communication systems and architectures will be described and discussed in order to represent the state of the art of research within the field of ubiquitous communication: Section 3.3.1 contains an in-car universal

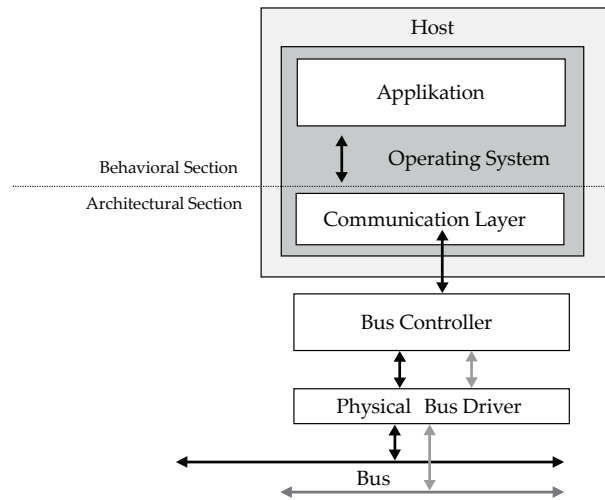
CM fulfilling the specific requirements for automotive. Then, a multimodal dialogue system with a semantic analysis of the conversation is described in Section 3.3.2. The IoT (Section 3.3.3) enables the communication of anything, and thus, the human communication with machines. In Section 3.3.4 a mobile communication and computing architecture for field engineers that consists of a user and a tool bag unit is discussed. Finally, in Section 3.3.5 a ubiquitous mobile communication architecture for next-generation heterogeneous wireless systems offering a consistent network access to users is described and discussed.

### 3.3.1 Universal Communication Model for Automotive

The Universal CM for an Automotive System Integration Platform (Car-UCM), developed by Demmeler and Giusto (2001) depicts a virtual integration platform that is based on design methodology for distributed automotive systems. This Car-UCM can be used as a framework for modelling different time- and event driven communication processes for an automotive bus network.

An automotive system network consists of several Electronic Control Units (ECU) connected via a bus system infrastructure (Figure 7): Software that is running on the host (upper part) is usually separated in hardware-independent application software and a communication layer that is hardware- (and sometimes) application-dependent. The advantage of the separation is, that only application software has to be loaded like for a parking heating. The lower part of Figure 7 is pure hardware for the (physical) bus controller and the bus which dispatches messages.

The application part (Behavioral Section) of the ECU is independent from the bus implementation (Architectural Section), and thus, enables a flexible hardware integration by the communication layer. The communication layer is based on a layered stack of architectural application modeling the single bus components of the network cluster. The continual modification of components in a refinement process is provided by the Car-UCM without changing other modules, e.g., changing the topology without modification the Car-UCM services.



**Figure 7: Electronic Control Units for an Automotive Bus Communication System**  
 Source: Demmeler and Giusto (2001)

This architecture supports the specific requirements of an automotive Car-UCM which are considered in the following.

In-car communication systems have strong reliability requirements, i.e., zero fault tolerance, since safety-related functions like the anti-lock system of the brakes (ABS) must work properly in each driving situation. Important requirements are:

- Real-time responses are required for safety-related functions and sensor / actuator communication.
- Security aspects are important factors in the automotive domain to support ABS, door control unit, or multimodal human-machine-interaction, to name a few.

These requirements are ensured by enabling high-speed data transfer and minimizing jitter and collision on the system-bus resulting in error-free communication between sender and receiver components.

The described Car-UCM for automotive provides new methods of data frame packaging or enhanced activation policies enabling new applications and services. The modular setting of the model enables a flexible replacement of new components for future technology development without changing other parts of the infrastructure and underlines the wide range of applicability for automotive. The authors propose an optimization of the real-time capabilities of the bus controller by introducing blocking mechanisms that model response delays. This

may improve the depicted Car-UCM by valuable milliseconds that can avoid crashes in extreme driving situations. However, these requirements are only applicable to domains like automotive or airplanes.

### 3.3.2 Symmetric Multimodal Dialogue System with Semantic Conversation Analysis

The multimodal dialogue system SmartKom (Wahlster, Reithinger and Blocher, 2006) from the German Artificial Intelligence Research Institute (DFKI) provides full symmetric multimodality in a dialogue-based system with a semantic analysis of the conversation. Multimodality exploits both verbal and nonverbal expressions like gesture and mimic (Wahlster, 2002). The latter both enrich human communication and make them more natural. The term modality refers to the five basic human senses: Vision, audition, touch, taste and olfaction. Human communication is also based on gestures, body posture, and facial expressions that provide additional information and semantics (Englert and Glass, 2006). A multimodal dialogue system needs to fuse all these modalities. Therefore, a synchronized representation of the input, e.g., friendly gesture and smile, is a prerequisite for a semantic analysis of the meaning. The analysis can be done by applying semantic networks to the input, where expressions (verbal and nonverbal) are represented by relations and annotations providing a meaning (Berger, 1985; Russell and Norvig, 2010). Multimodality has the challenge to be symmetric for input and output in order to appear natural, i.e., if someone uses gestures and speech for input (fission), then both modalities should also be used for the output, meaning a speech- and gesture-based output (fusion). The challenge is that both output modalities are synchronized and support the same meaning for the user.

The SmartKom architecture is depicted by a communication panel that applies three cameras from different perspectives in order to support multimodality (Figure 8): The microphones and cameras gather secondary to speech input also gesture and facial input (from different perspective). A projection surface and speakers for speech output provide output (fusion) to the user, whereas gestures or facial expressions are projected onto the surface via an avatar as is known from AR (Section 3.2.6).



**Figure 8: SmartKom-Mobile, SmartKom-Home/Office and SmartKom-Public**  
 Source: Wahlster, Reithinger and Blocher (2006)

As exemplary scenario a communication companion that helps with phone, fax, e-mail, and authentication is described. A user can execute 43 different tasks with the dialogue system to perform communication based on various media like phone, fax, and e-mail. The user's speech, facial expressions, and gestures are recorded and analyzed in order to recognize and perform the intended task, e.g., send a video message to my daughter. As a result a camera including a microphone needs to be configured for the record and the movie has to be sent to the proper address assuming that authentication is successful. The authors propose exemplary an interactive biometric authentication by hand contour recognition.

SmartKom offers a comfortable support for communication using dialogue systems. However, the full symmetric multimodality requires a semantic analysis of the input which needs to be modelled by experts. This bottleneck restricts the depicted system to a set of predefined scenarios. On the other side, these well-defined scenarios support users in a natural way of communication.

### 3.3.3 Internet of Things and H2M Communication

Atzori et al. (2010) provided a survey of the IoT: The basic idea of the concept IoT is that things are pervasive through wireless telecommunication. Things are

various items like tags, sensors, actuators, and also mobile phones. This research field is also known as M2M communication (Boswarthick, Hersent and Elloumi, 2012). The IoT is a combination of several paradigms, resulting in a new one:

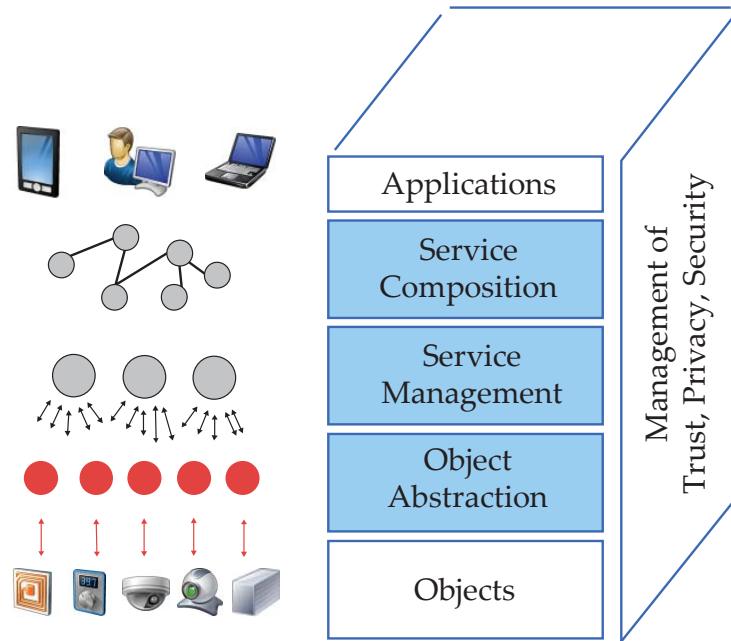
- Things-oriented vision: which is characterized by connectivity for anything.
- Semantic-oriented vision: reasoning over data and semantic execution environments like SmartKom (Section 3.3.2).
- Internet-oriented vision: communication of things and also smart semantic middleware.

The new, combined paradigm paves the way to the vision of the International Telecommunication Union (ITU) “from anytime, anyplace connectivity for anyone, we will now have connectivity for anything” (Biggs and Srivastava, 2005). A prerequisite is a so-called service layer in the Internet that provides the functionalities for the composition of single services in order to build specific applications.

Figure 9 shows the main three architecture components that are necessary for the communication of things, i.e., the architecture model from objects (lower part) to applications (upper part):

- 1) Object Abstraction: A huge and heterogeneous set of objects is expected, each one providing specific functions. There is thus the need for an abstraction layer capable of harmonizing the access to the different devices. Additionally, different languages and access procedures need to be harmonized.
- 2) Service Management: This layer covers a basic set of services for object discovery, status monitoring, and service configuration. A basic feature for services is Quality of Service (QoS) management and semantic functions like context management.
- 3) Service Composition: It provides the functionalities for the composition of single services to build specific applications. On this layer there is no awareness of devices and the only visible assets are services. An important task is to have a repository of all currently connected service instances including their configurations. These service instances are executed in run-time to build so-called composed

applications that consist of several applications like call-forwarding and international (roaming) phone number handling.



**Figure 9: Application-Enabling Middleware for the IoT**

Source: Atzori, Iera and Morabito (2010)

Numerous applications from transportation and logistics, over healthcare and social services, to futuristic are possible: Mobile ticketing on highways and fleet management make transport more efficient. Sensing and tracking both support elderlies in Active Aging (Section 2.3). Social networks are well-known for social services, and robot taxi and a city information model can be imagined as futuristic applications.

The IoT enables the communication of anything, and thus, the human communication with machines (also known as human-to-machine), e.g. humans to robots, to avatars, or to automata. Some service are already widespread like banking via smartphone. However, the needs and requirements of natural human communication including multimodality are not yet addressed.

### 3.3.4 Mobile Communication and Computing Architecture

The Mobile Communication and Computing Architecture (MoCCA) (Smailagic et al., 1999) is a portable computing system to increase the efficiency of geographically distributed mobile workers. MoCCA provides assistance for field engineers by (a) collaborative multimedia communication, and (b) database access to combine multiple devices and functions.

The MoCCA architecture supports synchronous and asynchronous data exchange with voice, video, and touch-activated mailbox (voice, e-mail, and video-mail) for rich interaction.

The architecture of MoCCA is divided into a Hardware (Hw) and a Software (Sw) part, where the Hw consists of a tool bag unit and a user unit (Smailagic et al., 1999): The Hw device of the user (right part of Figure 10) has as a wireless access, large screens, and long battery life with low obtrusiveness in size and weight.

The tool bag unit (left part of Figure 10) is connected to the user unit "Cassiopeia" (wired) and to a headset (wireless), the latter as a wearable device. Voice and data I/O for information exchange is provided by a modular cell phone unit. Multimodal I/O services empower the user to choose the most appropriate interface according to the specific situation (Englert and Glass, 2006). A touchscreen and LCD screen enable the user interaction with the software interfaces.

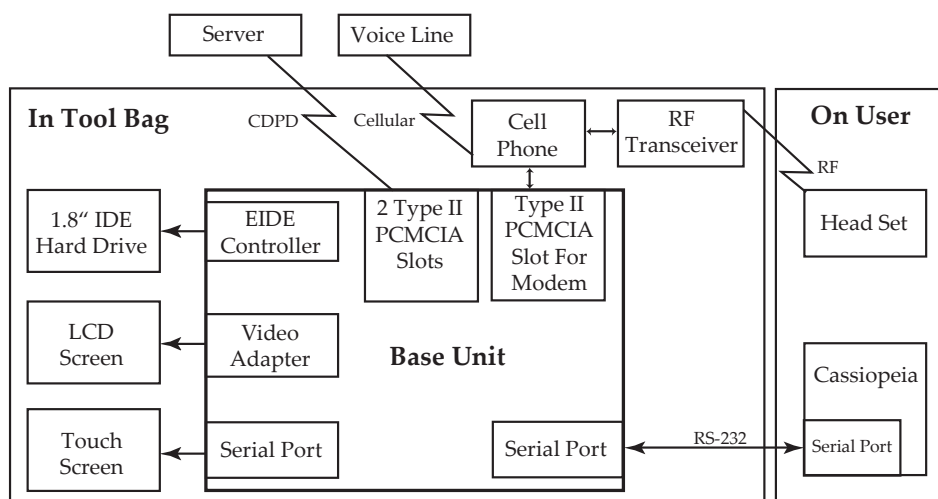
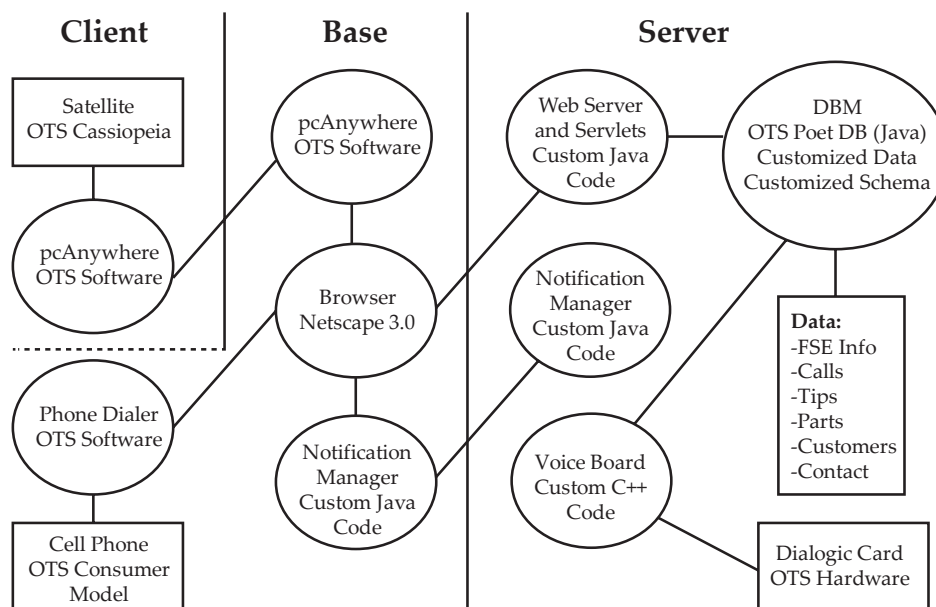


Figure 10: Hardware Architecture of MoCCA: Tool Bag Unit and User Unit

Source: Smailagic et al. (1999)



The software architecture of MoCCA is depicted in Figure 11: The user unit (left part) is a client-based design approach with primary display functions to interact with the software agents that are running on the base unit (center part), the end-user application and the services running which is part of the tool bag unit. The base unit facilitates the interaction between on the server infrastructure (right part), which is also part of the tool bag unit.



**Figure 11: Software Architecture of MoCCA (Client, Base, and Server)**

Source: Smailagic et al. (1999)

MoCCA devices support a multimodal conversation and enable due to its multiple functionalities an effective collaboration. Documented knowledge can be assimilated by wireless access to an information database in order to increase the geographic independence of the mobile user. This multi-tier networking and application architecture is modular, scalable, and flexible connectable by Transmission Control Protocol/Internet Protocol (TCP/IP) over a variety of media. The MoCCA head set may become a boost by “Google Glass” (Oculus VR, 2014). However, carrying a tool bag can be an option for field engineers. But MoCCA as a communication solution for everybody, and especially for elderlies, is uncomfortable due to the required tool bag (backpack).

### 3.3.5 A Ubiquitous Mobile Communication Architecture for Next-Generation Heterogeneous Wireless Systems

Akyldiz et al. (2005) propose a novel Architecture for Ubiquitous Mobile Communications (AMC), where wireless networks like Wi-Fi, cellular and satellite networks are being integrated into one sole network. These networks are using different protocols and offering different QoS. Thus, inter-network communication between these heterogeneous networks is a big challenge, i.e., roaming.

The Next Generation Wireless Systems (NGWS) need to fulfill several features from the user's perspective:

- Support for the best network selection based on users' service needs and preferences like willingness to pay.
- Mechanisms to ensure security and privacy, e.g., for banking services.
- Protocols to guarantee seamless intersystem mobility, offering a UX of using one sole network.

The architecture of NGWS has the challenge to combine Wi-Fi and cellular and networks with each other and to preserve the Authentication, Authorization, and Accounting (AAA) of the user in its AAA home network (AAAH), where s/he logged-in initially. The idea is to use a common backbone with the widespread IP protocol as interconnection. This IP-based interconnection hides on the one hand the heterogeneous lower network layers, and on the other hand it enables roaming.

Figure 12 shows four different network types: operator A (left upper corner) with a cellular network of the 3<sup>rd</sup> generation (3G), operator B (left lower corner) with a cellular network of the 2<sup>nd</sup> generation (2G) that is enriched by data transmission (generation 2.5), operator C (middle lower part) with a satellite network, and operator D (right lower corner) with a Wi-Fi network. These four networks are having connections to the backbone IP network via dedicated network nodes:

- Packet Data Serving Node (PDSN), as a gateway between the core IP network and the radio access for Code Division Multiple Access 2000 (CDMA2000) mobile networks.
- GPRS Gateway Support Node (GGSN), with a similar function as the PDSN but supporting GSM and UMTS networks.

- Gateway Station (GS), and Access Router (AR) for CDMA2000, to provide access for the satellite- (over GS) and Wi-Fi (over AR) networks to the core IP network.
- And General Packet Radio Service (GPRS), to allow the transmission of IP packets over 2G and 3G mobile networks

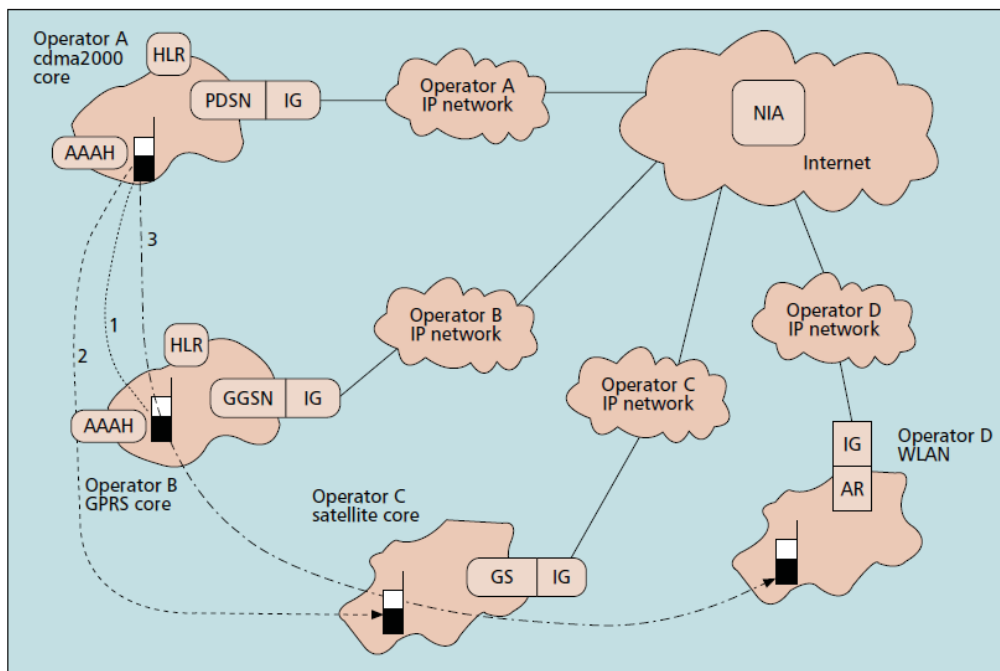


Figure 12: Integrated Architecture for NGWS

Source: Akyildiz, Mohanty and Xie (2005)

The NGWS requires to new entities for the AMC, namely the Network Interoperating Agent (NIA) and the Interworking Gateway (IG). The NIA acts as a mediator between the network operators and the IG as the gateway between a particular system and the NIA. The NIA needs to be added to the Internet, whereas an IG has to be implemented at the edge of each operator network.

Why does this architecture fulfill the above described user requirements? A seamless network choice is possible based on user preferences, since the user traffic is transferred via the NIA. Thus, the NIA can be implemented as a broker agent that negotiates the best connection for a user based on her/his preferences. The NIA is also capable to keep associated security connections, since this is a basic capability of IP networks, e.g., using the World Wide Web (WWW) secure

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communication protocol “https” (Internet Engineering Task Force, 2000). Seamless network interoperability, i.e., roaming can be easily performed through the common backbone and the IP interconnection. For this purpose the NIA needs to keep the user’s authentication information, which can be provided by the home network of the user, here the AAAH.

A further advantage of this architecture is the comfortable scalability, since in case of a new network, only the IG has to be added, and the NIA needs the corresponding information of the new network. The NGWS is an enabler for heterogeneous communication networks, especially for the integration of wireless networks. The authors of NGWS omitted QoS, since it depends on the individual network, e.g., 3G is offering QoS and Wi-Fi doesn’t. Additionally, the backbone IP network must also offer QoS, which is only possible with the end-to-end implementation of IPv6 (Internet Engineering Task Force, 1998).

The discussion of the described communication architectures and systems demonstrate the efforts to implement ubiquitous communication on the one hand. On the other hand open topics like the integration of several wireless radio standards with a diversity of devices and services with multimodal and semantic Human Computer Interaction (HCI) underline the need for a UCM architecture.

## 4 UNIVERSAL COMMUNICATION MODEL

Weiser's vision of disappearing technologies (Section 3.2.1) and the CM of Shannon (Section 3.1.1) will be materialized by the UCM for the future elderly society (Muschiol, 2013). UCM's architecture is described in the following Section 4.1. The implementation requires various (wireless) technologies and developments that are depicted and motivated in Section 4.2.

### 4.1 ARCHITECTURE OF THE UNIVERSAL COMMUNICATION MODEL

The UCM consists of five domains in which two of them are doubled, i.e., three different domains in total, namely "anybody", "any device", and "any media" (Figure 13). The UCM domains support Ubiquitous Communication for multiple communication agents with a variety of devices. The (a)synchronous interaction enables via seamless media the transfer of H2H text, voice and video messages, and provides also M2M communication (Section 3.3.3).

These three domains are described in the following.

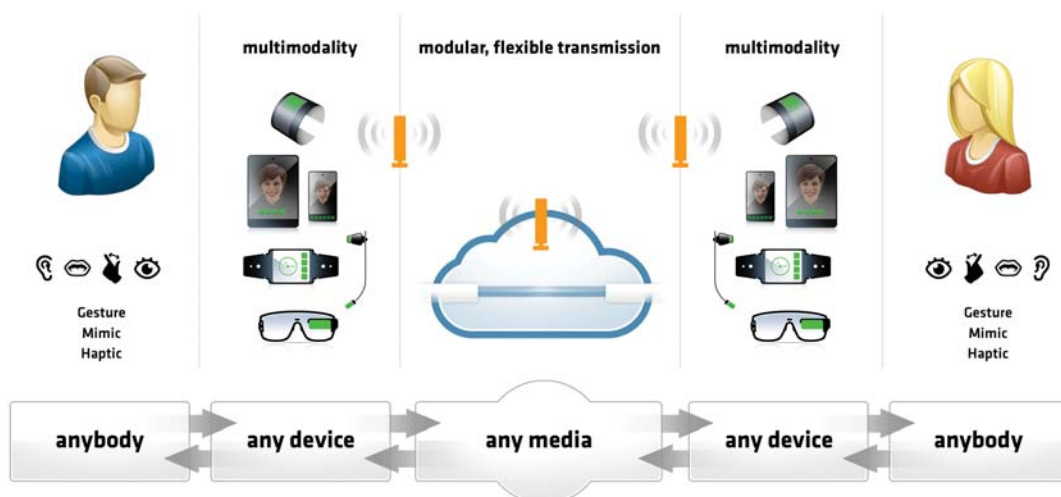


Figure 13: Universal Communication Model (UCM) for the Future Society

Source: Muschiol (2013)

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#### 4.1.1 UCM Domain: Anybody

The domain “anybody” is shown on the left and right sides of Figure 14: This domain represents a human (any human) who wants to perform a H2H communication. Natural tele-communication requires rich media (media rich communication) that applies a variety of techniques depending on the provided communication media channel (Daft and Lengel, 1983), e.g., a media rich communication includes speech, inflexion, gesture and mimic. The richness of the media format determines the efficiency of the communication process, i.e., a phone call is less effective as a video call because of the missing visual channel, which provides important information as gesture and mimic of both communication partners (cf. Section 3.1.3). Lengel and Daft (1988) state that media richness enables several dimensions of ability:

- Ability to handle multiple information cues simultaneously.
- Ability to facilitate rapid feedback.
- Ability to establish a personal focus.
- Ability to utilize natural language.

Human communication implies the usage of gestures and mimic (cf. Section 3.1) and today’s results of communication research enables the recognition of 21 categories provided by computational patterns (Du, Tao and Martinez, 2014). Additionally, haptic feedback like reinforcement during pressing a knob provides valuable information for the users (3GPP, 2014b). The UCM has strong usability requirements (cf. the detailing of the prototype usability in Section 5.1), since people with different cultural background, and with varying age and education are potential users. The development of successful future communication end-user services must cope with the challenge of systems’ capabilities and the human (in)ability to manage new emerging, complex technology. HCI has to be “enjoyable and intuitive with an ease of use and a user-centric approach (Norman, 1998). The successful and unconscious use of new technical services without any previous knowledge is stated as intuition (Bosenick et al., 2006). Customized user profiles can additionally reduce complexity and help to satisfy the user needs.

AR enhances the communication environment with additional context information in order to support the sender and the receiver (cf. Shannon’s CM in Section 3.1.1). Exemplary enhancements are the adaptation of the voice pitch in

order to compensate listening barriers, or to send and receive three dimensional (3d) environment views with multiple cameras and displays. Additionally, sensitive topics like privacy protection can be supported with the application of avatar technology (Schreer et al., 2005): Humans are represented by animated avatars that are steered by live body motion of the senders. The hand and head motion (including mimic) is transferred directly to the avatar at the receiver's side in order to represent a more natural representation of the virtual human. Tracking of the head and the body needs to be done in real-time to support a convenient UX for the user. Providing a trusted environment to the user helps to accept and integrate technology in everyday life (Hoffmann et al., 2011).

#### 4.1.2 UCM Domain: Any Device

The domains on the interior left and right sides of Figure 13, labeled with "any device", represent the class of multimodal devices like tablets, smartphones, and wearables including smart glasses and smartwatches. Wearable devices allow the users to access information anywhere and anytime, especially as they traverse in the environment (Barfield and Caudell, 2001).

As an example future devices will be specialized on certain tasks (e.g. shoes that analyze steps), and other devices have multiple functions and will provide only favored services in a context sensitive way (e.g. glasses with multimodal I/O like voice, gesture, or view). Furthermore, a flexible bracelet or a smartwatch, with an elastic high definition display, can be used as a central communication device. It provides wireless connectivity to the carrier, and the wirelessly associated devices.

Future "any device" will be fully integrated and inconspicuous into everyday things with the ability of high connectivity and energy self-sufficiency (Barfield and Caudell, 2001; Boswarthick, Hersent and Elloumi, 2012). These devices provide location-based and context-sensitive information for the user or other devices. Prevent data and information overload is important for: First, the provisioning of user-centric information. Second, the capacity load of infrastructure and devices can be monitored, and third, also the overall bandwidth performance of the networks. One possible option is that software agents on the device analyze all measurable information data and filter the data stream with intelligent algorithms

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for the relevant information. A further option evolves from mass data transmission (IEEE802.org): Big Data technology in the cloud can help to solve the challenge of mass data evaluation using cloud computing power.

Multimodal interfaces are the system/human interaction panel for the sequential or parallel application of several I/O modalities like voice, keyboard, stylus, gesture, mimic, and/or kinesthetic. Furthermore, multimodal interfaces have to be symmetric for input and output. Thus, for the input several modalities have to be analyzed and formulated in a consistent hypothesis (fusion). The application of multiple channels in parallel enables a user, e.g., to provide input via stylus and speech in order to tap onto a map and to speak “zoom in here”.

The system has to generate several actions for gestural, mimic, and speech output (fission). The challenge is to generate a consistent input hypothesis and consistent output actions (IEEE802.org).

The “any device” domains can also be used for human-to-machine communication, e.g., a user receives information on the display of his glasses. In this case only the three domains from the left side of the UCM architecture are required (Figure 13).

#### **4.1.3 UCM Domain: Any Media**

The domain “any media” (Figure 13, center) contains media for data transmission with high bandwidth and low latency. An exemplary application are huge data like High Definition (HD) video communication. This domain has to fulfill technical requirements like seamless connection with smart antennas as depicted in Table 3.

These technologies altogether enable a seamless connection and data transmission. They are described in detail in Section 4.2.



4G	5G	6G	7G
<ul style="list-style-type: none"> <li>• LTE advanced</li> <li>• All IP network</li> <li>• Up to 1 Gbit/s</li> <li>• &lt;5 ms latency</li> <li>• Various technologies FDD/TD</li> <li>• Frequencies 700 MHz – 3.5 GHz</li> </ul>	<ul style="list-style-type: none"> <li>• Carrier aggregation</li> <li>• Pervasive networks</li> <li>• Wireless mesh network</li> <li>• Smart antennas</li> <li>• Cognitive radio technology</li> </ul>	<ul style="list-style-type: none"> <li>• Wi-Fi 802.11ad (WiGig) with 7 Gbit/s and 60 GHz frequency</li> <li>• Bridge for last mile</li> <li>• Wi-Fi/WiGig policy management</li> <li>• Channel interference avoidance</li> </ul>	<ul style="list-style-type: none"> <li>• Integration of WiGig, cellular and fixed networks</li> <li>• Seamless network choice</li> <li>• Flexible and wearable devices - fully ubiquitous</li> </ul>

**Table 3: Feature Ideas for the Cellular Access Network Evolution 4G till 7G**

**Source: Muschiol (2013)**

## 4.2 WIRELESS TECHNOLOGIES FOR THE UCM

The UCM supports on the one hand the important aspect of the WHO requirement “participation” (cf. Section 2.3.1) as described in the introduction of this chapter: Communication as a human need in order to participate in the society. On the other hand a further aspect is the following: The communication market (IT, devices) is pushed by various successful companies (Gartner Inc., 2014) like Apple Inc. (Apple Inc., 2014), Google Inc. (Google Inc., 2014a), and Microsoft Corp. (Microsoft Corp., 2014b). Hence, this boost of up-coming technologies including (wireless) network evolvments will be considered in the following section.

### 4.2.1 4G Technologies

The 4<sup>th</sup> generation of cellular networks is a pure IP-based network and can be viewed as an extension of the Internet for nomadic users. The aim of 4G is a throughput of 1 Gigabit per second (Gbit/s) with a latency for the data packets

lower than 5 milliseconds. This network will be called “LTE advanced” (Table 3). A further challenge is the application of different technologies for

- big mobile network cells, with frequency division duplex (FDD), and
- small cells, with time division duplex (TDD) in the same network.

FDD means that the sender and the receiver are using different frequencies. As an example consider the situation where the sender is a mobile device (e.g. cellular) and the receiver is the antenna of a cellular network (e.g. UMTS). Then, the sender may use for data upload to the antenna the frequency 1800 Mega Hertz (MHz) and for data download from the antenna the 2100 MHz frequency. Complementary to FDD exists TDD, where for data up- and download the same frequency is applied, but the frequency band is partitioned into alternating slots for up- and download. The demerit of FDD is, that more than one frequency must be available in parallel, and the inefficiency of TDD is, that the partitioning of the frequency requires some synchronization effort between the cellular and the antenna.

A further challenge is that the frequencies are distributed between 700 MHz and 3.5 Giga Hertz (GHz), which requires an integration of different antennas into one system. The world-wide roll-out of LTE advanced is envisaged before 2020 (3GPP, 2014a).

#### 4.2.2 5G Technologies

With the 5<sup>th</sup> generation (5G) many technology improvements will be established: The European project for “Mobile and wireless communications Enablers for the Twenty-twenty Information Society” (METIS) (Queseth, 2014) aims to specify and prototypically implement a technology boost which is named “5G” until 2020. Goal is to provide a system concept that supports (Queseth, 2014):

- 1000 times higher mobile data volume per area,
- 10 times to 100 times higher number of connected devices,
- 10 times to 100 times higher typical user data rate,
- 10 times longer battery life for low power MMC, and
- times reduced end-to-end latency.

This technology boost is expected to be reached by the application and development of various technologies (NGMN, 2014) (Table 3):

First, the so-called carrier aggregation, where different frequencies are used in parallel to transmit data in order to reach a higher bandwidth. Second, the implementation of pervasive networks will enable users to be concurrently connected to several wireless access technologies and to move seamlessly between them. Third, wireless mesh networks with a variety of access schemes will make it possible to link to several nearby networks. As a result a speedier data flow is expected. Fourth, smart antennas will allow to alter the beam direction in order to enable more direct communications.

Finally, the cognitive radio technology will enable the user equipment to be aware of the radio landscape in which it is located and to choose the optimum radio access network.

#### 4.2.3 6G Technologies

Then, latest the 6<sup>th</sup> generation (6G) will renew Wi-Fi with the not yet completed IEEE standard 802.11ad (IEEE802.org). This standard is expected to have a throughput of up to 7 Gbit/s. Therefore, the name of this standard is also Wireless Gigabit (WiGig) (Wi-Fi Alliance, 2014b). An auspicious application of Wi-Fi 802.11ad is to serve as a wireless bridge for the “last distance” to sites (e.g. buildings), or the transmission of visual data to ultra-high resolution screens. Furthermore, a multi-gigabit wireless connectivity between any two (mobile) devices will be enabled like connections between video-based communication devices and other high-speed and mass data peripherals.

The extremely high frequency band around 60 GHz will be used. This frequency is not able to penetrate and pass walls, but the new technology is expected to be able to detect reflections and to switch the protocol to lower frequencies like 5 or 20 GHz which are able to propagate through walls.

Wi-Fi and also WiGig lack in policy management for several users and has a problem today with interferences at congested locations. These shortcomings will be balanced by the introduction of service quality like policy management and interference avoidance mechanisms (IEEE802.org).

#### 4.2.4 7G Technologies

Finally, the 7<sup>th</sup> generation (7G) has the big challenge to integrate the extremely high frequency bands into cellular networks. This integration will enable a seamless network choice for big data transmission like 3D computer tomography videos.

Additionally, flexible and wearable end-user equipment (cf. Section 3.2.5) can be fully connected and integrated into the meshed and seamless wireless 7G networks. Wearables, also known as smart, electronic devices or miniaturized computers which are integrated in textiles or everyday things worn by the user. Especially flexible wearables may act as displays on the hand angle or in general on the body using high frequency networks with broad bandwidth for high resolution image or video transmission as is envisaged for 7G (Qiu, Buechley and Dubow, 2013).

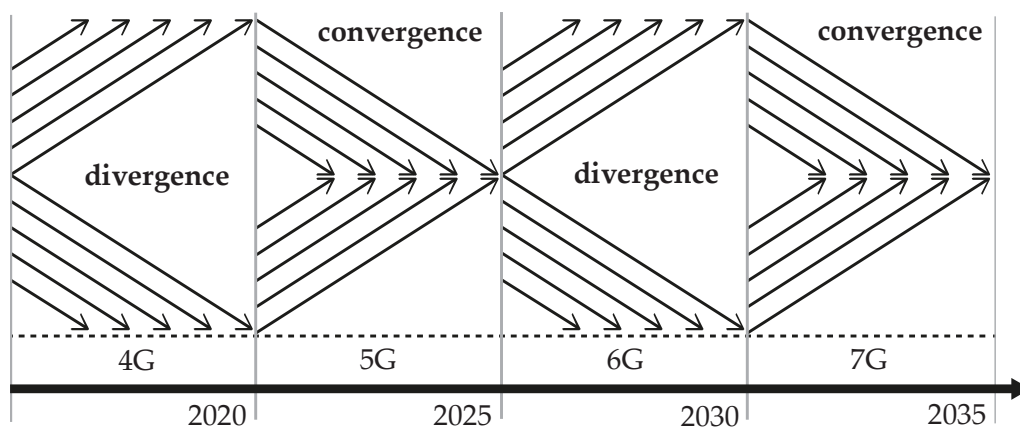


Figure 14: Alternating Technology Divergence and Convergence for the Sequenced Cellular Network Generations

Source: Muschiol (2013)

The invention of a new network technology like LTE implicates a divergence of the applied technologies in the current generation, here the 4<sup>th</sup> generation (Figure 14): The year numbers indicate estimations for the generations as they are provided by the 3rd Generation Partnership Project (3GPP) (2014b).

In the subsequent 5<sup>th</sup> generation convergence effort is always required in order to integrate the various technologies into a network. These alternating phases of divergence and convergence are repeating. 6G and 7G are inventing and

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integrating a wireless short range transmission technology (~30 meters). Thus, they are expected to be implemented in densely populated areas like North Rhine Westphalia in Germany or Nagoya in Japan. These areas are technologically well developed and applications with a great demand for QoS like video streaming or video phone calls will be the main usage.

QoS is a common feature of future networks and enables the implementation of the above depicted UCM that formalizes Weiser's vision of Ubiquitous Communication.



## 5 HUMANS AND ICT USAGE

The user interacts with technical devices via interfaces, and hence the acceptance of ICT services is deeply influenced by the UX. Section 5.1 describes the disciplines to be considered for convenient usability and joy of use with digital solutions. The approach of a user centered development requires deep knowledge about user needs. Methodologies of human behavior analyses are depicted in Section 5.2 to provide needs-oriented ICT services for the experiments in Chapter 6. Case studies in Section 5.3 point out the ICT requirements of nowadays and the future society. These sections depict the basic parameters for the prototype development of the UCM.

### 5.1 HUMAN COMPUTER INTERACTION

HCI is a discipline concerned with design and implementation of interactive computer systems for the human use (Hewett et al., 1992). HCI connects the human via an interface to the machine and it is the way how a task can be accomplished with a device and how it responds (Raskin, 2000). Norman (2004, p.101) depicts

*“Technology should bring more to our lives than the improved performance of tasks: it should add richness and enjoyment.”*

Efficiency and effectiveness are important aspects to solve a task with technical assistance but focusing on the user hedonic attributes has to be recognized for perceived quality of interactive products (Hassenzahl, Schöbel and Trautmann, 2008). Referring to the vision of ubiquitous computing (cf. Section 3.2.1) technology becomes more and more seamless, especially due to an intuitive and simple use. The aspects for successful ICT use in elder live are described in Section 5.1.1 and emphasize the challenge of the multidisciplinary required participation of experts in the fields such as aging, computer science, human factors, usability, and psychology (O’Connel, 2007; Stone et al., 2005).

In the following sections the human aspects of technology usage are depicted with the focus on the aging society: The different kinds of user interfaces are discussed in Section 5.1.2. Usability Engineering is about the technical and

economic aspects of using products (Section 5.1.3). Interaction Design considers the User Interface (UI) design aspects and the interaction of the user with the device (Section 5.1.4). The UX is depicted in Section 5.1.5 and covers the design aspects, the usability of the device and the whole range of user involvement with the product.

The approach of Ubiquitous Computing moves the use of devices from the PC desktop interaction to a new level of technical environment that becomes intuitive and seamless.

### 5.1.1 Human Aspects of Technology Use in Elderly Lives

The majority of people encounter problems when interacting and using new consumer products with new functions and innovative technical features. Many users avoid new technology solutions because they fear damaging it or that they are unable to use it (Behrenbruch et al., 2013). In various cases the problem is rooted in the design and development process of products and not in the behavior of the user (Hernandez-Encuentra, Pousada and Gomez-Zuniga, 2009). Complex user interfaces and inconsistency in the features of technical solutions increase the frustration in the use of technology for everyday tasks (Fisk et al., 2009; Selwyn, 2004). The Commission of the European Communities (2007) states that,

*“Moreover, products and services are often not adapted to meet the specific needs of older users or are not adequately available, thus increasing their sense of frustration and dependency. Unless measures are taken this situation will also hold true for the ‘future old’ given the fast technological evolution.”*

The aim is to make human system interaction error-free, productive, safe, comfortable, and enjoyable. Especially the group of elderly users has strong requirements on usability according to the change on mental and physical resources in old age (Charness and Boot, 2009; Hernandez-Encuentra, Pousada and Gomez-Zuniga, 2009). The technology industry is concerned with developing senior-friendly products, such as PC, mobile phones, etc. to meet the requirements of our today’s elderly generation (Doro Inc., 2014). However, large keys and easy to read displays are not the only requirements for the successful use of technology devices by the elderly.



Mollenkopf (2003) describes factors that influence the usage of technical devices by the elderly:

- Fear of the new,
- Motivation for use,
- Ease of use, and
- Advice and training.

Lee et al. (2011) depict that anxiety and a negative attitude against ICT acceptance are based on the following aspects:

- Intrapersonal (e.g., "I am too old for it."),
- Functional (e.g., related to memory decline, spatial orientation),
- Structural (e.g., "costs too much to own a computer"), and
- Interpersonal (e.g., "no one teaches me how").

Up to date, the technology acceptance of the generation 60+ is mostly limited due to complicated and difficult-to-use solutions with complex user interfaces and lacking instruction manuals (Hernandez-Encuentra, Pousada and Gomez-Zuniga, 2009).

With each use, special senior-optimized products remember oneself of the personal limitations and prevent the joy of use (O'Connel, 2007). Various new technologies are not optional for elderly, but they need to accept and manage them, e.g. telephone voice menu systems, online card catalogs or train ticket automats (Tacken et al., 2005). A universal and inclusive design concept with convenient usability improves the quality of use for older and younger people, and helps to enhance market penetration of technical consumer products (Fisk et al., 2009). It mediates between rapid technological developments and the changing user needs and capabilities, e.g., the decreased dexterity can cause an older person to have difficulty in pressing a small button (Lim, 2010).

Nowadays, German elderlies 60+ still have to cope with the English language as a significant challenge to use technical solutions or getting detailed product information over the internet. These elderly were born around 1950 and are categorized as the generation "Baby Boomers". People within the same generation mostly share the same perception and the same product experiences. Moreover the human needs vary by different influences as monetary income, social levels, or health issues (cf. Section 5.3).

The future generation 60+ in 2030 is today's generation 30+ and has learned technology use in private and business environments (Eisma et al., 2004; Mollenkopf and Fozard, 2004). Language barriers will decrease because the English language is nowadays a more common language as in the past. This future generation will have less initial hurdles with ICT, so that an uncomplicated usage can be assumed (Mynatt et al., 2004; Mollenkopf and Fozard, 2004).

Finally, the sensual, physical and cognitive changes in human live, which are described in Section 2.4 has to be considered to provide convenient and successful product experience without restrictions for the elderly.

### 5.1.2 Human Computer Interface

The user interface is the mutual possibility for the end-user and the ICT device to interact. Lauesen (2005) states:

*"The user interface is the part of the system that you see, hear and feel."*

Galitz (2007) extends this statement to a more modern interpretation with more possibilities for user interaction:

*"The user interface is the part of the computer and its software that people can see, hear, touch, talk to, or otherwise understand or direct."*

This approach also supports multimodality as touch and voice commands of modern devices, i.e. tablets and smartphones. A majority of good devices has to suffer from low user acceptance because of poor user-interfaces. Therefore, this is a central architecture component of a technical systems. The subpart of the International Organization for Standardization (ISO) norm 9241-110 (International Organization for Standardization, 2006) describes the principles of dialogues between humans and information systems, which are important for the user acceptance of a technical system. This framework provides guidance for the following topics:

- Suitability for the task
- Suitability for learning
- Suitability for individualization
- Conformity with user expectations
- Self-descriptiveness

- 
- Controllability
  - Error tolerance

The history of ICT shows several kinds of human computer interfaces which have been developed. The Command-Line Interface (CLI) appears as one of the first UIs of early computer systems and provides textual interaction possibilities on the base of commands and parameters (Nielsen, 1993). Typing abstract text commands with a keyboard into a text field is not intuitive, unemotional and allows only less feedback (monomedial) by the user dialog. The operation systems on huge mainframe computers and later on the first PC with Microsoft Disk Operating System (MS-DOS) (Microsoft Corp., 2014b) are examples for that way of HCI.

The next generation was the Graphical User Interface (GUI), which replaced the textual interaction with a graphical UI (Cooper, Reimann and Cronin, 2007; Nielsen, 1993). In 1973, researchers of Xerox PARC developed a computer with the first GUI called “Xerox Alto” (Thacker et al., 1979). The Xerox Alto is equipped with 128 Kilo Byte (KB) of main memory and a hard disk drive of 2.5 Mega Byte (MB) (Xerox Corp., 1976). A black and white CRT display mounted in “portrait” orientation, a keyboard and a three button mouse embodies the approach of an innovative user interaction.

Today’s OS are still similar to this approach in certain aspects, e.g. three button mouse, WYSIWYG editor<sup>4</sup>, windows, buttons and visual metaphors (Cooper, Reimann and Cronin, 2007). In 1984, Apple Inc. (Apple Inc., 2014) developed the first computer with an OS including a GUI. Later on Microsoft (Microsoft Corp., 2014b) generated a GUI for MS-DOS called Microsoft Windows (Microsoft Corp., 2014b) with great success until today (Statista, 2014). Using a mouse and a keyboard gives the user an indirect metaphor-oriented way of semi-natural symbolic and gestures. The in- and output is maintained by multimedial modes of user interaction, e.g. dropping a document into the recycle bin on the desktop via mouse gesture, additionally supported by sound and visual effects.

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<sup>4</sup> “What You See Is What You Get” (WYSIWYG)-editor is a user interface which enables working with the content on screen. It provides a view in a form closely corresponding to its appearance when printed or displayed as a finished product (Lohr, 2008).

A Natural User Interface (NUI) provides the basis for an ergonomic and natural way of interaction between humans and machines (Microsoft Corp., 2012). This principle deals with the approach of usability attributes of using real world objects translated to the virtual world. The technical settings of modern “smart” devices such as TVs, tablets and smartphones enable new possibilities for natural user interaction (Turk, 2014). Multimodal interaction combines the visual information with voice, gesture, sketch and other modalities to provide powerful dialogue approaches (Ferri and Paolozzi, 2009). HCI can be facilitated by a more natural way of communication. Using a fingertip with haptic feedback (Münch, S. and Dillmann, 1997) or speech helps the user to interact intuitively and directly with the multimodal device. E.g.

- Gesture (zoom in /out)
- Touch (press, slide)
- Text To Speech (TTS)
- Speech To Text (STT)
- Sensor-Information (Gyroskope, GPS, NFC, Temperature)

Supporting multimodality, a NUI provides configurable, flexible and context-sensitive user interaction to support a diversity of user requirements with high usability. The challenge for a good user interface design is the compromise between complexity and simplicity with a barrier-free access for all kinds of users and expectations.

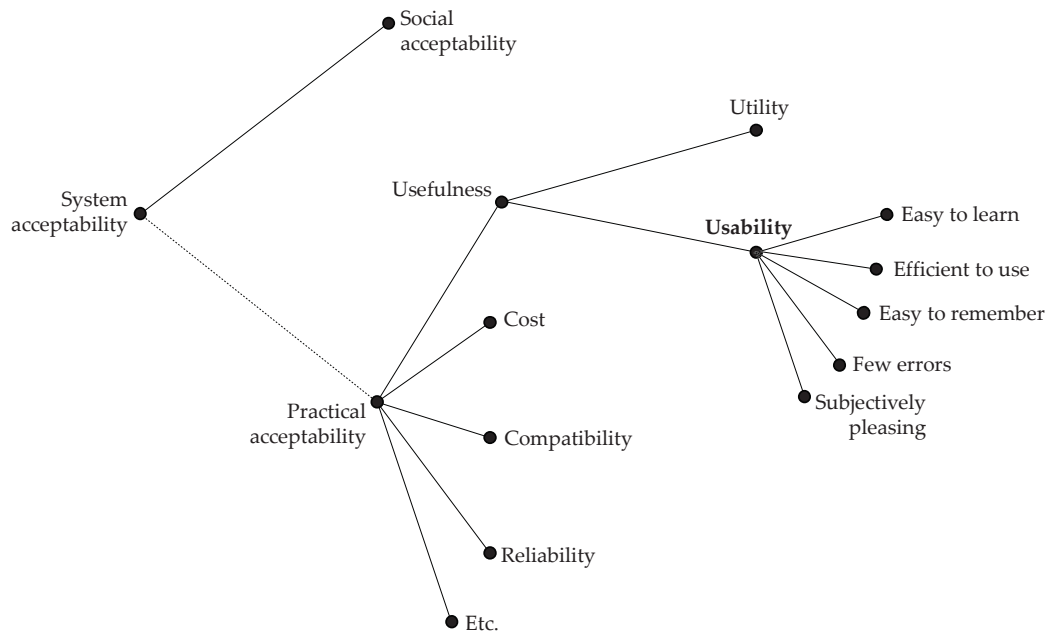
### 5.1.3 Usability Engineering

The International Organization for Standardization describes in the ISO norm 9241 (International Organization for Standardization, 1998) “Ergonomics of human-system interaction” the usability in the subpart 9241-11 as:

*“The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use.”*

Usability is a quality attribute to describe the effectiveness (task completion by users), the efficiency (task in time) and satisfaction (responded by user in term of experience) with a technical product (International Organization for Standardization, 1998). The development of software systems with good utility and usability provides solutions with a high user acceptance.

Nielsen (1993) developed a model (Figure 15) with the attributes of system acceptability for users where usability plays an important role.



**Figure 15: Model of the Attributes of System Acceptability**

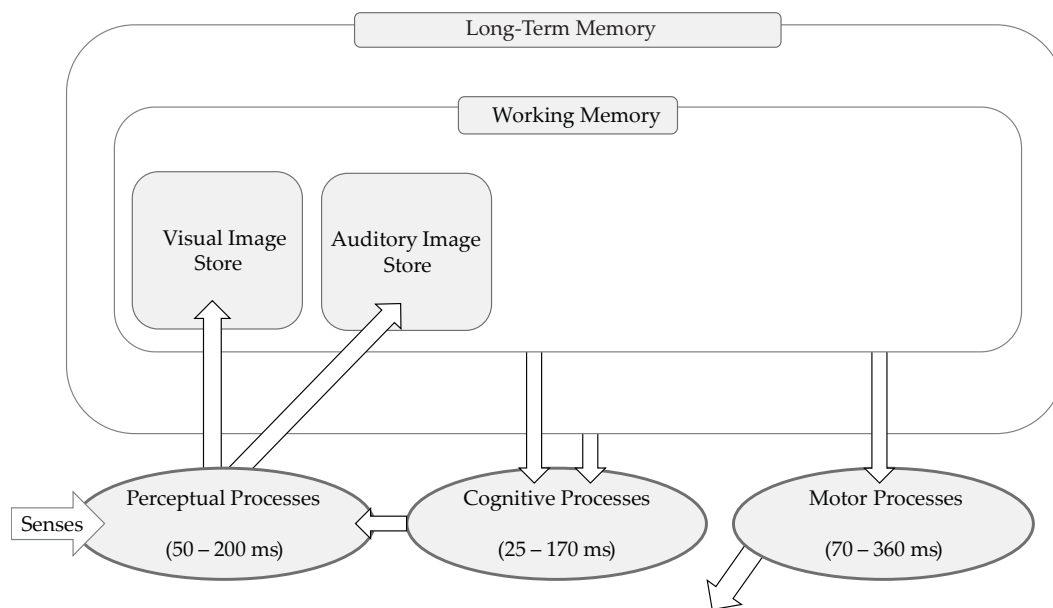
Source: Nielsen (1993)

Satisfaction is the most important factor for the user, but from an economic view efficiency and effectiveness are important to save time performing a task. Nielsen defines usability with a multiple dimensional approach with the following five attributes (Nielsen, 1993):

- 1) **Learnability:** The system should be easy to use at the first time and the user should learn the use of the system interaction rapidly.
- 2) **Efficiency:** The system should be efficient to use to provide a high level of productivity for the user.
- 3) **Memorability:** The system should be easy to remember that the user can perform the tasks easily again, even after some period of time without using it.
- 4) **Errors:** The system should have a low error rate and the user should recover easily from them.
- 5) **Satisfaction:** The system should be pleasant to use, and the user should like the system.

Norman (1998) also queried the usability of PC and provides axioms for designing information appliances. These axioms are covering simplicity, versatility, and pleasure. Norman appeals in this consideration to the specialization of technical devices and a human-centered development. The Human Processor Model of Card, Moran and Newell (1986) illustrates several individual attributes which have to be considered for optimized human brain processing, and hence, human task improvement. The model can be divided up into three basic sections (cf. Figure 16):

- Perceptual system (visual and auditory),
- cognitive system (long-term and working memory),
- and motor system.



**Figure 16: The Model Human Processor (Memories, Processors, and Basic Principle of Operation)**  
Source: According to Card, Moran and Newell (1986)

The sensory information (lower left side, Figure 16) flows into the working memory through the perceptual processor. The working memory (cf. Section 2.4.3) consists of the visual image store and the auditory image store (center left side, Figure 16). The working memory activates chunks in the long term memory to proceed with motoric further cognitive processes (lower right side, of Figure 16).

The model provides parameters which increase for elderlies and have to be considered for designing interfaces and reasonable solutions.

Mynatt and Rogers (2001) state that,

*"...designers sometimes believe that they are representative of the user population and will be able not only to understand user needs but also to predict and rectify usability problems themselves;"*

Providing age-sensitive technologies with an intuitive usability requires to "know the user" (Nielsen, 1993). O'Connell (2007) states six requirements for positive use of technology for elderlies:

- Make software configurable.
- Provide large clickable areas.
- Offer alternative access to information.
- Meet seniors' expectations.
- Assure multimodal interaction.
- Give seniors time to complete tasks.

Usability Engineering is an iterative process to develop functionality which cover user needs with an ease of use. Usability Engineering is one component of the Interaction Design which is described in the following Section.

#### 5.1.4 Interaction Design

Definitions of Interaction Design are provided by Preece et al. (2011, p.9):

*"Designing interactive products to support the way people communicate and interact in their everyday and working lives."*

and Cooper et al. (2007, p.xxvii) state that Interaction Design is:

*"...the practice of designing interactive digital products, environments, systems, and services."*

Both definitions include interactivity of the hard- and software with a daily use and high emotional binding (Jones and Marsden, 2006).

Mirel (2004) adds the behavior of the user as one further component to Interaction Design and supports the User-Centered Design (UCD) approach. Norman (1988) developed the "Human Action Cycle" shown in Figure 17: The user wants to solve a task using the digital system. Responding by his goals, s/he acts with a sequence of steps to reach the aim. The system processes the user inputs and

reacts in a certain and predefined way, changes and shows the system status to the user. This process continues until the user achieves his objectives.

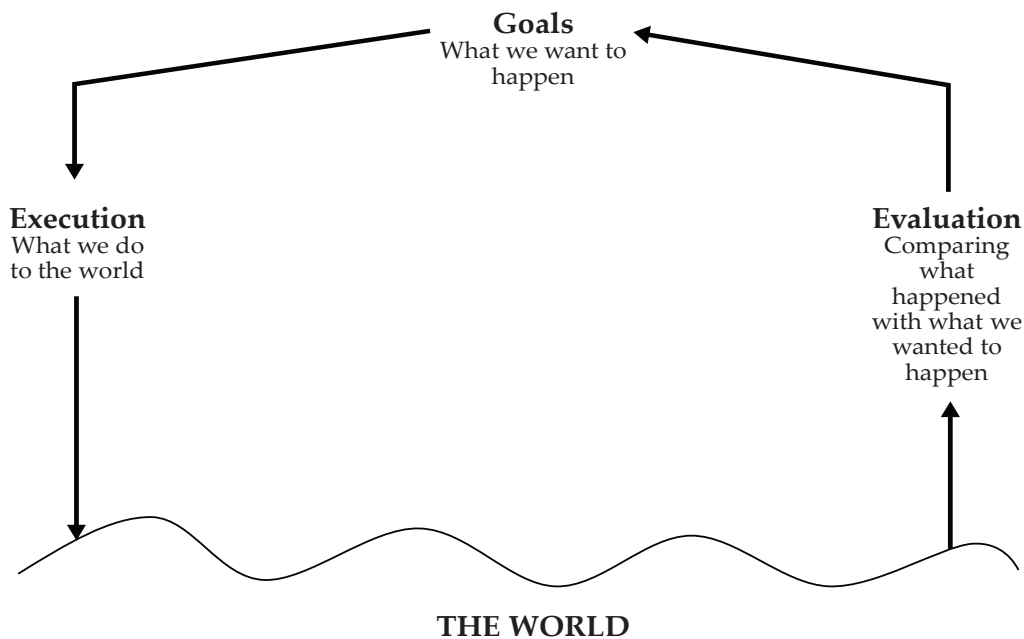


Figure 17: Human Action Cycle

Source: Norman (1988)

Norman (1988) defines the following design principles for interaction design to give an easy and convenient access to system functions for everybody:

- Visibility
- Feedback
- Constraints
- Mapping
- Consistency
- Affordance

System Interaction as typing a text, selecting an option or executing a function can be realized in different ways in a software product. For example, pressing a button with a mouse or touching the screen; typing on a keyboard or speech recognition. The techniques and styles of interaction were summarized by Shneiderman with the following seven tasks (cited from Shneiderman, 1996):



- 
- 1) Overview: Gain an overview of the entire collection.
  - 2) Zoom: Zoom in on items of interest.
  - 3) Filter: Filter out uninteresting items.
  - 4) Details-on-demand: Select an item or group and get details when needed.
  - 5) Relate: View relationships among items.
  - 6) History: Keep a history of actions to support undo, replay, and progressive refinement.
  - 7) Extract: Allow extraction of sub-collections and of the query parameters.

Shneiderman also describes five styles of interaction (cited from Shneiderman, 1996):

- 1) Visual representation, also known as “direct manipulation” to execute a task directly on the object. This interaction is easy to learn and gives the option to a well-designed visual representation of the task.
- 2) Menus represent large sets of actions with layer, support child sets but provide no physical metaphors.
- 3) Form fill-in elements are simple for data input and similar to the use of CLI. They are not flexible in use and often with poor usability.
- 4) Command line interaction was used with the first OS and is difficult to learn for novice. For experienced users it is quickly and powerful.
- 5) Natural speech allows the user to communicate with the electronic device through a series of spoken commands and enables a human approach to the interaction.

The latter style, natural speech interaction enables a future approach of the interaction between a human to a computer and supports multimodality in combination with gesture and sensor driven data fusion (Turk, 2014).

The various kinds of sensory modalities are described by Blattner and Glinert (1996) (Table 4): Visual (e.g., lip reading), auditory (e.g., speech input), touch (e.g., pressure), and other sensors (e.g, sensor-based motion capture).

Modality	Example
<b>Visual</b>	Face location
	Gaze
	Facial expression
	Lip reading
	Face-based identity
	Gesture
	Sign language
<b>Auditory</b>	Speech input
	Non-speech audio
<b>Touch</b>	Pressure
	Location and selection
	Gesture
<b>Other sensors</b>	Sensor-based motion capture

**Table 4: Human Sensory Modalities Relevant to Multimodal HCI**

Source: Blattner and Glinert (1996)

Touch display devices with sensors like smartphones and tablets enable an easy and feature rich interaction for the user. Therefore, the mapping of functions for an interactive design has to be structured clearly. The implementation has to be intuitive, without confusion, simple, and direct (Lao et al., 2009), i.e., zoom in a photo with a two fingers apart gesture or rotate a photo with a two fingers rotation. According to the common user behavior and the usability guidelines an interaction concept for the application platform has to be adapted for a “one fits all”.

The concepts of “Universal Design” and “Design for all” describe how products should be realized to give everyone the greatest extent of using a product, regardless of the person’s age, ability, or status in life (Clarkson et al., 2007). Considering guidelines for barrier-free implementation of functionalities can help the elderly people to use environments or technical products without a hindrance. The commission of the European Communities (2007, p.6) queries for the elderly society in the “Action Plan on Information and Communication Technologies and Aging”:

*“Access, accessibility and user-friendliness of devices and services are prerequisites for the inclusive delivery of advanced services for the aging society.”*

Interaction Design is more than the planning of how to “press a button”: The challenge is to perform a combination of information in- and output, with a process

view and a fitting concept of the application functionality. Finding the compromise between a user-specific design approach and a “Design for all” is still a challenge.

### 5.1.5 User Experience

Norman (2014) defines:

*“‘User experience’ encompasses all aspects of the end-user’s interaction with the company, its services, and its products.”*

The paradigm shift from pure technology-driven ICT development to a user-centered and needs-oriented product development was coined out by Shneiderman (2002, p.2):

*“The old computing was about what computers could do; the new computing is about what users can do. Successful technologies are those that are in harmony with users’ needs. They must support relationships and activities that enrich the users’ experiences.”*

Functionality is the important attribute of a product but Schmitt (1999, p.22) states that the customer wants products,

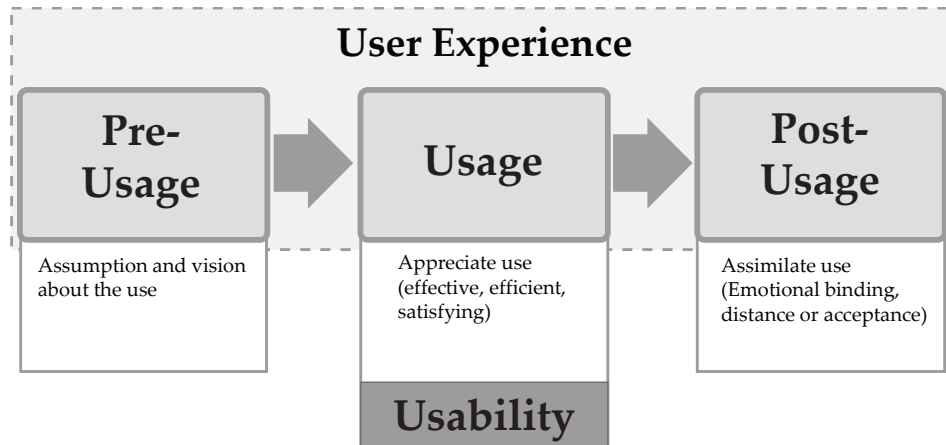
*“that dazzle their senses, touch hearts and stimulate their minds”*

Hassenzahl, Beu, and Burmester (2001) focus that the development of software products has to provide a basic utility and usability but has also to consider hedonic attributes. Solutions with a more holistic perspective on human needs and desires encompasses the real UX, with a “joy of use”.

The more industrial approach of UX is defined in the ISO norm 9241-210 (International Organization for Standardization, 2006). It provides requirements and recommendations for human-centered design principles and activities throughout the life cycle of computer-based interactive systems concerning software and hardware components.

The entire process of UX is depicted in Figure 18 with the definition of three phases:

- “Pre-usage”, assumption and vision about the use.
- “Usage”, appreciate use with effectiveness, efficiency and satisfaction.
- “Post-usage”, assimilate use with emotional binding or distance.



**Figure 18: Process of UX**

Source: According to the International Organization for Standardization (2006)

Cooper (2007) describes in his work methods to analyze and measure user needs and compare them with the users' experiences e.g.:

- Contextual Inquiries  
(Analyze users in solving real tasks)
- Cognitive Walkthrough  
(Usability expert attends several tasks in mind, to evaluate where a typical user might fail to operate in a critical process.)
- Personas  
(Archetypal description of user groups, representing the typical user with motive, preference, knowledge and user habitudes)
- Storyboards  
(Explaining the real product use)
- Prototyping  
(Rapid development of certain product features, to evaluate i.e. the usability or special topics for the complete functionality)
- User-testing  
(Measure and analyze product use with real tasks)
- A/B Tests  
(Two different tasks are executed by several users and the results are statistically compared)

- 
- Scenarios and Use Cases  
(Description of a typical user scenario is defined ahead and can be compared with the realized solution)
  - Surveys  
(Questionnaire or interview based method to get information about user opinion)

UX combines “the look” (authenticity, trust, harmony, and mood), “the feel” (joy of use, interaction, and reaction) and “the usability” (functionality, intuitively, and predictability) to one common topic. Extensive knowledge is taken from the disciplines HCI (Section 5.1.2), Usability Engineering (Section 5.1.3) and Interaction Design (Section 5.1.4) and has to be merged for suitable UX.

## 5.2 SOCIAL TYPOLOGIES

A typology represents an approach to classify entities into groups or classes on the basis of their similarity (Bailey, 1994) and helps to understand the human attitude and behavior in a general approach. Typologies are segmented clusters of reference groups built up on key criteria types that are based on e.g., empirical experiments or socio demographic factors (Bailey, 1994). Classification techniques based on statistical and mathematical analyses provide methods to cope with the variances and deviations in the group clusters (Duda and Hart, 1973). Typologies provide a variety of characteristics of human behavior and needs which are subcategorized and defined with e.g. demographic data, health attributes or life satisfaction to describe the generalist profile. The persona method (Section 5.1.5) adds to the cluster profile an authentic face and describes the typical behavior of a person belonging to this group.

The following sections describe specific approaches of the three applied typologies: First, humans are segmented into groups on the basis of the biographic life course (Section 5.2.1), and second is the adopter model which segments human behavior depending on the acceptance of innovations (Section 5.2.2). A cross sectional typology concept, namely the Sinus Milieus (Sinus Markt- und Sozialforschung, 2014), incorporates the social situation and the value orientation, and is described in Section 5.2.3.

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### 5.2.1 Biographic Life Course Model

Life course perspectives describe human life's in a structural, social and cultural context (Elder, Johnson and Crosnoe, 2003; Elder, 1994). Elder (1998, p.9) states that, life course perspectives give an overview

*"...how lives are socially organized in biological and historical time, and how the resulting social pattern affects the way we think, feel, and act".*

Giele and Elder (1998, p.22) defined the life course model as

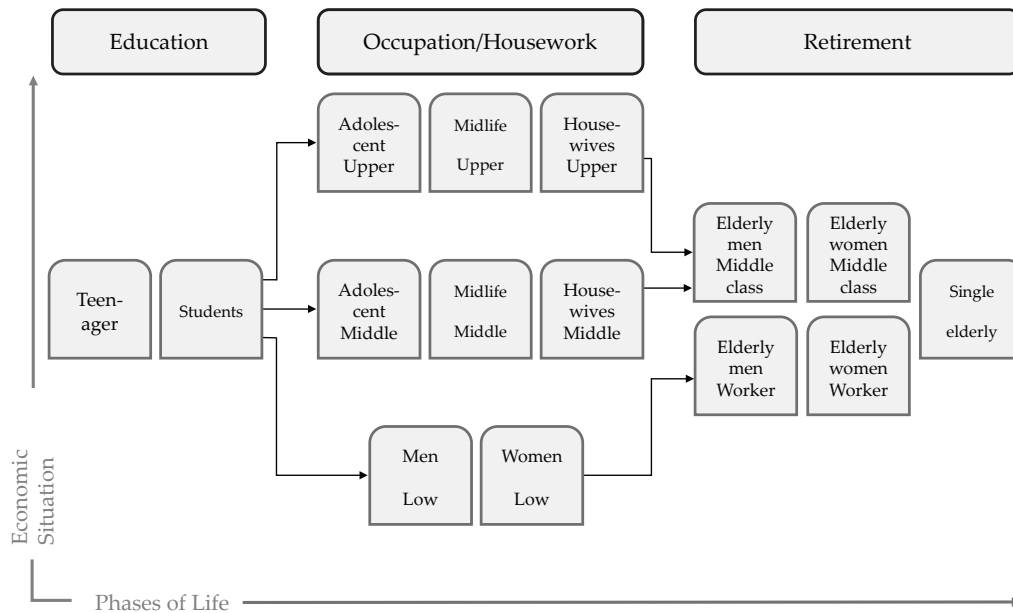
*"...a sequence of socially defined events and roles that the individual enacts over time."*

The life course perspective considers the transition from birth over the adulthood to old age (Schulz and Heckhausen, 1996). An integral part of the biography are the early experiences of youth that are influencing people's later life (Elder, Johnson and Crosnoe, 2003). The life course approach represents the differences of aging divided up into several life course phases (Elder, 1978). The biographic age does not match to the physical age in any case and the life course typology matches to the approaches of the WHO strategy of Active Aging (cf. Section 2.3).

Kleining (1968) specialized the segmentation of the life course approach in the 1970s into the model of "Biographic and Family Life Course" and correlates the life span with horizontal and vertical dimensions as depicted in Figure 19:

- The horizontal dimension splits the life course model into three parts (education, occupation/ housework, retirement) with an individual biographic or a family cycle perspective.
- The vertical dimension introduces different levels of social status and social class from the bottom (lower class) up to the top (upper class).

The Model of the Biographic Life Course begins with the educational phase, leads to the work period, and ends with the retirement. The segmentation is based on values, attitudes, and behavior with demographic, social, and economic values. Kleining and Witt (2001) emphasize that the first phase (education) has initial consequences on the later economic activities in the development of the person.



**Figure 19: Model of the Biographic Life Course**

Source: According to Kleining and Moore (1968)

The model is based on statistical data and proves the approach that the educational phase is the root for further development in the occupation, and the retirement phase. It provides valuable market research information and a forecast over aspects of social, consume, and media behavior based on hundreds of variables with over 20 dimensions. The economy consumption of products is based on the human needs, but is grounded on monetary resources. The individual monetary environment influences the way of life, attitudes, and product consumption. As an example, a higher educational attainment should lead to a higher classified job with higher salary and therefore a higher pension.

This life course perspective enables a development of technical solutions that are based on consumer needs, behaviors and social classes.

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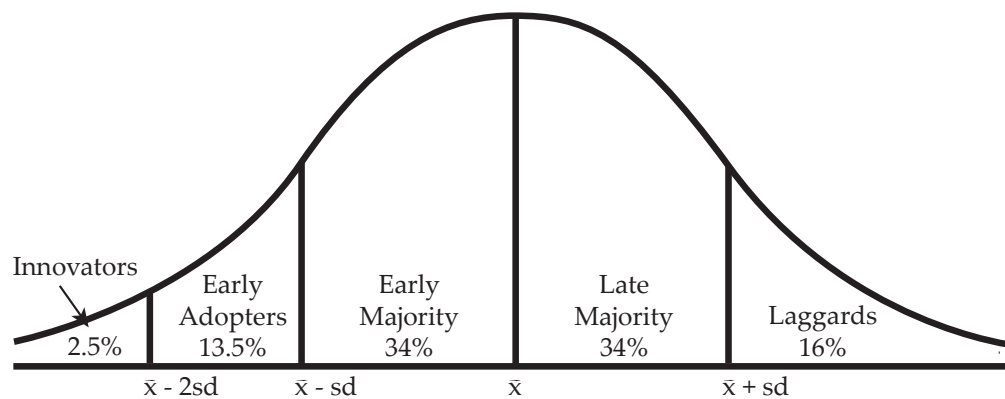
### 5.2.2 Adopter Model

The term “adopter categorization” was defined by Rogers (1958) and generalized in his first edition of the groundbreaking work “Diffusion of Innovations” (Rogers, 1962). Technology innovations have to be developed with a forecast of future consumer markets (Rogers, 2003); Lieberman and Montgomery, 1988). Rogers depicts how new ideas and technologies divide society into several clusters. His model of “Adopter Categorization on the Basis of Innovativeness” (Rogers, 1958) provides five categories with an approximate percentage of individuals that are summarized as follows (for details see Rogers (2003)):

- 1) Innovators (2.5%) are interested in new ideas and connected globally to more cosmopolite social relationships. Substantial financial resources and technical knowledge help to identify and utilize new innovations. Innovators are gatekeepers for new ideas into a system.
- 2) Early Adopters (13.5%) help to trigger the critical mass, when they adopt an innovation. They are a more integrated part of the local social system and have a higher degree of opinion leadership as the innovators. Early adopters are open-minded to many topics, embody success, and discrete the use of innovations.
- 3) Early Majority (34%) adopt new ideas just before the average member of the system and provide interconnectedness to the interpersonal network. They are one of the most numerous adopter categories with one third of all, follow with deliberate willingness. The early majority is no leader with the adaptation of new ideas.
- 4) Late Majority (34%), are skeptical persons related to innovations. They adopt new ideas just after the average and represent also 34% (as the Early Majority) of the adopter categorization, which is an economic necessity. Members of the late majority are doubtful and uncertainty must be removed about new ideas, before they feel save to adopt them.
- 5) Laggards (16%) have no opinion leadership, are most localized, isolated and the last group in the social system who adopt innovations. Laggards have traditional values, are suspicious of new ideas, and have limited financial resources.



Figure 20 shows the five categories of the adopters with the deviations from the mean of the Gaussian distribution: The mean ( $\bar{x}$ ) of the normal curve is the average of the individuals of the system and the standard deviation ( $sd$ ) is a measure of the variation of the mean. This variance from the mean helps to partition the Gaussian distribution into the five adopter groups with percentage values.



**Figure 20: Adopter Categorization on the Basis of Innovativeness**

Source: Rogers (2003)

Rogers (2003) describes the spread of the internet and how it changes human's communication. Rogers (2005, p.3) states that

*"Diffusion is the process through which an innovation spreads via communication channels over time among the members of a social system".*

The saturation level and the market share of products is described as an S-shaped diffusion curve (Figure 21) (Rogers, 2003): The factor time is drawn on the abscissae and shows that at the beginning (left side) of a diffusion of innovations only a small percentage of persons (ordinate of Figure 21) adopts the innovation. This is caused by the fact that innovations have to be placed on the markets and the due of consumers is only a small percentage.

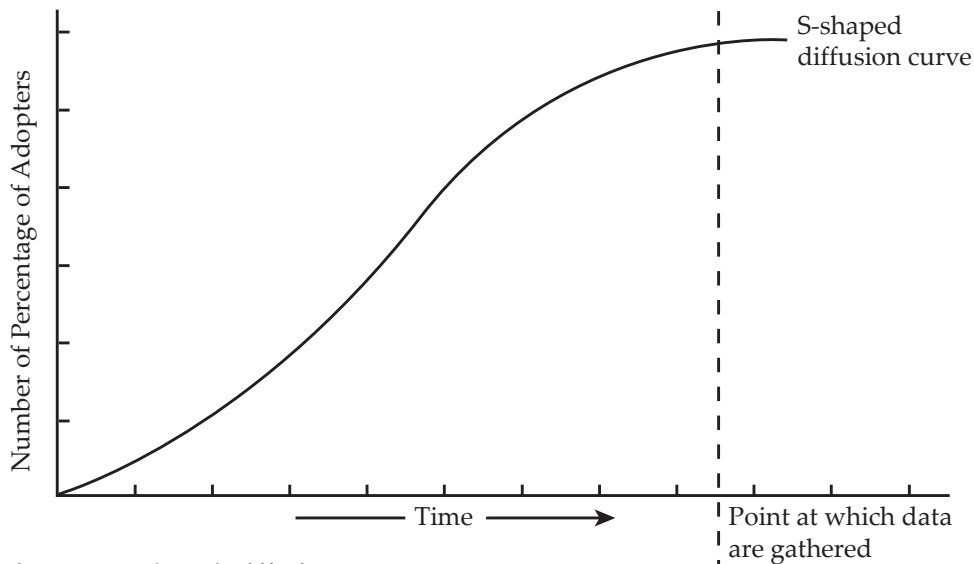
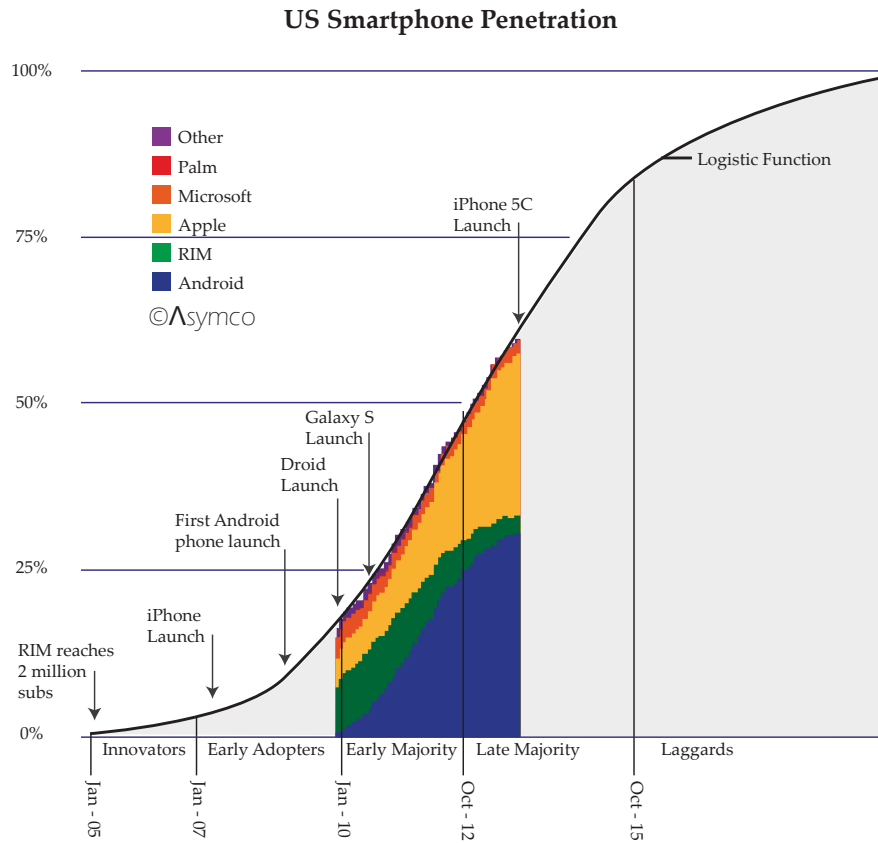


Figure 21: S-Shaped Diffusion Curve

Source: Rogers (2003)

Once the innovation is established within the system the share of interested person's increases and ends with the saturation of consumer demand (right side of Figure 21). Figure 22 exemplifies the approach of the adopter model with the US smartphone penetration. The study and forecast of Figure 22 show that:

- The Innovators were engaged in the first smartphone technologies from January 2005 to February 2007, one month after the iPhone was announced.
- The Early Adopters use smartphones from the beginning of February 2007 to January 2010. They use mainly iPhone 3GS and BlackBerry Devices.
- The Early Majority reached the critical mass in October 2012, with devices as iPhone 4, Droid and Galaxy.
- The Late Majority started from October 2012 and will reach the saturation by November 2015.
- The Laggards will adopt smartphones from late 2015 until late 2020.



**Figure 22: US Smartphone Penetration**

Source: According to asymco (2014)

The use of new technologies is nowadays, and especially in the future, essential in everyday life.

**5.2.3 Sinus Milieus Model**

The term Sinus Milieus (Sinus Markt- und Sozialforschung, 2014) depicts a model with target group typology which incorporates attributes as age, gender, education, income in segmentation to geographic and behavior-related environments (Sinus Markt- und Sozialforschung, 2014). The model is divided up to the social situation (upper, middle, or lower class) and the value orientation (traditional, standard, or modern attitude) into so-called milieus.

Figure 23 depicts the Sinus Milieus with ten “potato slices”, the so-called society clusters. The higher a milieu is situated in the model, the better are education, income and the social situation. A position maximum to the right, is an indicator for a more modern and innovative attitude of the milieu. The borders of the several Sinus Milieus are floating and thus they overlap, which is defined as “uncertainty relation of daily realness”.

**SINUS:**

## Sinus-Milieus® in Germany

Social Status and Basic Orientation

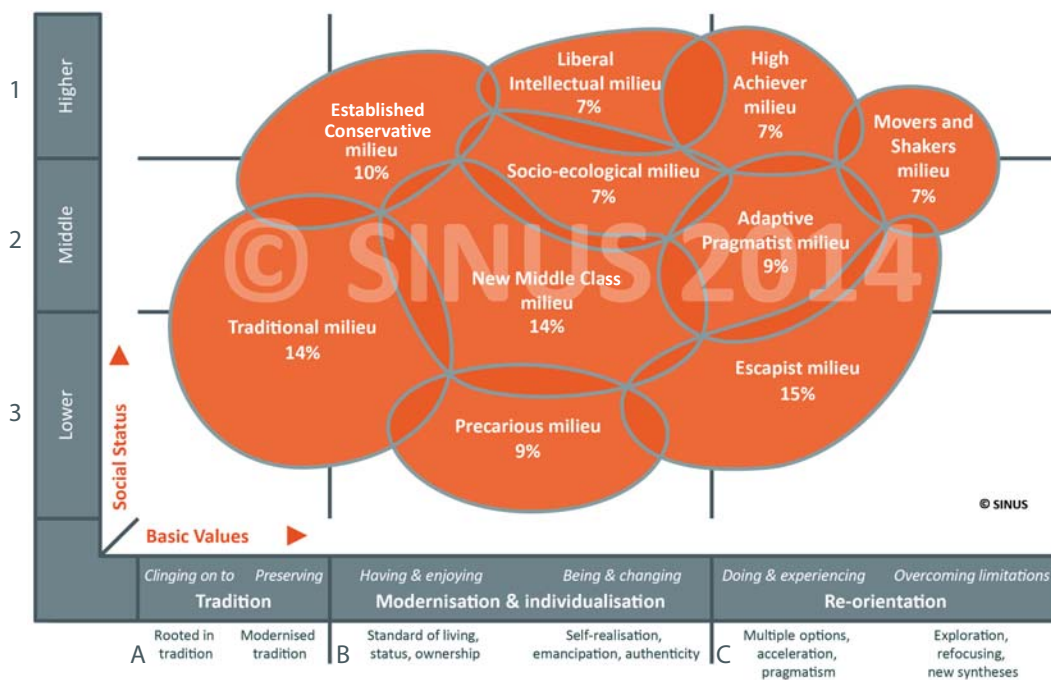


Figure 23: Sinus Milieus in Germany

Source: Sinus Markt- and Social Research (2014),  
Sinus Markt- und Sozialforschung, Heidelberg (2014)

The generated society clusters represent the way of life and attitudes towards work, family, leisure, money, and consumption. The ten Sinus Milieus can be characterized as follows (for detailed descriptions refer to (Sinus Markt- und Sozialforschung, 2014)):

- 
- **Established Conservative Milieu**

This group essentially consists of freelancers or qualified employees with an intermediate to high educational background. Many of them are married with children and provide higher incomes. They are oriented on class society, act ethically and strive for responsibility, success, and leadership at the same time.
  - **Liberal Intellectual Milieu**

The Liberal Intellectual Milieu includes an above-average number of self-determined, self-employed professionals, as well as qualified and executive employees, mostly holding high professional education and academic degrees. They have a liberal basic attitude and post-material roots. In relationship to the other Sinus Milieus this group is also characterized by families with children and the highest income level.
  - **High Achiever Milieu**

To a large extent, this group consists of full-time workers and self-employed persons and freelancers. Their global economic mindset and their academic attainments lead to high-level IT and general technical know-how. Representative for this group is a high income level and households including couples without or with younger children.
  - **Movers and Shakers Milieu**

This milieu includes generally mobile, mostly unmarried singles, who are completely networked online and offline. They have the highest number of high-school graduates, permanently seeking new challenges. This group is formed by either executive employees or self-employed, mostly coming from well-situated parental homes, holding high formal education and earning an above-average income.
  - **New Middle Class Milieu**

This group is characterized by mostly married persons with an intermediate-level education and only few university graduates. They generally accept the social order and strive to become established at a professional and social level. Most of them are employed as clerks or in qualified jobs, allowing an ordinary household income. Reaching a continuous way of life is a main target in their lives.

- **Adaptive Pragmatist Milieu**

The typical adaptive pragmatist is success oriented and always prepared to compromise. His flexible, hedonistic, and conventional acting and his strong desire for anchoring and belonging are characteristic for him. Most people of this group have middle to higher educational attainment and work as simple or qualified employees, whereby about one fourth seeks work or still is in training. To a large extent, adaptive pragmatists earn an average to higher income and are married, however, in many cases without children.
- **Socio-ecological Milieu**

This group consists of qualified employees, higher officials, as well as some self-employed and freelancers. It also includes the highest share of part-time jobbers and those no longer employed. This milieu is characterized by pronounced ecological and social conscience and globalization sceptics with high professional background. More than one third hold high-school or university degrees and earn average to high incomes.
- **Traditional Milieu**

This group is rooted in the world of the middle and working class, incorporating economical thinking and adaptability to requirements. It includes a high portion of women, pensioners, and widowed, most with low educational background. Most of them work as clerks or skilled workers, having small to medium incomes.
- **Precarious Milieu**

The precarious milieu, mainly consisting of singles and widowed, has a reactive attitude towards life and tries to keep up with the standards of the middle classes. Social disadvantages and low development prospects result from typically low educational background. This group includes mostly skilled or unskilled workers with low household income and also the highest number of unemployment in comparison to the other Sinus Milieus.
- **Escapist Milieu**

This group consists of individuals, living without or together with partners, who completely avoid conventions and expectations of

society. They have no typical identifiable level of education or standard of work, and include unemployed, simple and qualified workers as well as employees, all with a broad distribution of income.

The clusters in Germany are segmented as follows (Table 5):

Sinus Milieus	Share of Population	Title
Established Conservative Milieu	10.0%, 7.02 m.	The classical establishment
Liberal Intellectual Milieu	7.1%, 5.0 m.	The fundamentally liberal, enlightened educational elite
High Achiever Milieu	7.4%, 5.2 m.	Multi-optional, efficiency-oriented top performers
Movers and Shakers Milieu	7.1%, 5.0 m.	The ambitious creative avant-garde
New Middle Class Milieu	14.0%, 9.8 m.	The modern mainstream with the will to achieve and adapt
Adaptive Pragmatist Milieu	9.3%, 6.6 m.	The ambitious young core of society
Socio-ecological Milieu	7.1%, 5.0 m.	Idealistic, discerning consumers with normative notions of the "right" way to live
Traditional Milieu	13.9%, 9.8 m.	The security and order-loving wartime/post-war generation
Precarious Milieu	9.1%, 6.4 m.	The lower class in search of orientation and social inclusion
Escapist Milieu	15.0%, 10.5 m.	The fun and experience-oriented modern lower class/ lower middle class

**Table 5: Sinus Milieus Share of Population in Germany 2013**

**Source: Gesellschaft für integrierte Kommunikationsforschung mbH & Co. KG (2013)**

The Sinus Milieus were developed in the early 1980s and continuously updated by the Sinus Institute (Sinus Markt- und Sozialforschung, 2011), in correlation to the constant change of social values. Moreover, the German Sinus Milieus has been transferred to 18 other countries (Sinus Markt- und Sozialforschung, 2011). Depending on the research question a cluster of several milieus can be compiled with the definition of several sections (cf. Figure 23, p. 108). The Sinus Milieus global clusters (Sinus Markt- und Sozialforschung, 2011)

are named with alphabetic character and numbers (On the abscissae from A (left side) to C (right side) and on the ordinate from three (bottom) up to one (top)), e.g., “Modern Elite Milieus” summarized with B1 + C1. Individual cluster combinations can be assembled by the merging of neighbored milieus, e.g., “Post-material-oriented Milieus” as B1 + B12.

The typology of the Sinus Milieus provides a user-centered approach for product development and research with a basis on real statistical demographic data with the consideration of personal life styles and attitudes. Elderlies can be mapped to the Sinus Milieu clusters, since they are settled, having strict habits, and their professional life is completed. Physical and mental changes in elderly life influence the attitudes, needs and behavior. Nevertheless the social affiliation with the manifested values are mostly stable.

The following sections apply typologies to technical usage and attitudes towards communication technologies.

### 5.3 GENERATIONS AND TECHNOLOGY ACCEPTANCE

The demographic change causes a partitioning of the society in aging clusters (cf. Section 2.1). Typologies describe e.g. communication needs, mobility behavior or technology use (cf. Section 5.2). Section 5.3.1 defines the typology of Digital Immigrants and Digital Natives. In Section 5.3.2 a case study about Internet usage and communication needs is presented in order to describe the requirements to the proband selection for the UCM evaluation. Section 5.3.3 concludes with a summary of proband requirements that are applied in Section 6.3.1 to the selection of the probands.

#### 5.3.1 Typologies of Digital Immigrants and Digital Natives

The digital divide groups the society into two clusters: First, a group with access to digital information and communication technologies, and second, a group without any access to ICT (Warschauer, 2004). This separation depends on socio-economic aspects, policy factors, and demographic categories (Chinn and Fairlie, 2007). The usage of ICT solutions depends on the user’s attitude and personally traits have an effect of the acceptance of technology (Behrenbruch et al., 2013).



As an example, today's elderlies have often less experience in modern technical devices and they learned the usage of ICT in their later working life. Thus, technology use has hurdles for them as described in Section 5.1.1.

Prensky (2001) defines the two terms "Digital Natives"<sup>5</sup> and "Digital Immigrants" in order to describe the differences between people born after and before 1980:

Digital Natives grow up with digital media and are influenced in the fast development of new technology (Palfrey and Gasser, 2008) (Table 6, left column): They are native speakers of the "digital language" and familiar with mobile phones, the Internet and e-mails from childhood and apply it intuitively to their thinking, dreams, and daily life (Kennedy et al., 2008). Digital Natives think and act like early adopters and are open-minded to new digital technologies and innovations (Vodanovich, Sundaram and Myers, 2010).

The difference and intensity of thinking and acting of younger Digital Natives (since year of birth 1990) increases in comparison to the "older" Digital Natives (born before 1990) (Jones et al., 2010). Prensky (2005) states that a smartphone is more important for a Digital Native than a conventional PC, which exemplifies the "everywhere" and "anytime" attitude of using digital devices in a ubiquitous way (cf. Section 3.2.1).

Traxler (2010, p.1) explains that mobile devices, like smartphones and tablets, are used in a very personal manner by Digital Natives:

*"...(users) invest considerable time, effort and resources choosing, buying, customizing and exploiting them. These devices express part or much of their owners' values, affiliations, identity and individuality through their choice and their use. They are both pervasive and ubiquitous, both conspicuous and unobtrusive, both noteworthy and taken-for-granted in the lives of most people."*

Molenaar (2010) defines the attitudes of Digital Natives and Digital Immigrants in Table 6.

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<sup>5</sup> Synonyms for the term Digital Natives are "Net Generation" (N-Gen) and "Digital Generation" (D-Gen) (Autry Jr., and Berge, 2011).

Digital Natives	Digital Immigrants
Online is the same as offline. They feel connected and friendship like in real life.	Online is different to offline. They use the Internet for very specific personal reasons. The Internet is an add-on to real life.
They are always online, very sociable, well informed.	Online is a choice with a reason. It should fit in with their normal behavior.
Early adopters will try anything, strong group behavior, use chatting, social media, mobile as fact of life.	Use e-mail, search for information and use the Internet for practical reasons.
Digital and physical are combined, they feel no difference.	Two separate worlds. The Internet is still a strange thing, no idea how it really works. It should fit in with my life.

**Table 6: Digital Natives and Digital Immigrants**

Source: Molenaar (2010)

Digital Immigrants “speak” the digital language similarly, but they use it with an “accent” (Prensky, 2014):

- A Digital Immigrant starts with reading a user manual, before s/he uses a new device in contrast to a digital native who learns the use of the new device by usage and trying out.
- A Digital Immigrant prints out an e-mail for further handling and a Digital Native processes the message on a digital device.

They grew up in a world without technology saturation and the use of Internet and digital media consume was learned in adulthood (Molenaar, 2010) (Table 6, right column). Prensky (2005) compares this to learning a foreign language and a spoken accent: A technology affine Digital Immigrant will still be recognized by its accent.

Digital Immigrants divide the virtual and the real world, whereas Digital Natives merge both worlds. Table 6 depicts the differences between both human clusters. These two human clusters cannot be applied without exceptions to all persons of these generations. The exceptions are called “participation gap” (Jenkins, 2006) and depend on the individual decision to be engaged with new media and technologies, and additionally, if people have the ability to get in contact with technology.

### 5.3.2 Case Study for ICT Usage

Private Internet usage has grown over the last years up to over 70% in Europe (BITKOM, 2013a). Over 35% of German users access the Internet with a smartphone and up to 26% with a tablet computer (BITKOM, 2013b). The “Milieu Study on Trust and Security on the Internet” (DIVISI, 2013) partitions the German society into three groups of Internet users:

- 1) Digital Outsiders
- 2) Digital Natives
- 3) Digital Immigrants

For the UCM evaluation the focus is on the clusters of the Sinus Milieus in the context of technology use of the German society. The three groups of Internet users are subdivided applying the Sinus Milieu Model that is described in Section 5.2.3.

Figure 24 depicts the seven socio cultural groups in Germany to the attribution of Digital Outsiders, Digital Natives and Digital Immigrants. The two main axes represent the fundamental values (horizontal) and the social situation (vertical). The higher a group is located the higher the level of education, income, and professional status is (DIVISI, 2013):

- 1) Digital Outsiders (40%, The Internet Wary and Order-seeking Internet Laymen), are off-liner and occasional users of the Internet with self-sufficiency, moral principles and integrity. They have a huge need for security and control mechanisms, and act defensive-careful with a high reliability. They are either completely offline or very insecure about the Internet, which they hardly use.
- 2) Digital Immigrants (20%, Responsibility-driven Individuals and Post-material Skeptics) are regular but selective Internet users with a skeptical view of many developments. They are educated with a responsibility-driven attitude towards the digital progress. The Post-material Skeptics has a critical attitude towards the commercial structure and “blind” fascination about technology.
- 3) The Digital Natives (40%, Carefree Hedonists, Efficiency-oriented Performers, Digital Vanguard), have grown up with the Internet and integrate technology completely into their lives. A wide range of Internet services is desired by this user group from an entertainment

and adventured individual use, up to performance-driven business processes with high convenience values.

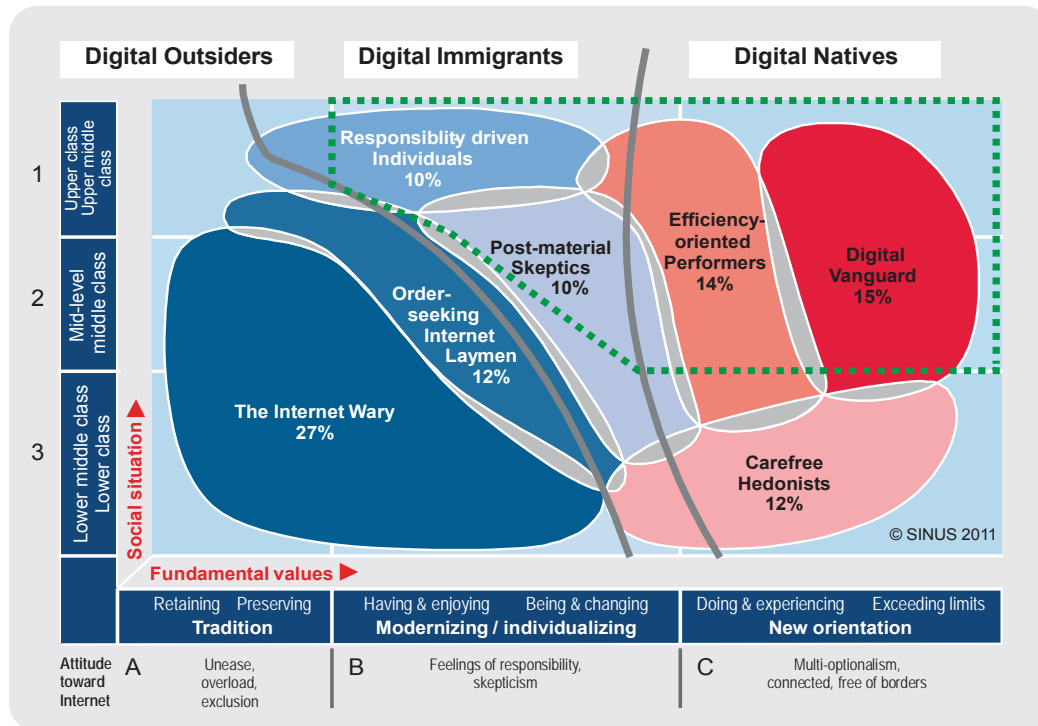


Figure 24: User Clusters Based on Trust and Online Security

Source: DIVISI (2013)

The seven clusters of Figure 24 depict how members of each group think about and act with ICT. Future technological development will enhance the possibilities to apply technical solutions to human lives but it will not change the attitude and the way persons of the Sinus Milieu cluster will use it.

Focus for the UCM evaluation is on the groups (Figure 24, green frame):

- “Responsibility-driven Individuals” (B1),
- “Post-material Skeptics” (B2),
- “Efficiency-oriented Performers” (C1/C2), and
- “Digital Vanguard” (C1/C2).

Table 7 describes properties of these Sinus Milieu groups.

	Digital Immigrants		Digital Natives	
	Responsibility-driven Individuals	Post-material Skeptics	Efficiency-oriented Performers	Digital Vanguard
Attitude	Utilitarian and pragmatic Internet use  Professionally and financially established and integrate technology for advantages in live	Ambivalent relationship to the Internet  Are online for information and communication with some mistrust	Use state of the art Internet services  Are online to make things easier and faster in work and private	Internet Services are used extensive  Have grown up with the Internet and usage is natural
Intention	Prefer technology use only for specific benefits	Like information and Internet offers but have doubts about the virtual and the global world	Use technology every time and everywhere with a utilitarian pragmatic perspective	Are always online in business and private cases  Using technology is no barrier
Know How	Less understanding of technology because of less	Technology is not refused but should not dominate in live	High Level of IT and Internet Skills	Extensive IT-skills
Frequency	Use only for specific benefits	Use selective with a critical attitude	Use intensive but pragmatic	Spend amount of time online
Engagement	Go along and me-too attitude	Conservative and pragmatic	Modern and settled	Young and trendy

**Table 7: Selected User Clusters of Digital Immigrants and Digital Natives**

Source: According to, DIVISI (2013)

They are assigned to one of the two groups based on attributes like "Attitude" or "Intention" (Table 7, left column), if they are pragmatic Internet users like the Responsibility-driven Individuals, or if they are always online like the Digital Vanguard (DIVISI, 2013).

Further properties are “Know-How”, e.g., a high level of Information Technology and Internet skills like the Efficiency-oriented Performers, and “Frequency”, e.g., a selective use of technology and Internet with a critical attitude like the Post-material Skeptics. And finally, “Engagement”, e.g., young and trendy for the Digital Vanguard.

These properties are underlined by the ICT usage investigation “Pedestrian on the Data-Highway - Compendium of ICT Usage in Germany” (Buchwald et al., 2006): The properties demonstrate how the described four groups apply and integrate communications technology and the Internet in their daily life.

### 5.3.3 Requirements of ICT Usage to UCM

Digital Immigrants are the first users of a generation that are accustomed to a high level with ICT. The subsequent generation Digital Natives thinks and speaks the digital language and less hurdles in technology usage can be assumed. Digital Outsiders will refuse technology as long as possible, and therefore, they are not incorporated into the evaluation of the UCM.

The case study of the former section indicates that the properties which are depicted in Table 7 (attitude, intention, know-how, frequency, and engagement) have to be applied to the selection of the probands. Section 6.3.1 describes the proband selection based on a questionnaire and how the probands are distributed over the Sinus Milieus groups (Established Conservative Milieu, Liberal Intellectual Milieu, High Achiever Milieu, Movers and Shakers Milieu, Socio-ecological Milieu and Adaptive Pragmatist Milieu).

## 6 USE CASES, PROTOTYPES AND EXPERIMENTS

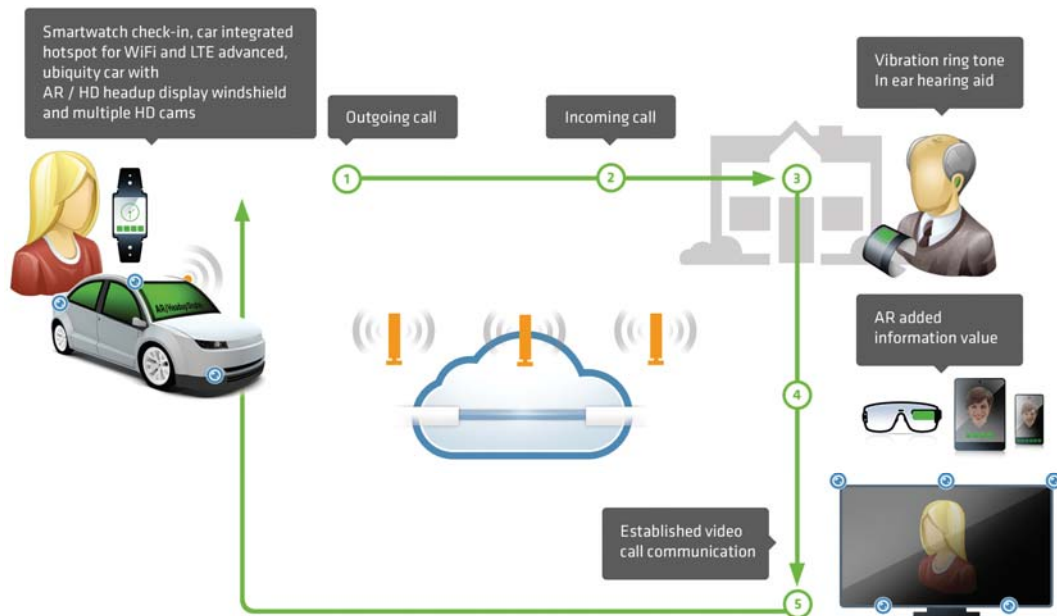
The UCM architecture supports future innovative technologies with a diversity of devices and a variety of upcoming media for seamless data transmission (Chapter 4). The evaluation of the UCM architecture model is provided based on two use cases that describe the daily use of ICT solutions for the future elderly society (Section 6.1): Scenario 1 “Media Rich Communication” and Scenario 2 “Mobility”, where both prototypes are described in Section 6.2. Based on these use cases two experiments with 24 tasks overall are performed. The tasks are executed by elderly probands in experiments. The setting of the experiments is described in Section 6.3.

### 6.1 ELDERLY SOCIETY FOR THE UCM EVALUATION

In this section two use cases for the UCM with focus on elderly people are described: First, a daughter is calling her elderly father from her car at home (Section 6.1.1), and second, grandma has an appointment at a medical center and during her trip she is receiving information about her public transportation route (Section 6.1.2).

#### 6.1.1 Use Case “Daughter and Father”

The first use case demonstrates how the UCM enables elderlies to communicate, i.e., to compensate the loss of abilities like hearing impairment and lowered prestidigitation (cf. Section 2.4). Getting older, most elderlies prefer to live as long as possible at home (even alone) (cf. Section 2.3.2). Thus, the UCM needs to provide an easy-to-use communication interface based on standard devices that are convenient and trusted for elderlies.



**Figure 25: Call Flow of Use Case "Daughter and Father" Applying the UCM**

Source: Muschiol (2013)

This use case is explained using the domains of the UCM architecture (Figure 13, p.77): In this scenario the domain "anybody" of the UCM (Section 4.1.1) relates to an elderly person with hearing loss and low vision (Figure 25, step 3), who is performing a H2H and H2M communication. The daughter (caller) initiates the call to her father from her car (Figure 25, step 1). The call is initiated per voice dial. The name of the callee (here her father) and further information of the last corresponding calls are displayed on the (high definition AR / head-up display) windshield of the car. Multiple HD cameras record the daughter and the environment out of different positions and video live streams are provided to her father's display device(s).

The communication devices of the father detect the incoming call (Figure 25, step 2), and subsequently they activate a vibration ringtone on his multimodal and transparent bracelet (Figure 25, step 3), and display the live streams of his daughter. The father has the choice to handle the call with suggestions from its devices: First, he can decide to accept to use the touching bracelet and voice command, or to reject the call, whereas the device recommends to agree since his daughter calls him every



Sunday afternoon when he is at home in the living room. Trilateration and fingerprinting of the Wi-Fi stations provide the environment indoor localization for context-sensitive information value. AR (Figure 25, step 4), supports the elderly father with extended information. As an example recorded and marked STT information of the last call is displayed on another tablet device or several live video streams of the daughter's environment (or different views of her).

To emerge communication as real and effective as possible the UCM provides high resolution video and high definition audio signals for media richness.

A core feature of the UCM is its ability to compensate personal inabilities in hearing and sensing using several (specialized) devices that are connected seamlessly and via smart antennas and cognitive radio technology (cf. Table 3).

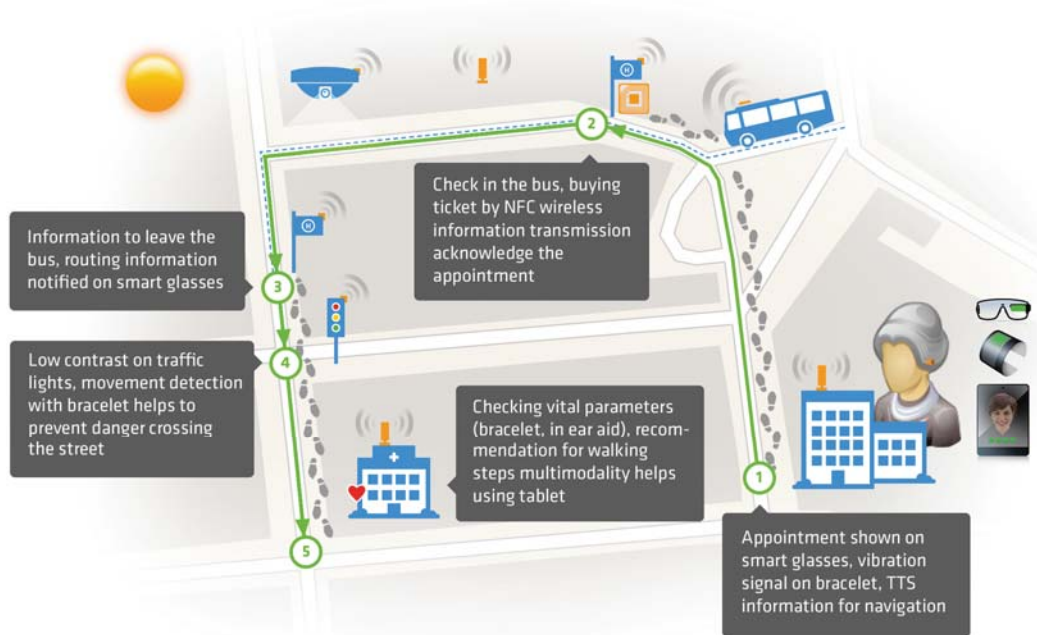
In this scenario the caller and the callee, both are connected via a high-speed IP data connection ensuring QoS: The daughter's car (left side, Figure 25) is connected via LTE advanced, which enables QoS HD video calls. On the roof of the car multiple antennas provide with "Multiple Input Multiple Output" (MIMO) (cf. Section 4.1.3) a broadband and stable connectivity. Her father (right side, Figure 25) is connected via broadband Wi-Fi, aka 802.11ad, allowing the transmission of video calls and AR-added information in parallel. The father is receiving a 360 degree view of the environment where his daughter is located, provided by the multiplicity of HD cameras in the car. These views are enriched by AR-added information for him (cf. Section 3.2.6), providing for convenience picture-to-speech information, i.e., similarly to TTS a scene of the video can be depicted by voice. The voice output is distributed via wearables with loudspeakers and in parallel to an ear hearing aid device via wireless connection.

### 6.1.2 Use Case "Grandma"

The second use case applies the combination of M2M and M2H communication to the UCM. A grandma needs to visit the doctor and is walking and bus driving from her flat to the medical center. Due to her age she is forgetful, has a low vision, hearing loss, and is tremulous. These properties can be compensated by several aids that are supported by the UCM:

The appointment is shown in advance on the smart glasses (right side Figure 26, step 1), emphasized by a vibration signal of the bracelet. A virtual reality avatar

reminds her using a TTS notification to take the bus early and gives gentle hints for pedestrian navigation to her hearing aid. Entering the bus (Figure 26, step 2) at the rear door, she pays the ticket via NFC and STT recognition, making the reading of little displays redundant. Corresponding to the appointment an agent-based service communicates in the background to provide all necessary information, e.g. arrival time calculation, sending a message to the doctor being on time and sending a picture of the medical center to the smart glasses for an easier orientation.



**Figure 26: Grandma's Way to the Doctor and Navigation Support due to her Physical Limitations**

Source: Muschiol (2013)

Arriving at the destination bus station (Figure 26, step 3), the avatar informs her about the exit and gives further routing information. The smart-glasses notice low contrast on the red traffic lights due to sun shine, and send a request to the bracelet to observe the environment when crossing the street (Figure 26, step 4). Switching to green she passes the street and enters the building (Figure 26, step 5). Checking the vital parameters (pulse, temperature, perspiration) the bracelet and the ear hearing aid are sending a notification to the glasses and the avatar

recommends to take the stairs to the second floor, to participate in some little fitness exercise.

Entering the waiting room the bracelet registers the grandma at the doctor's front desk. A tablet in the waiting room is notifying her about the estimated waiting time, and she decides to send a text message with a picture to her grandchildren. The device detects a little tremor and compensates the blur in the picture and helps typing the message.

This scenario underlines the flexibility and modularity of the UCM. Focusing on the term "sender-message-receiver" (cf. Section 3.1.1), the UCM enables agent-driven information transmission from the grandma to the medical center.

Disappearing technology in the background engages the acceptance of this UCM scenario with underlying needs for ubiquitous services. In this scenario "any device" communicates independent of the media ("any media") with each other, which is M2M communication, and also "any device" interacts with "anybody", here the grandma, doctor, or bus driver (cf. Figure 26):

The bracelet provides a high-speed IP data connection with LTE advanced and Wi-Fi 802.11ad by tethering the wearable and portable ubiquitous devices like smart glasses, tablet, and ear hearing aid. The bus exchanges ad-hoc messages with people by long distance (Wi-Fi or cellular) and short distance (NFC) wireless technology.

Network technology of the 7<sup>th</sup> generation is envisaged for 2030 (cf. Table 3, p.81) and will establish seamless high-speed connections with flexible and ubiquitous use of communication devices to support the aging society with mobility assistance at the peak of the demographic change.

## 6.2 RESEARCH SETTING AND PROTOTYPING

The two prototypes UCM-Scenario 1 (UCM-S1) with "Media Rich Communication" and UCM-Scenario 2 (UCM-S2) with "Mobility" apply the two use cases depicted in Section 6.1. Both prototypes embody the architecture and the functionality provided by the UCM.

The first use case "Daughter and Father" (Section 6.1.1) is implemented by the prototype UCM-S1 (Section 6.2.1). "Media Rich Communication" between the

users (H2H) is provided by UCM-S1 with multiple video cameras, in/output devices and modalities. Information richness with enjoyable UX supports H2H and H2M communication. I.e., a video phone call is signalized with a preview of the caller on a huge screen, the huge smartphone, and the smartwatch notifies via sound and vibration signal. The user can accept the call via gesture or touching the smartphone/ smartwatch (H2M). (UCM-S1 and UCM-S2 uses a device called phablet, which is a mixture of a smartphone and a tablet.)

The second use case “Grandma” (Section 6.1.2) is materialized by the prototype UCM-S2 (Section 6.2.2). This example for future communication services enables M2M and M2H communication services: I.e., easy appointment confirmation (“to be in time”) is send over UCM-S2 to the other person’s device, triggered by the wireless localization by the bus stop (M2M). And, i.e., a bus stop is identified wirelessly via an NFC label by the phablet and provides time table information with TTS support over a cloud service for the user (M2H).

The experimental setting is based on two hypotheses (Table 8 and Table 9). Based on Assumption 1 (cf. Table 8) “UCM enables digital socializing” Hypothesis 1 is formulated and claims that:

“Elderlies have difficulties in stress and ad-hoc situations to cope with ICT solutions”.

The two sub-hypotheses (cf. H 1-1, H 1-2) divide the main hypothesis in one sub-hypothesis without UCM and one with UCM support.

<b>Assumption 1:</b>	UCM enables digital socializing.	
<b>Hypothesis 1:</b>	H 1	Elderlies have difficulties in stress and ad-hoc situations to cope with ICT solutions.
	H 1-1	Elderlies have problems to (inter)act with tablets and smartphones.
	H 1-2	UCM enables easy, intuitive usability through multimodality.

Table 8: Hypothesis 1 of UCM Evaluation

The following Table 9 shows Assumption 2 with the claim “UCM enables communication with the environment”.

Hypothesis 2 states that:

“Elderlies have problems to reach destinations”.

The two sub-hypotheses split Hypothesis 2 into one sub-hypothesis without UCM and one with UCM support.

<b>Assumption 2:</b>	UCM enables communication with the environment.	
<b>Hypothesis 2:</b>	H 2	Elderlies have problems to reach destinations.
	H 2-1	Elderlies have problems to reach destinations/ appointments in time.
	H 2-2	UCM assists elderlies to reach destinations in time, through multimodality.

**Table 9: Hypothesis 2 of UCM Evaluation**

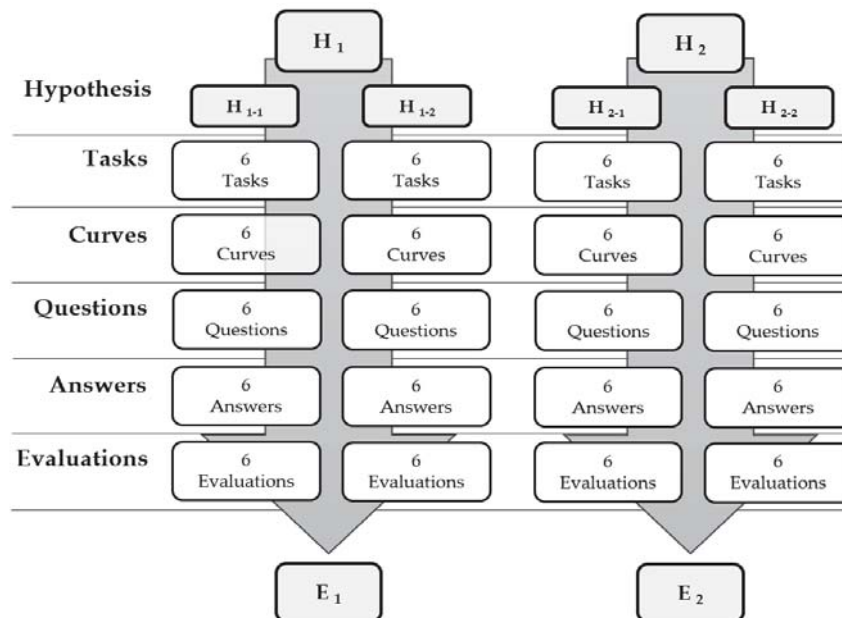
These two hypotheses represent the WHO claim for participation of elderly people. The goal of the UCM is to support participation and activity for elderlies by H2H and H2M communication.

The experiments compare the hypotheses with settings without and with UCM support, for H 1 (Table 8) and for H 2 (Table 9), e.g.,

- H 1-1, 6 tasks without UCM (Tasks 1-1-1 to 1-1-6), and
- H 1-2, 6 tasks with UCM (Tasks 1-2-1 to 1-2-6).

Figure 27 contains the experimental setting for the two hypotheses H 1 (Table 8) and H 2 (Table 9) including their sub-hypotheses. For the evaluation of each sub-hypothesis six tasks are performed leading to six measurements and corresponding curves.

Each measurement will be qualitatively investigated by a questionnaire (cf. Appendices E-4 and E-5 for an overview of all values of the questions for both scenarios). Their answers are used to support the evaluations that are based on statistical fittings to the Gaussian distribution (cf. Section 7.3.5). The experiments contain 1440 measurements (24 values for each hypothesis, and multiplied with 30 probands, multiplied with two hypotheses) to validate the UCM.



**Figure 27: Research Setting for UCM Evaluation**

The detailed description of the investigation process of Scenario 1 “Media Rich Communication” is depicted in Figure 28 and the one for Scenario 2 “mobility” in Figure 29. Note, the three colors (yellow, blue, green) that are used in the following overviews of the research scenarios represent the experiment setups of the scenarios. They are continuously applied in the descriptions of the experiment setups and test environments of UCM-S1 and UCM-S2. This provides an orientation for the reader across each setup of the two scenarios (see also, Appendices C-1 and C-2). The scenarios with the experiment setups are detailed in this section and the used devices are identified by an ID Code, e.g., MRD01 = Media Rich Device 01 (see also Table 10, p.138, Table 23, p.161) and referenced as follows:

- UCM Information Flow Architecture<sup>6</sup>
- Setup and Test Environment<sup>7</sup>
- Experiment Setup and Test Environment<sup>8</sup>

Appendices A-1 to A-7 shows the technical specifications of the devices.

<sup>6</sup> See also, Figure 30, p.138; Figure 37, p.163

<sup>7</sup> See also, Figure 34, p.142; Figure 40, p.167

<sup>8</sup> See also, Appendix C-1, p.255-260; Appendix C-2, p.261-266

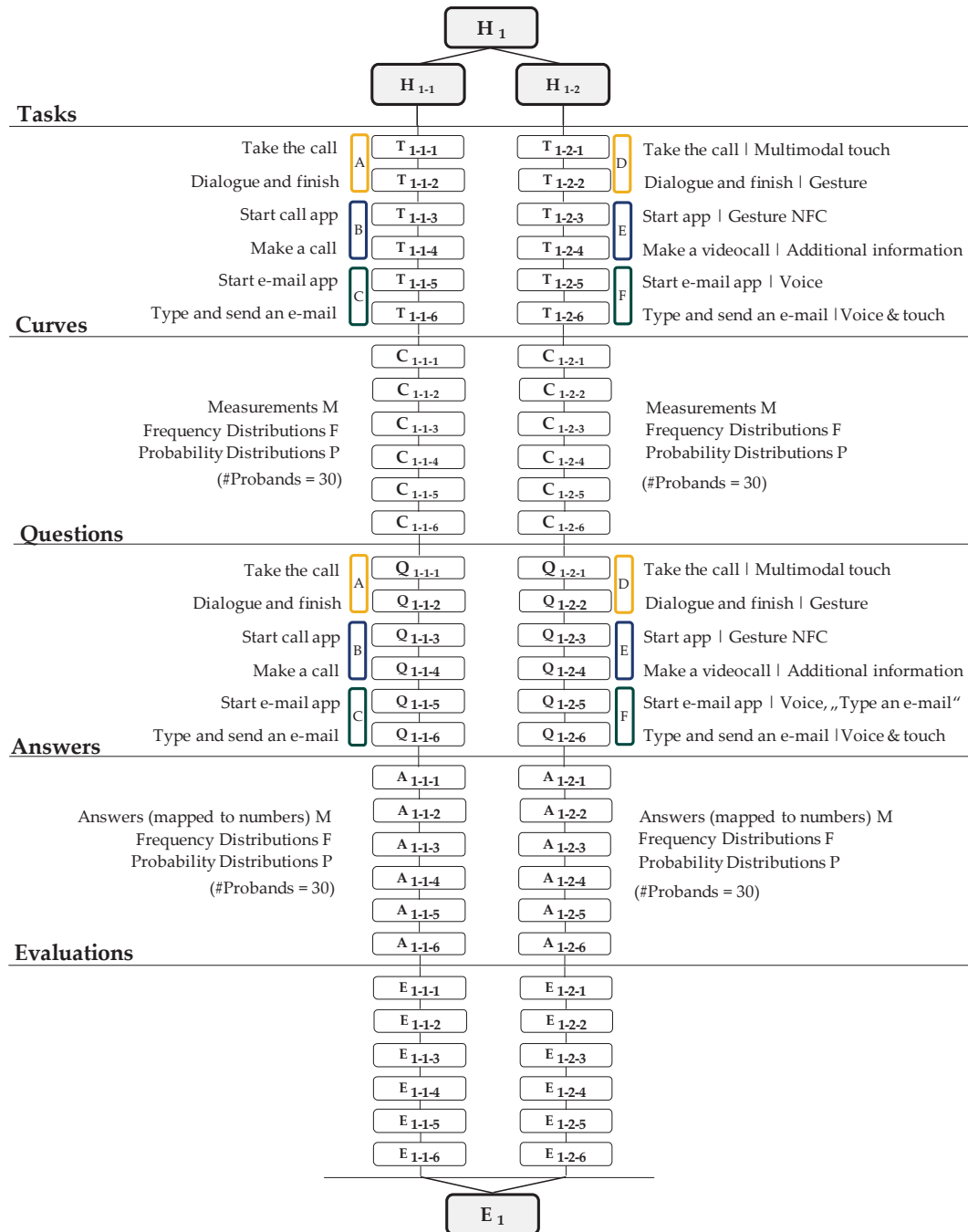


Figure 28: Research Scenario 1 “Media Rich Communication”

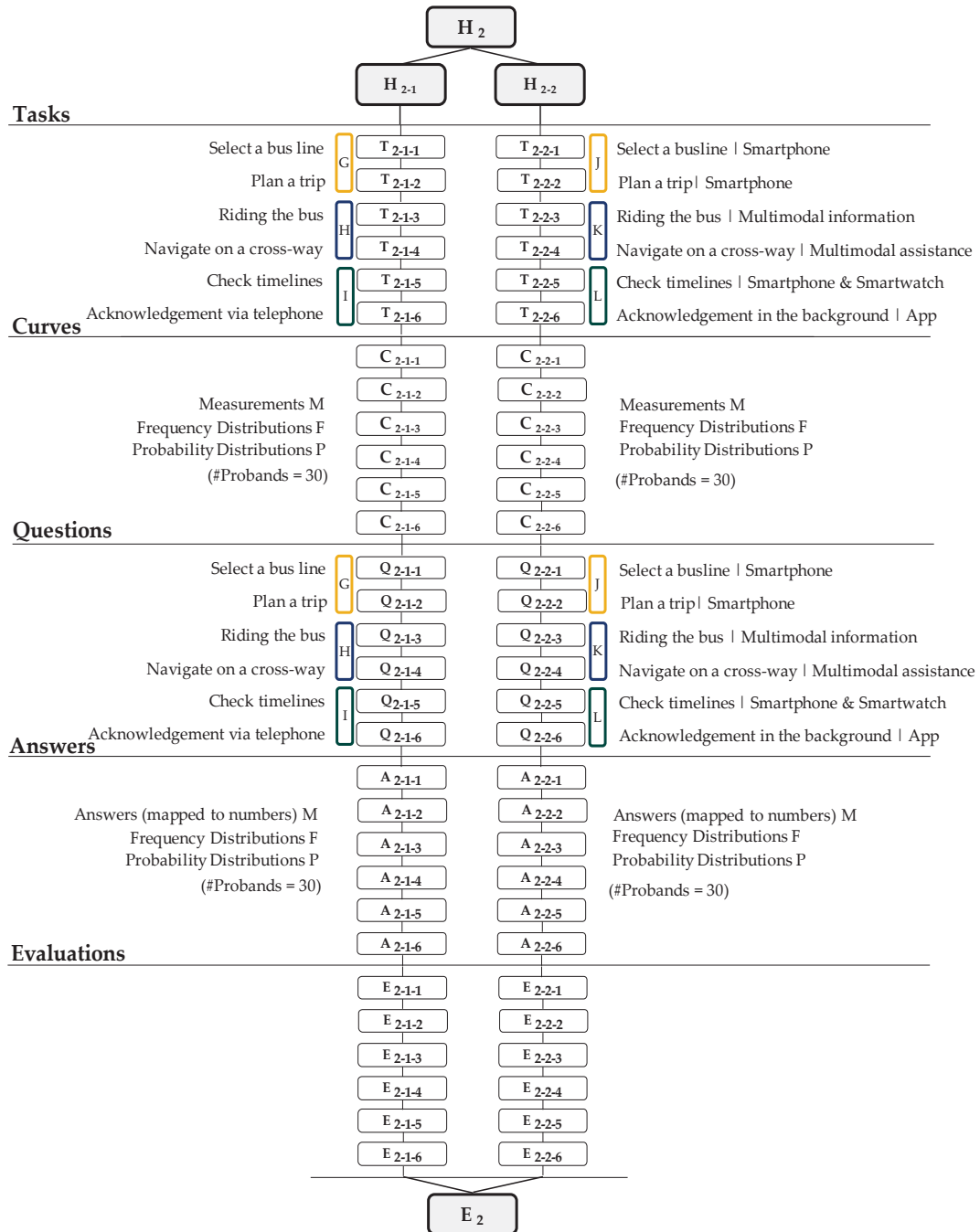


Figure 29: Research Scenario 2 "Mobility"



### 6.2.1 Scenario 1: Media Rich Communication

The prototype UCM-S1 is a “Media Rich Communication” system that considers the interaction options described in the use case “Daughter and Father” (Section 6.1.1). This prototype enables an innovative usage of multimodal communication devices to utilize a H2H communication. The scenario exemplifies the integration of the UCM Domains “anybody”, “any device” and “any media” to empower feature rich communication specified for the future elderly society. Three main tasks are divided up into six subtasks and embodies nowadays communication needs. Today's technical devices and telecommunication services are therefore used to

- Answer a voice call,
- Establish a voice call, and
- Type and send a message.

These tasks are adopted to the UCM-S1 prototype,

- Answering a telephone call with multimodal I/O,
- Make a call provided by gesture, and
- Type an e-mail with STT recognition and send it.

The used devices in the scenarios are a phablet, a PC and a smartwatch. The prototype UCM-S1 embodies the aggregation of several technologies into one sole media rich communication system.

#### 6.2.1.1 Features of Prototype UCM-S1

The prototype UCM-S1 enables H2H communication with a diversity of devices and media which are integrated into one single service considering the requirements of communication needs of elderly persons.

The architecture enables wide-spread possibilities to interact with the system (to name a few important ones):

- Gesture to dial or accept/finish a call
- STT recognition and TTS
- Touch gestures, on a phablet or smartwatch which are optional
- Sound and vibration signals
- Multiple HD Cams with multiple live streams integrated in one user interface

- Diversity of devices are synchronized with a huge HD display, smartwatch display or phablet screen
- Wireless integration of devices for data transmission with high bandwidth and low latency or flexible, energy saving device integration for a smartwatch or loudspeakers
- Integration of additional information as weather or time information services

The elements of user interaction and design are implemented under consideration of the attributes for the usability of elderly people, e.g.,

- The interval for "pressing a button" has less sensitivity
- Complex sliding gestures on a touch display are avoided
- Sound output and vibration signals are intensified
- Speech recognition is adapted to the voice and behavior
- Contrast and display attributes consider guidelines for barrier free development on ICT

Information beaming (Section 3.2.2) through the wireless architecture has to cope with several technical challenges, e.g.,

- 1) Real time voice and video communication has high requirements on synchronous transmission with low latency and high bandwidth.
- 2) Information transmission is distributed via several protocols and has to be synchronized between devices.
- 3) Information richness can result in information overflow, and a diversity of displays with different information leads to user confusion.

The input and output modalities are handled by the UCM-S1 prototype, e.g., a photo of the caller is shown on the smartwatch, the phablet, and the screen. The call can be established with one easy gesture on the smartwatch or the phone.

#### *6.2.1.2 Technical Architecture of Prototype UCM-S1*

The prototype UCM-S1 integrates several distributed systems into one synchronously interacting service, which are coordinated by the UCM Server Application (cf. Figure 30, center part). The UCM interaction application (media rich device) provides the sound and video services which are extended with the

additional information services, e.g., weather or time information (cf. Figure 30, left part). The UCM Connector establishes connections between the several client devices (cf. Figure 30, left part). The implementation of UCM-S1 requires a software and a network architecture platform to provide capabilities for:

- 1) Diversity and multiplicity of devices,
- 2) Multimodal I/O,
- 3) High bandwidth with low latency, and
- 4) Seamless integration with a variety of application protocols.

In order to meet the above described requirements, the multimodal architecture is based on a scalable and extendable (with further services or devices) platform, which is depicted in Figure 30:

The media rich device component is shown on left top the figure, combines the I/O of HD video and audio signals and provides the UCM interaction application. This service permits data aggregation from external live streams, external information, or external service components that are linked by the UCM Connector and coordinated by the UCM Server Application.

The variety of touch devices is represented on the left middle box of the figure and can be applied to the UCM architecture by the UCM Connector. The sensor information of each device is handled by the local UCM Application and processed to the UCM Connector, in view of the fact that the information is required of other devices. The additional devices (Figure 30, left side, bottom) are further display and interaction devices like smartwatches or wireless speakers. They interact directly via a dedicated wireless connection (e.g. Bluetooth) or via the local UCM Application to the UCM Connector, i.e., the phablet and the media rich device connects directly to the speaker or the smartwatch interacts via the UCM architecture to the phablet in order to provide multimodal user interaction.

The UCM Connector enables a flexible and wide range of connectivity to integrate external live streams of HD video sources or Additional Information, e.g. location-based Weather- or Time Information. The central service is the UCM Server Application (Figure 30, middle part), that works as a controller and converter to aggregate the diversity of client and service data.

External services (Figure 30, right side, bottom) provide e.g., TSS and STT functionalities based on a cloud infrastructure, which allows the extension of the

infrastructure with further web-services and functionalities. The WebRTC Service is responsible for audio and video communication. It is also integrated with individual adapters on the UCM Connector component and serves as a central service for the UCM multimodality functions.

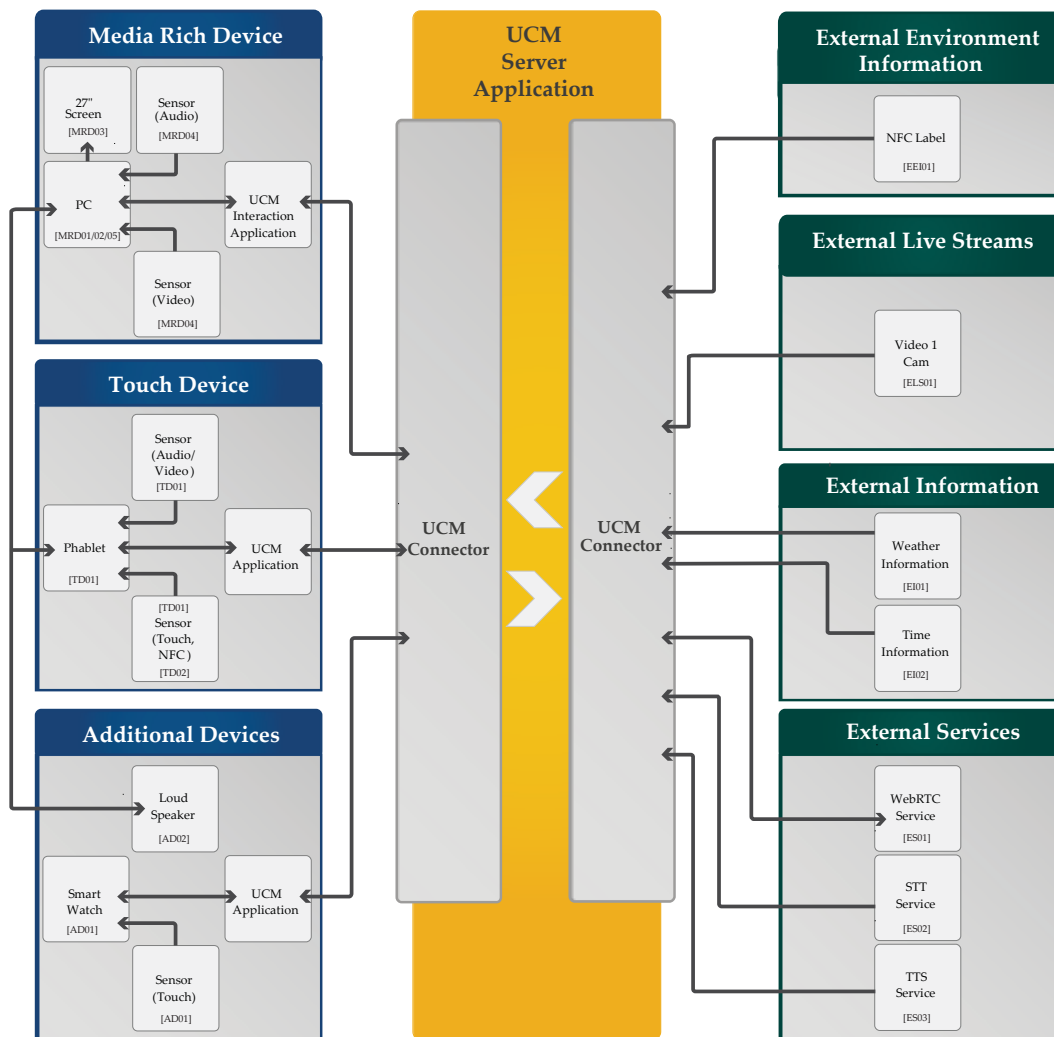


Figure 30: UCM Information Flow Architecture of Prototype UCM-S1

Finally, the wireless data transmission connectivity in UCM-S1 is provided by a wireless router infrastructure with low latency and high bandwidth. The touch device is a phablet and the media rich device is a “regular office” PC running

Windows 7 (Microsoft Corp., 2014a). The wireless speaker and the smartwatch are connected via Bluetooth.

Every device (except the loudspeaker) interacts via the local UCM Application to the UCM Connector that interchanges with the UCM Server Application. This central processing service coordinates the multimodal information distribution in the UCM infrastructure.

The UCM architecture provides a flexible integration of a diversity of devices and services in one infrastructure, with low latency and scalable bandwidth.

#### *6.2.1.3 Technical Setup and Test Environment of UCM-S1*

The infrastructure for UCM-S1 is based on a distributed client/server architecture with native functions of the communication devices, servers, and the installed OS. A variety of modifications on the OS and software are additionally implemented to support the requirements of the UCM: As example, parameterization on the Google STT (Google Inc., 2014a) engine to optimize the recognition of speech in dependency of speech habits of elderlies or lengthening the response time when pressing a button on the touchscreen.

The technical infrastructure architecture for the client (left side), the media (middle) and server application (right side) is depicted in Figure 31. The client request is initiated on the "Interaction Service Layer" based on a web browser or Android app architecture. This interaction process can be triggered by an application service or a user-driven event.

The UCM client content aggregator on the "Information Service Layer" combines and processes the several information for transmission over the "I/O Management Layer" to the "OS Layer" which is represented by the OS. Data transmission is transparent for the UCM Application and is processed by the "Transmission Layer" which connects client to client or client to server over wireless (IEEE 802.11ac, Bluetooth 4.0) or wired (Ethernet 1000base-T) media for interaction.

The sequence of the communication process is similar to the variety of UCM clients while they interact in the same way over the layer. On the server side the request is handled vice versa and the applicable modalities constitute the basis for an intelligent and flexible interaction.

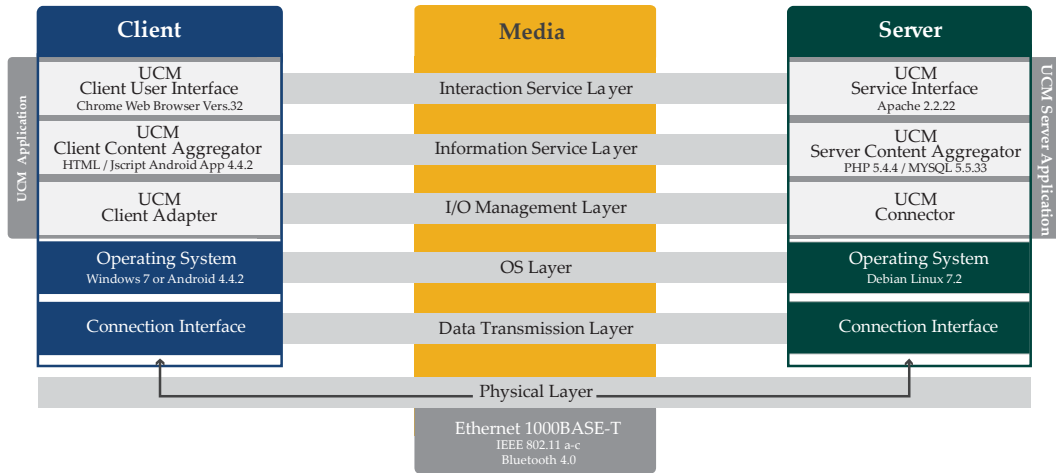


Figure 31: Technical Infrastructure Architecture

The Media Rich Client PC (HP Compaq Elite 8300 Ultra-Slim Desktop) (see Appendix A-1 for further specification) is a “state of the art” office PC that runs the Windows 7 OS. The required application infrastructure for the UCM client interaction application is a web browser with a native support of the WebRTC protocol. In this scenario a Google Chrome Browser Google Inc., 2014a in version 32 is used to enable the technical communication basis for UCM-S1.

The video signal is displayed on a 27 inch LED screen (Samsung S27A550HS, see Appendix A-1 for further specification) connected via Display Port to HDMI cable. The local HD video and audio signal is captured by a video cam with a microphone included (Logitech HD 920 USB HD Pro, see Appendix A-1 for further specification) and is connected to the PC via USB2 port. The network connectivity of the PC is enabled via a Wi-Fi Adapter IEEE 802.11ac (Asus USB AC56, see Appendix A-1 for further specification) and Bluetooth 4.0 is supported with a Bluetooth Hama-USB-Adapter V.4 (see Appendix A-1 for further specification).

The audio signals of the PC and the phablet are synchronized with a Bluetooth connected loudspeaker system (Harman Kardon Sound Sticks II, see Appendix A-1 for further specification)).

These devices are mounted in the environment that they disappear and are not noticeable for the user (cf. Section 3.2.1). The installation of the 27 inch display is shown on Figure 32 with the media rich device of UCM-S1. The PC, keyboard, power supply are covered by furniture. The loudspeaker system is mounted under the table.

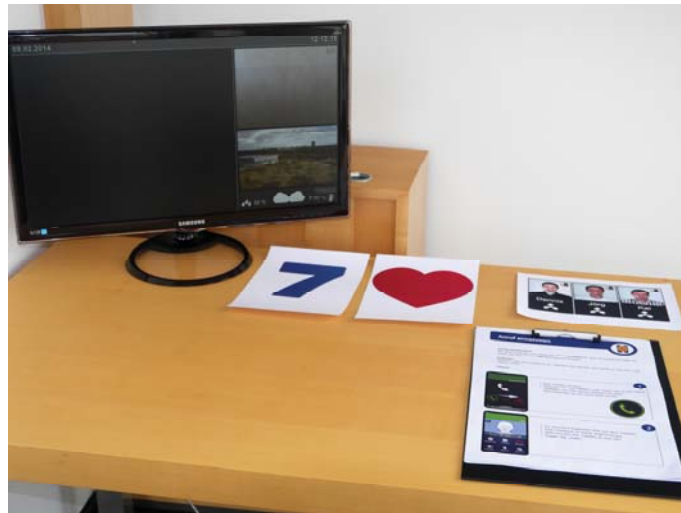


Figure 32: Media Rich Device

Figure 33 shows the phablet running the UCM-S1 touch device interface and the smartwatch for additional multimodal I/O. The phablet (Samsung Galaxy Note 3, see Appendix A-2 for further specification), provides a user interface with several multimodalities, i.e., display, audio signal, vibration signal, STT input, TTS output.



Figure 33: UCM-S1 - Phablet (left side) and Smartwatch (right side)

The phablets network connectivity is provided via the internal Wi-Fi adapter with IEEE 802.11ac standard and Bluetooth 4.0.

All devices are connected to the loudspeaker system via Bluetooth to distribute audio signals seamlessly and synchronously. The additional device “smartwatch” (Sony Smartwatch 2, see Appendix A-3 for further specification) is connected via Bluetooth and controlled by the phablet UCM Application for multimodal information beaming and an additional user interface to operate with the UCM-S1.

The following example depicts how a telephone call is notified on the multimodal devices:

- Via screen, audio and vibration signal on the phablet,
- via audio and screen signal on the Media Rich Client, and
- via screen, and vibration signal on the smartwatch.

The wireless connectivity infrastructure is provided by a Wi-Fi Access Point (Asus RT-AC68U, see Appendix A-4 for further specification) with high bandwidth (up to 1.3 Gbit) and low latency (<5 ms). The communication standard is supported by the used Wi-Fi network adapter of the media rich device and the touch device.

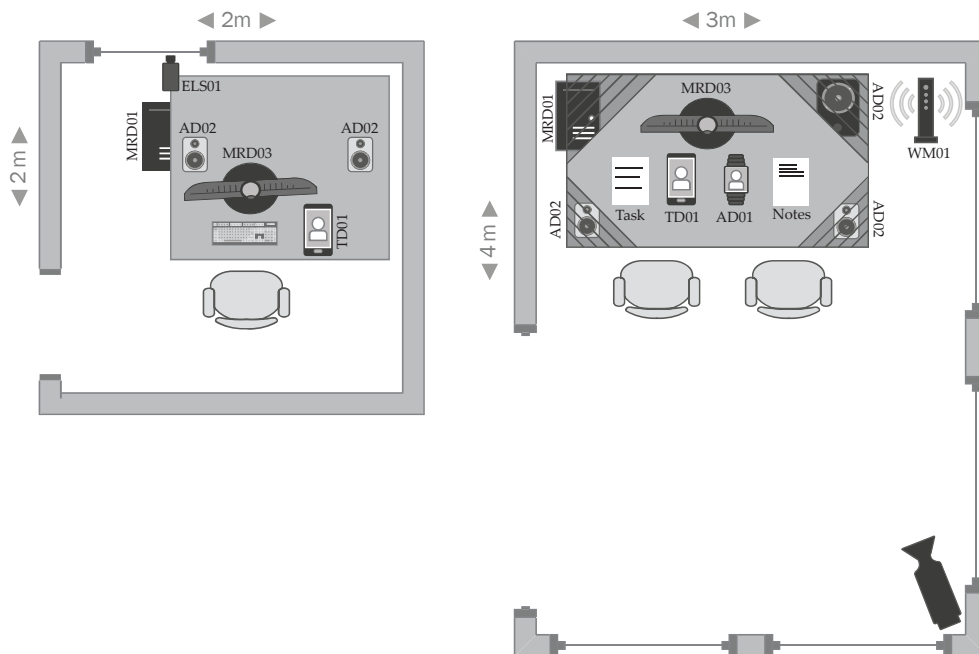


Figure 34: Setup and Test Environment for UCM-S1



Figure 34 illustrates the wireless connected and multimodal environment for the UCM-S1 proband experiment specification. (For further details see also Appendix C-1.) The following example “answering the call” describes the flow interaction (cf. Figure 30, p.132) of the several devices and UCM-S1 prototype application. Figure 35 shows the screen overview (caller, callee and additional information) on the 27 inch screen.



Figure 35: Screen Overview

Figure 36 shows the notification screen “answering the call” on the phablet (left side) and the smartwatch (right side). (For further details see also Appendix D-1.)



Figure 36: Multimodal Devices with UCM-S1

The proband receives a call and the 27 inch screen, the phablet and the smartwatch show a picture of the caller. A sound is additionally played via the seamless integrated loudspeaker system. A vibration on the phablet, and the smartwatch provides a notification. Pressing the button “accept” on the smartwatch or the phablet accepts the call and the communication is established.

The video and audio signals are synchronously transmitted between caller and callee and offer media rich communication with additional information about time, weather, and video streams of the mutual environment

Table 10 depicts the technical devices and services used in Scenario 1. The first column references the used object (ID-Code), followed by the category to describe the used item. The description provides product information and is detailed in Appendices A-1 to A-7.

<b>ID-Code</b>	<b>Category</b>	<b>Description</b>
MRD01	Media Rich Client	HP Compaq Elite 8300 Ultra-Slim Desktop
MRD02	Media Rich Client	Asus USB-AC56 Wi-Fi Stick
MRD03	Media Rich Client	Samsung LED Screen 27" (A550HS)
MRD04	Media Rich Client	Logitech C920 USB HD Pro
MRD05	Media Rich Client	Hama Bluetooth-USB-Adapter V4.
TD01	Touch Device	Samsung Galaxy Note 3
TD02	Touch Device	Android.NFC Service
AD01	Additional Device	Sony Smartwatch 2
AD02	Additional Device	Harman Kardon Soundsticks Wireless 2.1
WM01	Wireless Media	Asus RT-AC68U
ELS01	External Live Stream	D-Link DCS-2332L/E Wireless N
EI01	External Information	Wetter.com
EI02	External Information	Timeapi.org
EEI01	External Environment Information	NFC label
ES01	External Service	WebRTC
ES02	External Service	STT - Service, Google
ES03	External Service	TTS - Service, Google

**Table 10: Overview Technical Setup UCM-S1**

The tasks of the test environment of the UCM-S1 are detailed in the following section.

#### 6.2.1.4 Tasks of Scenario 1 “Media Rich Communication”

The specification of tasks usage take into account tasks that embody nowadays communication behavior of the elderly society (cf. Section 5.3.3), grounded on the sub-hypothesis H 1-1 (without UCM) and H 1-2 (with UCM). The following six tables (Table 11 to Table 16) describe the tasks without UCM support and the steps for the optimal task completion of the probands with start and end points for the measurements:

- 1) Task 1-1-1 based on Setup A (Table 11):  
Take the call by wipe the green icon on the smartphone from the left side to the right. The measured interval is defined from the first ring until the dialogue screen is displayed.
- 2) Task 1-1-2 based on Setup A (Table 12):  
Perform a dialogue with the delivery of information (e.g., name, time), and finish the call by pressing the red icon on the smartphone. The interval to measure is defined from displaying the phone dialogue until “Terminate” icon is pressed.
- 3) Task 1-1-3 based on Setup B (Table 13):  
Find and start the telephone app on the smartphone by pressing the right icon. The phone number has to be entered and dialed. The measured interval is defined from taking the smartphone off the table until dialing process is started.
- 4) Task 1-1-4 based on Setup B (Table 14):  
Making a call and the dialogue partner asks several questions. The questions are answered (e.g., number of persons in the room, weather conditions) and the call is terminated by pressing the right icon. The measured interval is defined from the dialogue start until the “Terminate” icon is pressed.
- 5) Task 1-1-5 based on Setup C (Table 15):  
Find and start the e-mail app and start the “Write e-mail” dialogue by pressing the right icon. The measured interval is defined from taking the smartphone off the table until the “Write e-mail” dialogue is displayed.

6) Task 1-1-6 based on Setup C (Table 16):

Type the required information (e.g., e-mail address, subject) and send the e-mail by pressing the right icon. The measured interval is defined from displaying the “Write e-mail” dialogue until the e-mail is sent.




Setup: A	No.: T 1-1-1	Task Name: Take the call
<div style="text-align: right; font-size: small;">Take the call A/1-1-1</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 15px; display: flex; justify-content: space-between; align-items: center;"> <span style="font-size: 24px; font-weight: bold;">Answering the call</span>  </div> <p><b>Initial situation:</b> You are at home, sitting at the living-room table. The smartphone is on the table in front of you. It rings.</p> <p><b>Task:</b> Accept the call, then hold the smartphone to your ear and say "Hello".</p> <p><b>Steps:</b></p> <div style="display: flex; flex-direction: column; gap: 20px;"> <div>  <div style="border: 1px solid #ccc; padding: 10px; margin-left: 10px;"> <div style="text-align: right; font-weight: bold; font-size: 24px; color: #0056b3; border-radius: 50%; width: 25px; height: 25px; display: flex; align-items: center; justify-content: center; margin-bottom: 5px;">1</div> <ul style="list-style-type: none"> <li>The phone rings.</li> <li>Take the phone off the table.</li> <li>Swipe the green icon from left to right.</li> </ul>  </div> </div> <div>  <div style="border: 1px solid #ccc; padding: 10px; margin-left: 10px;"> <div style="text-align: right; font-weight: bold; font-size: 24px; color: #0056b3; border-radius: 50%; width: 25px; height: 25px; display: flex; align-items: center; justify-content: center; margin-bottom: 5px;">2</div> <ul style="list-style-type: none"> <li>The following image is displayed on the phone.</li> <li>The call has been accepted.</li> <li>Hold the phone to your ear.</li> <li>Say "Hello".</li> </ul> </div> </div> </div>		
<b>Optimal solution:</b>	Wipe green icon from left to right.	
<b>Task completed:</b>	Phone call accepted.	
<b>Measurement:</b>	Interval from first ring until phone-dialogue screen is displayed.	

Table 11: Task and Measurement Descriptions of T 1-1-1





Setup: A	No.: T 1-1-2	Task Name: Dialogue and finish the call
<div style="text-align: right; font-size: small;">Dialogue and finish A/1-1-2</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 15px; display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">Talking on the phone and terminating the call</h2>  </div> <p><b>Initial situation:</b> You have answered the call.</p> <p><b>Task:</b> Talk on the phone: The caller asks for your last name and what time it is. After that, say good-bye and terminate the call by using the "Terminate" icon.</p> <p><b>Steps:</b></p> <div style="margin-bottom: 20px;">  <div style="margin-left: 20px;"> <p><b>1</b></p> <p>The caller asks:</p> <ul style="list-style-type: none"> <li>What is your last name?</li> <li>What time is it?</li> </ul> </div> </div> <div>  <div style="margin-left: 20px;"> <p><b>2</b></p> <ul style="list-style-type: none"> <li>Both of you say good-bye.</li> <li>Terminate the call by pushing the "Terminate" icon.</li> </ul> <div style="text-align: right; margin-top: 10px;">  </div> </div> </div>		
<b>Optimal solution:</b>	Say name, time, good-bye and terminate with icon.	
<b>Task completed:</b>	Last name and time are delivered, call is terminated with icon.	
<b>Measurement:</b>	Interval from displaying phone dialogue until "Terminate" icon is pressed.	

Table 12: Task and Measurement Descriptions of T 1-1-2

Setup: B	No.: T 1-1-3	Task Name: Start call app
<div style="text-align: right; font-size: small;">Start call app B/1-1-3</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 15px; display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">Starting the phone call application</h2>  </div> <p><b>Initial situation:</b> You are at home, sitting at the living-room table. The smartphone is on the table in front of you. You would like to make a call.</p> <p><b>Task:</b> Look at the home screen of your phone and find the "Phone" icon. Start the phone call application by pressing the respective icon. Then enter the phone number 0234 54607455 and start the dialing process by pressing the green "Dial" icon.</p> <p><b>Steps:</b></p> <div style="margin-bottom: 20px;"> <div style="display: flex; align-items: flex-start;">  <div style="border: 1px solid #ccc; padding: 10px; width: 300px;"> <div style="text-align: right; font-weight: bold; font-size: 24px; border: 2px solid #0056b3; border-radius: 50%; width: 20px; height: 20px; display: flex; align-items: center; justify-content: center; margin-bottom: 10px;">1</div> <ul style="list-style-type: none"> <li>Look at the home screen of the phone.</li> <li>Find the icon to start the phone call application.</li> <li>Start the phone call application by pressing the icon.</li> </ul>  </div> </div> </div> <div> <div style="display: flex; align-items: flex-start;">  <div style="border: 1px solid #ccc; padding: 10px; width: 300px;"> <div style="text-align: right; font-weight: bold; font-size: 24px; border: 2px solid #0056b3; border-radius: 50%; width: 20px; height: 20px; display: flex; align-items: center; justify-content: center; margin-bottom: 10px;">2</div> <ul style="list-style-type: none"> <li>The phone call application has been started.</li> <li>Enter the phone number 0234 54607455.</li> <li>Start the dialing process by pressing the green "Dial" icon.</li> </ul>  </div> </div> </div>		
<b>Optimal solution:</b>	Find the phone application and start it. Enter the phone number and dial. 0234 54607455	
<b>Task completed:</b>	Start phone application and dial the right number.	
<b>Measurement:</b>	Interval from taking smartphone off the table until dialing process is started.	

Table 13: Task and Measurement Descriptions of T 1-1-3





Setup: B	No.: T 1-1-4	Task Name: Make a Call
<div style="text-align: right; font-size: small;">Make a call B/1-1-4</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 15px 15px 0 0; display: flex; justify-content: space-between; align-items: center;"> <span style="font-size: 24px; font-weight: bold;">Making a call</span>  </div> <p><b>Initial situation:</b> The smartphone is in your hand; the active dialing process is visible.</p> <p><b>Task:</b> Your dialogue partner would like to know your last name, the number of people in the room with you and what the weather is like. Answer the questions and then terminate the call.</p> <p><b>Steps:</b></p> <div style="border: 1px solid #ccc; padding: 10px; margin-bottom: 10px;"> <div style="display: flex; justify-content: space-between; align-items: center;">  <div style="border-left: 1px solid #ccc; border-right: 1px solid #ccc; border-bottom: 1px solid #ccc; padding: 10px;"> <div style="text-align: right; font-size: 24px; font-weight: bold; color: #0056b3; border-radius: 50%; width: 25px; height: 25px; margin-bottom: 5px;">1</div> <ul style="list-style-type: none"> <li>Hold the phone to your ear.</li> <li>Your dialogue partner accepts the call and says "Hello".</li> </ul> </div> </div> </div> <div style="border: 1px solid #ccc; padding: 10px;"> <div style="display: flex; justify-content: space-between; align-items: center;">  <div style="border-left: 1px solid #ccc; border-right: 1px solid #ccc; border-bottom: 1px solid #ccc; padding: 10px;"> <div style="text-align: right; font-size: 24px; font-weight: bold; color: #0056b3; border-radius: 50%; width: 25px; height: 25px; margin-bottom: 5px;">2</div> <p>Your dialogue partner would like to know:</p> <ul style="list-style-type: none"> <li>What is your last name?</li> <li>How many people are in the room with you?</li> <li>What is the weather like?</li> <li>Answer the questions, say good-bye and terminate the call by pressing the "Terminate" icon.</li> </ul> <div style="text-align: right; margin-top: 10px;">  </div> </div> </div> </div>		
<b>Optimal solution:</b>	Say last name, number of people, weather, goodbye and terminate with icon.	
<b>Task completed:</b>	The three questions are answered and call is terminated with icon.	
<b>Measurement:</b>	Interval from dialogue start until the "Terminate" icon is pressed.	

Table 14: Task and Measurement Descriptions of T 1-1-4






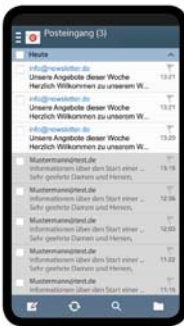


Setup: C	No.: T 1-1-5	Task Name: Start e-mail app
<div style="text-align: right; font-size: small;">Start e-mail app C/1-1-5</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 15px; display: inline-block; margin-bottom: 10px;"> <h2 style="margin: 0;">Starting the e-mail application</h2> </div> <div style="text-align: right; margin-bottom: 10px;">  </div> <p><b>Initial situation:</b> You are at home, sitting at the living-room table. The smartphone is on the table in front of you and you would like to send an e-mail.</p> <p><b>Task:</b> Look at the home screen of your smartphone and find the "E-mail" icon. Start the e-mail application by pressing the icon with your finger. Then switch to the "Write e-mails" dialogue box by pressing the respective icon.</p> <p><b>Steps:</b></p> <div style="border: 1px solid #ccc; padding: 10px; margin-bottom: 10px;"> <div style="float: right; background-color: #0056b3; color: white; border-radius: 50%; width: 20px; height: 20px; display: flex; align-items: center; justify-content: center; margin-bottom: 5px;">1</div> <div style="display: flex; align-items: flex-start;">  <ul style="list-style-type: none"> <li>Look at the home screen of your smartphone.</li> <li>Find the icon to start the e-mail application.</li> <li>Start the application by pressing the icon with your finger.</li> </ul>  </div> </div> <div style="border: 1px solid #ccc; padding: 10px;"> <div style="float: right; background-color: #0056b3; color: white; border-radius: 50%; width: 20px; height: 20px; display: flex; align-items: center; justify-content: center; margin-bottom: 5px;">2</div> <div style="display: flex; align-items: flex-start;"> <div style="display: flex; margin-right: 10px;">   </div> <ul style="list-style-type: none"> <li>The main view of the e-mail application is shown.</li> <li>Switch to the "Write e-mail" dialogue box by pressing the icon.</li> </ul>  </div> </div>		
<b>Optimal solution:</b>	Find the e-mail application, start it and find icon to write new e-mail.	
<b>Task completed:</b>	E-mail application started and "Write e-mail" dialogue is displayed.	
<b>Measurement:</b>	Interval of taking the smartphone from the table until the "Write e-mail" dialogue is displayed.	

Table 15: Task and Measurement Descriptions of T 1-1-5




Setup: C	No.: T 1-1-6	Task Name: Type and send an e-mail
<div style="text-align: right; font-size: small;">Type and send an e-mail C/1-1-6</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 10px 10px 0 0;"> <h2 style="margin: 0;">Writing and sending an e-mail</h2> </div> <p><b>Initial situation:</b>            You are holding the smartphone in your hand and the dialogue box for writing an e-mail is displayed.            There is a red symbol and a blue number on the table in front of you.</p> <p><b>Task:</b>            Enter the following name into the "To" text box as the e-mail address: Dennis.            Then select the first entry on the displayed list. Enter the description of the red symbol into the "Subject" text box. Enter today's date into the next text box, and the blue number into the following line. Then send the e-mail.</p> <p><b>Steps:</b></p> <div style="display: flex; flex-direction: column; align-items: flex-start;"> <div style="margin-bottom: 20px;">  <ul style="list-style-type: none"> <li>Enter the following name into the "To" text box as e-mail address: Dennis.</li> <li>Select the first entry on the displayed list.</li> <li>Enter the information of the red symbol into the "Subject" text box.</li> </ul> </div> <div>  <ul style="list-style-type: none"> <li>Enter today's date into the text box.</li> <li>Enter the blue number into the following text box.</li> <li>Send the e-mail by pressing the "Send e-mail" icon.</li> </ul>  </div> </div>		
<b>Optimal solution:</b>	Enter e-mail address (name), subject (symbol), date and number. Then send e-mail.	
<b>Task completed:</b>	Required information is entered and e-mail is sent successfully.	
<b>Measurement:</b>	Interval from displaying "Write e-mail" dialogue until e-mail is sent.	

Table 16: Task and Measurement Descriptions of T 1-1-6

The following six tables (Table 17 to Table 22) describe the tasks with UCM support and the steps for the optimal task completion of the probands with start and end points for the measurements. The tasks validate the sub-hypothesis H 1-2:

- 1) Task 1-2-1 based on Setup D (Table 17):  
Take the call with multimodal touch by pressing a picture of the caller on the smartwatch or smartphone. The measured interval is defined from the first ring until the dialogue screen is displayed.
- 2) Task 1-2-2 based on Setup D (Table 18):  
Perform a dialogue with the delivery of information (e.g., name, time), and finish the call via gesture by waving into the camera. The interval to measure is defined from displaying the phone dialogue until the call is terminated by gesture.
- 3) Task 1-2-3 based on Setup E (Table 19):  
Start the telephone app with a gesture by placing the smartphone on the photo of the person that should be called. NFC triggers the dialing process in the background. The measured interval is defined from taking smartphone off the table until the dialing process is started.
- 4) Task 1-2-4 based on Setup E (Table 20):  
Make a video call and additional information are shown on the screen. The dialogue partner transmits the requested information (e.g., number of persons in the room, weather conditions) that are confirmed by the caller. The video call is terminated by waving. The measured interval is defined from the dialogue start until the termination by gesture (waving).
- 5) Task 1-2-5 based on Setup F (Table 21):  
Start the e-mail app with a voice command and the "Write e-mail" dialogue is shown automatically. The measured interval is defined from taking the smartphone off the table until the "Write e-mail" dialogue is displayed.
- 6) Task 1-2-6 based on Setup F (Table 22):  
Type and sent an e-mail with multimodal in- and output assistance. The information is entered via voice command and the message is sent by pressing a button on the smartphone. The process is assisted by voice commands. The measured interval is defined from displaying the "Write e-mail" dialogue until the e-mail is sent.

Setup: D	No.: T 1-2-1	Task Name: Take the call, multimodal touch
<div style="text-align: right; font-size: small;">Take the call   Multimodal touch D/1-2-1</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 15px; display: inline-block; margin-bottom: 10px;"> <b>Answering the call by using the watch or smartphone</b>  </div> <p><b>Initial situation:</b> You are at home, sitting at the living-room table. The smartphone is on the table and you are wearing a smartwatch. There is a large screen in front of you. A call is coming in, signalled by the caller's picture on the screen. The call is also indicated by vibration and a tone on the smartwatch and smartphone.</p> <p><b>Task:</b> Accept the incoming call by pressing the caller's picture on the smartphone or smartwatch.</p> <p><b>Steps:</b></p> <div style="border: 1px solid #ccc; padding: 10px; margin-bottom: 10px;"> <div style="display: flex; align-items: center;">  <div style="border: 1px solid #ccc; padding: 5px; border-radius: 5px;"> <div style="text-align: right; font-weight: bold; font-size: 24px; color: #0056b3; border: 1px solid #0056b3; border-radius: 50%; width: 20px; height: 20px; display: flex; align-items: center; justify-content: center; margin-bottom: 5px;">1</div> <ul style="list-style-type: none"> <li>The screen shows the caller's picture.</li> <li>The call is signalled by vibration and a tone on the smartphone.</li> <li>The smartwatch also gives a tone and vibration signal.</li> </ul> </div> </div> </div> <div style="border: 1px solid #ccc; padding: 10px;"> <div style="display: flex; align-items: center;">  <div style="border: 1px solid #ccc; padding: 5px; border-radius: 5px;"> <div style="text-align: right; font-weight: bold; font-size: 24px; color: #0056b3; border: 1px solid #0056b3; border-radius: 50%; width: 20px; height: 20px; display: flex; align-items: center; justify-content: center; margin-bottom: 5px;">2</div> <ul style="list-style-type: none"> <li>Accept the incoming call by pressing the caller's picture.</li> <li>Use either smartphone or smartwatch to accept the call.</li> </ul> </div> </div> </div>		
<b>Optimal solution:</b>	Press the caller's picture on the smartwatch or smartphone.	
<b>Task completed:</b>	Phone call accepted.	
<b>Measurement:</b>	Interval from first ring until phone dialogue screen is displayed.	

Table 17: Task and Measurement Descriptions of T 1-2-1




Setup: D	No.: T 1-2-2	Task Name: Dialogue and finish the call, gesture
<div style="text-align: right; font-size: small;">Dialogue and finish   Gesture D/1-2-2</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 10px; display: flex; justify-content: space-between; align-items: center;"> <div style="font-weight: bold; font-size: 1.2em;">Talking on the phone and terminating the call by waving</div>  </div> <p><b>Initial situation:</b> You have answered the call and are talking to the other person via the screen, using the video camera and microphone. There is no need for a handset. Speak freely towards the screen.</p> <p><b>Task:</b> The caller greets you by name and asks what time it is. The call is terminated by waving in front of the camera.</p> <p><b>Steps:</b></p> <div style="border: 1px solid #ccc; padding: 10px; margin-bottom: 10px; border-radius: 10px;"> <div style="text-align: right; background-color: #0056b3; color: white; border-radius: 50%; width: 20px; height: 20px; display: flex; align-items: center; justify-content: center; margin: 0 auto 10px auto;">1</div> <div style="display: flex; align-items: center;">  <div style="margin-left: 10px;"> <ul style="list-style-type: none"> <li>You have answered the call and the caller greets you by name.</li> </ul> <p>The caller asks:</p> <ul style="list-style-type: none"> <li>What time is it?</li> </ul> </div> </div> </div> <div style="border: 1px solid #ccc; padding: 10px; margin-bottom: 10px; border-radius: 10px;"> <div style="text-align: right; background-color: #0056b3; color: white; border-radius: 50%; width: 20px; height: 20px; display: flex; align-items: center; justify-content: center; margin: 0 auto 10px auto;">2</div> <div style="display: flex; align-items: center;">  <div style="margin-left: 10px;"> <ul style="list-style-type: none"> <li>Answer the question.</li> <li>Terminate the call by waving at the camera.</li> </ul> </div> </div> </div>		

Table 18: Task and Measurement Descriptions of T 1-2-2

Setup: E	No.: T 1-2-3	Task Name: Start call app, gesture NFC
<div style="text-align: right; font-size: small; margin-bottom: 10px;">Start app   Gesture NFC E/1-2-3</div> <div style="background-color: #004a7c; color: white; padding: 10px; border-radius: 15px; display: flex; justify-content: space-between; align-items: center;"> <div style="flex: 1;"> <h2 style="margin: 0;">Starting the call application using a gesture</h2> </div>  </div> <p><b>Initial situation:</b> You are at home, sitting at the living-room table. The smartphone is on the table. There is a screen, a camera with microphone and three photo contacts in front of you. You would like to make a call.</p> <p><b>Task:</b> Start the dialing process by placing the smartphone on the photo of the person you would like to call. The dialing process is carried out automatically and the connection to your dialogue partner is established.</p> <p><b>Steps:</b></p> <div style="border: 1px solid #ccc; padding: 10px; margin-bottom: 10px;"> <div style="text-align: right; font-weight: bold; font-size: 24px; color: #004a7c; border-radius: 50%; width: 30px; height: 30px; display: flex; align-items: center; justify-content: center; margin-bottom: 5px;">1</div>  <ul style="list-style-type: none"> <li>Take the smartphone and place it on the photo showing "Dennis" (dialogue partner).</li> </ul> </div> <div style="border: 1px solid #ccc; padding: 10px;"> <div style="text-align: right; font-weight: bold; font-size: 24px; color: #004a7c; border-radius: 50%; width: 30px; height: 30px; display: flex; align-items: center; justify-content: center; margin-bottom: 5px;">2</div>  <ul style="list-style-type: none"> <li>The phone dials automatically and establishes the connection.</li> </ul> </div>		

Table 19: Task and Measurement Descriptions of T 1-2-3




Setup: E	No.: T 1-2-4	Task Name: Make a videocall, additional information are shown
<div style="text-align: right; font-size: small; margin-bottom: 5px;">Make a videocall   Additional Information are shown E/1-2-4</div> <div style="background-color: #004a87; color: white; padding: 10px; border-radius: 15px; display: flex; justify-content: space-between; align-items: center;"> <div style="font-weight: bold; font-size: 1.2em;">Making a video call and terminating it by waving</div>  </div> <p><b>Initial situation:</b> The connection has been established. Both dialogue partners can see and hear each other. The screen shows additional information.</p> <p><b>Task:</b> The dialogue partner greets you by name. He states the number of persons in the room and what the weather is like. He asks you to confirm this information. The call is then terminated by waving.</p> <p><b>Steps:</b></p> <div style="margin-bottom: 20px;"> <div style="display: flex; align-items: center;">  <div style="margin-left: 20px;"> <p style="font-weight: bold; font-size: 1.5em; color: #004a87; border: 2px solid #004a87; border-radius: 50%; width: 25px; height: 25px; display: flex; align-items: center; justify-content: center; margin-bottom: 5px;">1</p> <ul style="list-style-type: none"> <li>The screen displays a video connection of you and your dialogue partner.</li> <li>The dialogue partner accepts the call and greets you.</li> <li>He states the number of persons in the room with you which he can see from the camera.</li> <li>The dialogue partner describes the weather which is displayed on the screen.</li> </ul> </div> </div> </div> <div> <div style="display: flex; align-items: center;">  <div style="margin-left: 20px;"> <p style="font-weight: bold; font-size: 1.5em; color: #004a87; border: 2px solid #004a87; border-radius: 50%; width: 25px; height: 25px; display: flex; align-items: center; justify-content: center; margin-bottom: 5px;">2</p> <ul style="list-style-type: none"> <li>The dialogue partner asks you to confirm the named information.</li> <li>Confirm the information if correct.</li> <li>Terminate the call by waving.</li> </ul> </div> </div> </div>		
<b>Optimal solution:</b>	Dialogue partner says name, number of persons, weather, confirmation, good-bye, then terminate (waving).	
<b>Task completed:</b>	Information are stated by dialogue partner and call is terminated by gesture.	
<b>Measurement:</b>	Interval from dialogue start until termination after waving.	

Table 20: Task and Measurement Descriptions of T 1-2-4


Setup: F	No.: T 1-2-5	Task Name: Start e-mail app, voice
<div style="text-align: right; font-size: small;">Start e-mail app   voice E/1-2-5</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 15px; display: flex; justify-content: space-between; align-items: center;"> <span style="font-weight: bold; font-size: 1.2em;">Starting the e-mail application with a voice command</span>  </div> <p><b>Initial situation:</b> You are at home, sitting at the living-room table. The smartphone is on the table. You would like to send an e-mail.</p> <p><b>Task:</b> Start the appropriate application with the voice command: "Write an e-mail to Dennis".</p> <p><b>Steps:</b></p> <div style="display: flex; align-items: flex-start;"> <div style="flex: 1;">   </div> <div style="flex: 2; padding-left: 20px;"> <p><b>1</b></p> <ul style="list-style-type: none"> <li>Take the smartphone and hold it in front of you (distance approx. 30 cm)</li> <li>Press the "E-mail" icon.</li> <li>Press the "Microphone" icon to start voice entry.</li> <li>Into the smartphone, speak the following command: "Write an e-mail to Dennis".</li> </ul> </div> </div> <div style="display: flex; align-items: center; margin-top: 20px;">  <div style="flex: 1; padding-left: 20px;"> <p><b>2</b></p> <ul style="list-style-type: none"> <li>The "Write an e-mail" dialogue box is displayed. The e-mail address has been inserted automatically.</li> </ul> </div> </div>		
<b>Optimal solution:</b>	Starting the application via voice command.	
<b>Task completed:</b>	E-mail application started and "Write e-mail" dialogue is displayed.	
<b>Measurement:</b>	Interval from taking smartphone off the table until "Write e-mail" dialogue is displayed.	

Table 21: Task and Measurement Descriptions of T 1-2-5









Setup: F	No.: T 1-2-6	Task Name: Type and send an e-mail, voice & touch
<div style="text-align: right; font-size: small;">Type and send   Voice &amp; touch F/1-2-6</div> <div style="background-color: #0056b3; color: white; padding: 5px; border-radius: 10px; display: inline-block;"> <b>Writing and sending an e-mail using voice input and touch gestures</b>  </div> <p><b>Initial situation:</b> The smartphone is in front of you and the "Write an e-mail" dialogue box is open</p> <p><b>Task:</b> The e-mail address has been entered automatically by the system. Using voice input, enter the e-mail subject, which is the description of the red symbol in front of you. Also using voice input, enter the blue number into the text box. Today's date is added automatically by the system itself. To send the e-mail, press the corresponding icon.</p> <p><b>Steps:</b></p> <div style="border: 1px solid #ccc; padding: 10px; margin-bottom: 10px;"> <div style="display: flex; justify-content: space-between; align-items: center;">  <div style="text-align: right; border: 1px solid #ccc; border-radius: 50%; width: 30px; height: 30px; display: flex; align-items: center; justify-content: center; background-color: #0056b3; color: white; font-weight: bold; font-size: 18px;">1</div> </div> <ul style="list-style-type: none"> <li>Voice input is started by pressing the icon at the end of the subject line.</li> <li>Read the information from the red symbol into the microphone.</li> </ul>  </div> <div style="border: 1px solid #ccc; padding: 10px;"> <div style="display: flex; justify-content: space-between; align-items: center;">  <div style="text-align: right; border: 1px solid #ccc; border-radius: 50%; width: 30px; height: 30px; display: flex; align-items: center; justify-content: center; background-color: #0056b3; color: white; font-weight: bold; font-size: 18px;">2</div> </div> <ul style="list-style-type: none"> <li>Today's date is added automatically.</li> <li>Start voice input by pressing the microphone icon on the lower bottom of the screen.</li> <li>Read the blue number into the microphone.</li> <li>Send the e-mail by pressing the "Send e-mail" icon.</li> </ul>   </div>		

Table 22: Task and Measurement Descriptions of T 1-2-6

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### 6.2.2 Scenario 2: Mobility

The prototype UCM-S2 is a mobility assistance service that enables the communication with an environment (M2M and M2H) (cf. Section 3.2.3) and also the H2H communication which is described in the use case “Grandma” (Section 6.1.2). The prototype illustrates the integration of the UCM domains “anybody”, “any device” and “any media” in order to enable a variety of communication opportunities (M2M and M2H communication). The focus is on wearable and mobile devices to utilize mobility and activity for an aging society providing orientation, navigation, activity planning with a sense of security.

The experiments are divided up into three main tasks which are subdivided into six subtasks in order to elaborate mobility and communication behavior of the elderly probands with and without technology assistance. The tasks cover the following mobility and communication challenges:

- Plan a trip and select the right bus line.
- Determine the actual position and navigate on a crossway.
- Check the time schedule and confirm an appointment.

These tasks are applied to the prototype UCM-S2. The used devices in the scenarios are mobility supporting devices, i.e., a phablet and a smartwatch. The UCM-S2 prototype is an example to show and evaluate the possibilities, and advantages of communication services based on the IoT and also H2H communication.

#### 6.2.2.1 Features of Prototype UCM-S2

The prototype UCM-S2 enables a human interchange with the environment and also H2H communication with multimodal I/O. A diversity of devices and media are integrated into one single service considering the requirements of mobility assistance and the communication needs of elderly persons. (cf. Section 2.3 and 2.5)

The elements of user interaction and design are implemented under the same consideration of the attributes for the usability of elderly people in UCM-S1, as described in Section 6.2.1.1.

The information beaming in the natural environment and the communication devices of UCM-S2 has to consider several technical requirements: Each object and

information service has to be modular and adaptive to be embedded for information interchange. For example, the bus line information (integrated with a web service) has to offer information in a format which is suitable for further interpretation for a technical service or a person. The transmitted value "579;+2" between two web services is a format that classifies a technical information about the delay of the bus line. A software service transmits these values to the user interface of the phablet and translates these information into suitable information for the user, i.e., "The bus line "579" will have "two" minutes delay".

The communication protocols that are used for the interaction between the environment and the user device have to be compatible to interchange the requested information. For example, the NFC label which is necessary for location identification of the bus stop, has to send the information in a compatible standard to the smartphone, otherwise the transmitted information cannot be interpreted.

Additional challenges are low latency and fast wireless external network connections to internet (cloud) services. These connections are required to provide a stable and useful data fusion/fission for contextual, location-based, and ubiquitous information exchange. Enabling multimodality on several devices with contextual I/O, the UCM-S2 pushes the required information on the best-fitting device and modality for the user.

For example, with sensor analysis the smartwatch recognizes that the user walks through a natural environment. Focusing on the personal preferences of device usage during a walk, the required information "go right" is provided by the smartwatch. The technical command "arrow to the right" is pushed by the phablet via Bluetooth to the smartwatch.

The input and output modalities are handled by the UCM Application and give the user flexible possibilities with an ease of use. For example, the confirmation of the appointment is shown on the smartwatch and the phablet. The appointment can be confirmed with one gesture on the smartwatch or the phablet.

The prototype UCM-S2 provides contextual information delivery with high usability over interchanging M2M communication. Scenario 2 enables social participation for the elderly society, supporting mobility with orientation in the environment, navigation and security.

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#### 6.2.2.2 *Technical Architecture of Prototype UCM-S2*

The prototype UCM-S2 integrates several distributed systems into one synchronously interacting service, which are coordinated by the UCM Server Application. The UCM Server Application coordinates the speech services (STT/TTS) and location-based information that are extended with further contextual additional information (e.g. bus line information or navigation/ routing information). The UCM Connector establishes connections between the several client devices and the environment. The implementation of UCM-S2 requires a software and network architecture platform that provides capabilities for:

- 1) Diversity and multiplicity of devices,
- 2) Multimodal I/O,
- 3) High bandwidth with low latency, and
- 4) Seamless integration of a variety of application protocols.

The UCM information flow architecture for UCM-S2 is depicted in Figure 37. The individual features of the device, including all sensor information is processed by the local UCM Application on the touch device component (Phablet), shown in the box on the left side in the middle of Figure 37. It combines the I/O of local HD video (for AR enhancement), audio signals (STT, TTS) and provides the information interchange with the smartwatch over the UCM Connector. The UCM Application permits data aggregation from external environment (NFC label), external information (Bus line information) or external service components (TTS/STT Services) which are linked by the UCM Connector and coordinated by the UCM Server Application.

The additional devices component (Figure 37, left side, bottom) represents further display and interaction devices as smartwatches or wireless speakers. The several devices interact directly “wireless” controlled by the local UCM Application, i.e. the phablet connects wireless to the speaker for multimodal output.

The central service for UCM-S2 is the UCM Server Application (Figure 37, middle part), which serves as a controller and converter to aggregate the diversity of client and service data. The UCM Connector enables a flexible and wide range of connectivity to provide interchange to the environment (M2M enables IoT) and communication devices (M2M and M2H enables H2H communication).

External services provide (Figure 37, right side, bottom) the STT/TTS services or the navigation/ routing services on a cloud infrastructure. They interact with localization services over the UCM Connector that are also integrated with individual adapters and work as central service for the several UCM Applications if required.

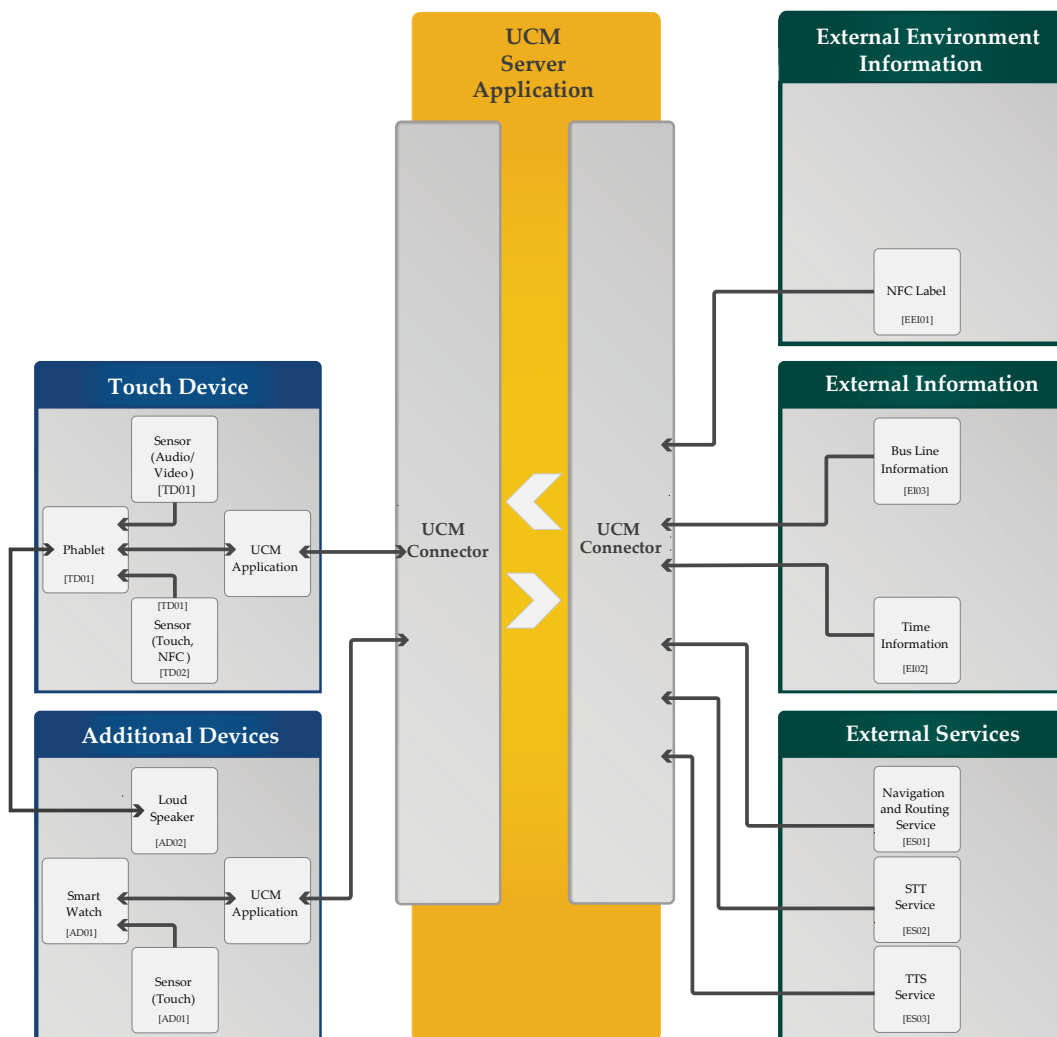


Figure 37: UCM Information Flow Architecture of Prototype UCM-S2

The wireless data transmission connectivity in this prototype UCM-S2, is provided by wireless router with low latency and high bandwidth. The touch device is the same phablet as in Scenario 1. The wireless speaker and the

smartwatch are connected with Bluetooth. Each device interacts via the local UCM Application to the UCM Connector which interchanges with the UCM Server Application. This central processing service coordinates the information distribution in the UCM infrastructure.

The UCM architecture provides flexible integration of a diversity of devices and services on a scalable infrastructure, with low latency and high bandwidth to enable environment-to-device and device-to-device communication.

#### *6.2.2.3 Technical Setup and Test Environment of UCM-S2*

The infrastructure for UCM-S2 is based on the same technical client/ server architecture as UCM-S1 (cf. Figure 31, p.134). This infrastructure enables for UCM-S2 a communication with the environment and also H2H communication via M2M and M2H services. The client devices are reduced to the phablet, the smartwatch and the external loudspeakers system. An external NFC label enables LBS.

The interaction process of the technical infrastructure architecture (cf. Figure 31) applies to the same logic as in Scenario 1 and the sequence of the communication process is similar to all the variety of UCM clients (in this scenario phablet and smartwatch). They interact in the same way over the layer to communicate with the server application.

The phablet (Samsung Galaxy Note 3, see Appendix A-2 for further specification) provides a user interface with several multimodalities, i.e. display, audio signal, vibration signal, STT input, TTS output. The network connectivity is provided via the internal Wi-Fi adapter with IEEE 802.11ac standard and Bluetooth 4.0. Short distance localization is provided via NFC functionality.

The audio output of the phablet is send to the loudspeaker system (Harman Kardon Sound Sticks, see Appendix A-3 for further specification) via Bluetooth and enables audio output mobilized in the environment.

The additional device smartwatch (Sony Smartwatch 2, see Appendix A-3 for further specification) is connected via Bluetooth and controlled by the phablets' UCM Application.

Synchronous information beaming to operate on both devices is supported by the UCM-S2 prototype. The wireless connectivity infrastructure in this scenario is provided with a single Wi-Fi access point (Asus RT-AC68U, see Appendix A-4

for further specification). High speed wireless infrastructure as IEEE 802.11ac has smaller coverage as “classical” wireless standards as IEEE 802.11n (cf. Section 4.1.3). The size of the room (18 meters long, 8 meters wide) for the proband experiments allows the highest bandwidth of the IEEE 802.11ac standard with one single access point.

The information interchange between the environment and the several devices is supported by LBS and displayed with context-sensitivity.

The AR enhanced phablet and the smartwatch of UCM-S2 are shown in Figure 38.



Figure 38: UCM-S2 - Phablet (left side) and Smartwatch (right side)

The following example “navigate on a cross-way with multimodal assistance” describes the flow of interaction with the several devices and UCM-S2 prototype application. An NFC label-featured bus line information enables the IoT device which is shown in Figure 39.



**Figure 39: IoT Device Bus Line Information with NFC**

The proband localizes the position via an NFC label (see Figure 40, Task 2-2-4 and for a detailed task description Table 33) which is attached to a bus stop. The phablet shows a live video of the local environment and the routing information which are received in the background providing an augmented navigation information to “turn right”.

This information distribution is supported with multimodality:

- Shown on the screen of the smartwatch, and supported with a vibration signal of the smartwatch,
- Shown on the screen of the phablet,
- TTS information is played on the seamless loudspeaker system

Context-sensitivity enables an intuitive check with a “one click gesture” on the smartwatch or the phablet, providing the information that the proband is in time for the appointment.



Figure 40 illustrates the wireless connected, seamless integrated, and multimodal environment for the UCM-S2 proband experiment specification. (For further details see also Appendix C-2.

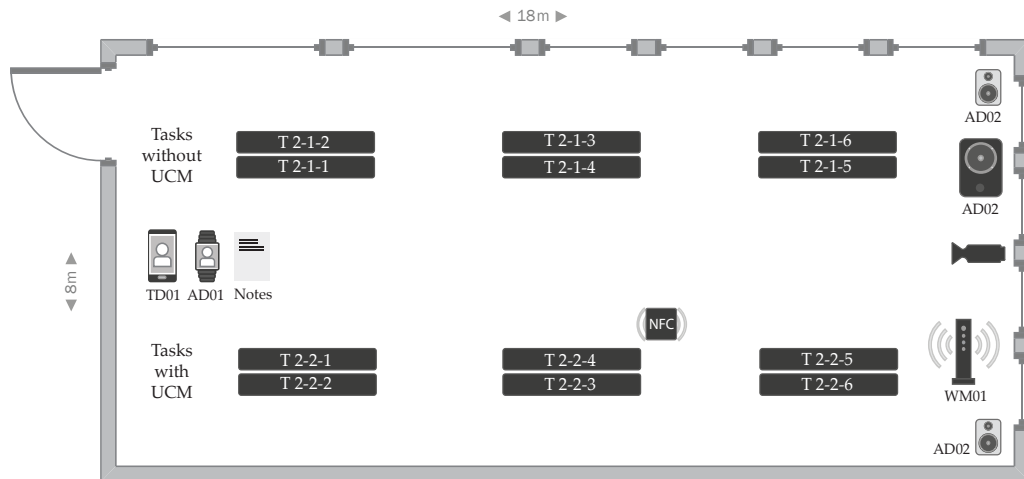


Figure 40: Setup and Test Environment for UCM-S2

Table 23 depicts the technical devices and services used in Scenario 2. It is built up on the same manner as Table 10 for UCM-S1. Detailed information is depicted in Appendices A-1 to A-7.

ID-Code	Category	Description
TD01	Touch Device	Samsung Galaxy Note 3
TD02	Touch Device	Android.NFC Service
AD01	Additional Device	Sony Smartwatch 2
AD02	Additional Device	Harman Kardon Soundsticks Wireless 2.1
WM01	Wireless Media	Asus RT-AC68U
EI02	External Information	Timeapi.org
EI03	External Information	Bus line
EEI01	External Environment Information	NFC label
ES02	External Service	STT - Service, Google
ES03	External Service	TTS - Service, Google
ES04	External Service	Maps - Service, Google

Table 23: Overview Technical Setup UCM-S2

The UCM-S2 activates the user with mobility assistance to participate with the society and the environment. The ease of use is maintained by convenient user interfaces on wearable and mobile devices. UCM-S2 provides security, daily task organization, and mobility assistance with M2M and M2H communication. Further details of the complete tasks of test environment of the UCM-S2 are described in the following section.

#### 6.2.2.4 Tasks of Scenario 2 “Mobility”

The specification of the “Mobility” tasks embodies nowadays requirements and behavior of the society (cf. Section 5.3.3) to interchange with the environment on actual communication devices. The tasks are based on the sub-hypothesis H 2-1 (without UCM) and H 2-2 (with UCM).

The following six tables (Table 24 to Table 29) describe tasks without UCM support and the criteria for the optimal task completion of the probands with start and end points for the measurements:

- 1) Task 2-1-1 based on Setup G (Table 24):  
Find a suitable bus line, using the maps and tools on the poster. The measured interval is defined from looking at the tools on the poster until the suitable bus line is named.
- 2) Task 2-1-2 based on Setup G (Table 25):  
Plan a trip, using the calendar to find the appointment and determine the required length of the trip with the departure time using public transport. The interval to measure is defined from looking at the tools on the poster until the correct length of the trip and departure time are named.
- 3) Task 2-1-3 based on Setup H (Table 26):  
Riding the bus and finding out, when and where to get off the bus. The measured interval is defined from looking at the information sign until the time and location of leaving the bus are named.
- 4) Task 2-1-4 based on Setup H (Table 27):  
Get off the bus and determine the location on the map. Decide whether to go left or right on a cross-way. The measured interval is defined from looking at the map until the correct direction is named.

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5) Task 2-1-5 based on Setup I (Table 28):

Determine the location on the map and check punctuality for the appointment. The measured interval is defined from looking at the map until punctuality information has been given.

6) Task 2-1-6 based on Setup I (Table 29):

The phone rings (shortly after Task 2-1-5 has been executed) and the caller asks for punctuality. The acknowledgement is given via telephone. The measured time interval is defined from the first ring until the call has been terminated.




Setup: G	No.: T 2-1-1	Task Name: Select a bus line
<div style="text-align: right; font-size: small;">Select a bus line G/2-1-1</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 15px; display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">Selecting a suitable bus line</h2>  </div> <p><b>Initial situation:</b> You have a doctor's appointment in town today, and plan to go there by public transport. There is an organizer, a bus route map, an overview of the bus lines and a city map with bus stops marked on it on the table in front of you.</p> <p><b>Task:</b> Using the map and the bus plans, find the best bus line to bring you as close as possible to your destination from your starting point (A). The destination address is written in your organizer.</p> <p><b>Steps:</b></p> <div style="display: flex; justify-content: space-between;"> <div style="width: 30%;">  <p>• Terminalkalender</p> </div> <div style="width: 65%;"> <p><b>1</b></p> <ul style="list-style-type: none"> <li>• In the organizer, find the address for your doctor's appointment and your destination point (B, C, D, E).</li> <li>• On the map, find the best bus stop in order to find the suitable bus lines.</li> </ul> </div> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="width: 30%;">  <p>• Stadtplan</p> </div> <div style="width: 30%;">  <p>• Linienübersicht</p> </div> <div style="width: 30%;">  <p>• Linienplan</p> </div> </div> <p><b>2</b></p> <ul style="list-style-type: none"> <li>• Check the bus timetables and name the best bus line for your destination. (No need to change bus lines.)</li> </ul>		
<b>Optimal solution:</b>	Find suitable bus line using the maps.	
<b>Task completed:</b>	Name the suitable bus line namely "579".	
<b>Measurement:</b>	Interval from looking at the tools on the poster until the suitable bus line is named (579).	

Table 24: Task and Measurement Descriptions of T 2-1-1


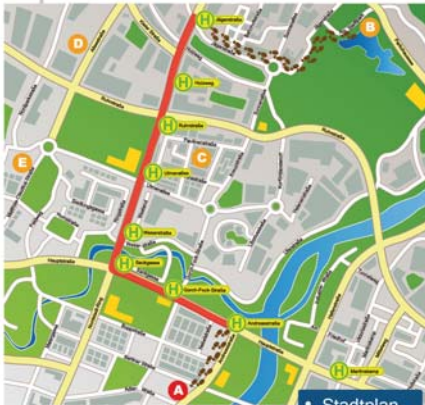
Setup: G	No.: T 2-1-2	Task Name: Plan a trip																																														
<div style="text-align: right; font-size: small;">Plan a trip G/2-1-2</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 15px; display: inline-block;"> <h2 style="margin: 0;">Planning the bus trip</h2> </div> <div style="float: right; text-align: center;">  </div> <p><b>Initial situation:</b> You have found the best bus line. There is an organizer, a bus timetable and a city map on the table in front of you.</p> <p><b>Task:</b> In your organizer, find the time of your doctor's appointment. The timetable and the accompanying notepad give information about the times required for the walking distance and for the bus ride. Calculate how long the trip to your appointment will take, and select the best departure time from the bus timetable.</p> <div style="display: flex; justify-content: space-between; align-items: flex-start;"> <div style="width: 30%;"> <p><b>Terminale:</b></p> <table border="1" style="font-size: x-small; border-collapse: collapse;"> <tr> <th>Termine: heute</th> <th>Termine: morgen</th> </tr> <tr> <td>08:15 Frühsport im Fitness-Club</td> <td>09:30 Verabredung zum Frühstück Cafe Müller</td> </tr> <tr> <td>12:00 Dr. med. Schmidt, Am Stadtpark 22</td> <td>13:00 Besuch im Krankenhaus Tante Ilse</td> </tr> <tr> <td>15:00 Auto aus der Inspektion abholen</td> <td>17:00 Jahreshauptversammlung Kegelerverein</td> </tr> <tr> <td>21:00 Treffpunkt vor dem Kino in der Innenstadt</td> <td>19:30 Besuch bei Franz und Elisabeth</td> </tr> </table> <p style="text-align: center; background-color: #0056b3; color: white; padding: 2px;">• Terminkalender</p> </div> <div style="width: 30%;"> <p><b>Steps:</b></p> <ol style="list-style-type: none"> <li style="margin-bottom: 10px;">1 • Take the required information from your organizer, the notepad and the bus timetable to plan the trip to your appointment.</li> </ol> </div> <div style="width: 30%;">  <p style="text-align: center; background-color: #0056b3; color: white; padding: 2px;">• Stadtplan</p> </div> <div style="width: 30%;"> <p><b>Fahrplan</b></p> <p>579 Richtung: Werrastraße</p> <table border="1" style="font-size: x-small; border-collapse: collapse;"> <tr> <th colspan="2">Abfahrt (minuten)</th> </tr> <tr><td>05</td><td>10</td></tr> <tr><td>06</td><td>10</td></tr> <tr><td>07</td><td>10</td></tr> <tr><td>08</td><td>10</td></tr> <tr><td>09</td><td>10</td></tr> <tr><td>10</td><td>10</td></tr> <tr><td>11</td><td>10</td></tr> <tr><td>12</td><td>10</td></tr> <tr><td>13</td><td>10</td></tr> <tr><td>14</td><td>10</td></tr> <tr><td>15</td><td>10</td></tr> <tr><td>16</td><td>10</td></tr> <tr><td>17</td><td>10</td></tr> <tr><td>18</td><td>10</td></tr> <tr><td>19</td><td>10</td></tr> <tr><td>20</td><td>10</td></tr> <tr><td>21</td><td>10</td></tr> </table> <div style="border: 1px solid black; border-radius: 10px; padding: 5px; margin-top: 10px;"> <p>8 Minuten Fußweg bis zur Bushaltestelle</p> <p>??? Busfahrt</p> <p>16 Minuten Fußweg Bushaltestelle -&gt; Arztpraxis</p> </div> <p style="text-align: center; background-color: #0056b3; color: white; padding: 2px;">• Notizzettel</p> </div> </div> <div style="margin-top: 10px;"> <p style="font-size: 2em; background-color: #0056b3; color: white; border-radius: 50%; width: 30px; height: 30px; display: flex; align-items: center; justify-content: center; margin-left: 0;">2</p> <p>• Calculate how long the bus trip will take and select the best departure time from the bus timetable.</p> </div>			Termine: heute	Termine: morgen	08:15 Frühsport im Fitness-Club	09:30 Verabredung zum Frühstück Cafe Müller	12:00 Dr. med. Schmidt, Am Stadtpark 22	13:00 Besuch im Krankenhaus Tante Ilse	15:00 Auto aus der Inspektion abholen	17:00 Jahreshauptversammlung Kegelerverein	21:00 Treffpunkt vor dem Kino in der Innenstadt	19:30 Besuch bei Franz und Elisabeth	Abfahrt (minuten)		05	10	06	10	07	10	08	10	09	10	10	10	11	10	12	10	13	10	14	10	15	10	16	10	17	10	18	10	19	10	20	10	21	10
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<b>Optimal solution:</b>	Take calendar, find today's appointment, determine the duration of the trip and the departure time using public transport.																																															
<b>Task completed:</b>	Name correct duration of the trip and departure time "38 minutes, 11:10 a.m."																																															
<b>Measurement:</b>	Interval from looking at the tools on the poster until the correct length of the trip and departure time are named (38 minutes, 11:10 a.m.)																																															

Table 25: Task and Measurement Descriptions of T 2-1-2

Setup: H	No.: T 2-1-3	Task Name: Riding the bus
<div style="text-align: right; font-size: small;">Riding the bus H/2-1-3</div> <div style="background-color: #004a87; color: white; padding: 5px; border-radius: 10px; display: inline-block; margin-bottom: 10px;"> <b>Determining where you are during the bus trip</b> </div> <p><b>Initial situation:</b> You are on the bus and have passed some stops.</p> <p><b>Task:</b> Look at the overview of the bus timetable and find out the stop at which you have to get off the bus. Calculate the normal travelling time.</p> <p><b>Steps:</b></p> <div style="border: 1px solid #ccc; padding: 10px; margin: 10px 0;"> <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="width: 30%;"> <ul style="list-style-type: none"> <li>• Orientate yourself on the bus timetable and find Jägerstraße as your destination bus stop.</li> </ul> </div> <div style="width: 60%; text-align: center;"> <p><b>Fahrplan</b> <span style="font-size: 2em; color: green; border: 1px solid green; border-radius: 50%; padding: 2px 5px;">H</span> <span style="float: right; border: 1px solid blue; border-radius: 50%; padding: 2px 5px;">1</span></p> <p><b>579</b> Richtung: Werrastraße</p> <p>Haltestellen: Meißelskamp, <del>Kochhausstraße</del>, Gerch-Fock-Straße, Jakobstraße, Werrastraße, Ulmenallee, Mühlentorstraße, Jägerstraße, Jägerstraße, Baumhaidstraße, Am Fock, Universitäts-, Cammerstraße, Jägerstraße, Wessberg, Theater</p> <p>Fahrzeit in Min.    ▲ 02 04 06 08 10 12 14 16 18 20 22 24 26 28</p> </div> </div> <div style="display: flex; justify-content: space-between; align-items: center; margin-top: 10px;"> <div style="width: 45%;"> <p style="text-align: center;">• Stadtplan</p> </div> <div style="width: 50%;"> <p><b>Current bus stop:</b> <span style="border: 1px solid blue; border-radius: 50%; padding: 2px 5px;">2</span> Ulmenallee</p> <ul style="list-style-type: none"> <li>• How many minutes will it take until you have to leave the bus</li> </ul> </div> </div> </div>		
<b>Optimal solution:</b>	Find out during the bus trip, when and where to get off the bus.	
<b>Task completed:</b>	Name the time until leaving the bus, namely "6 minutes".	
<b>Measurement:</b>	Interval from looking at the information sign until time and location of leaving the bus are named (6 minutes).	

Table 26: Task and Measurement Descriptions of T 2-1-3

Setup: H	No.: T 2-1-4	Task Name: Navigate on a cross-way
<div style="text-align: right; font-size: small; margin-bottom: 10px;">Navigate on a cross-way H/2-1-4</div> <div style="background-color: #004a87; color: white; padding: 10px; border-radius: 15px; display: inline-block; margin-bottom: 10px;"> <h2 style="margin: 0;">Navigating at an intersection</h2> </div> <div style="text-align: right; margin-bottom: 10px;">  </div> <p><b>Initial situation:</b> You have left the bus and are standing in front of the bus stop sign, facing the street.</p> <p><b>Task:</b> Orientate yourself on the map. Decide whether you have to leave the intersection to your right or left in order to get to your doctor's appointment on time.</p> <p><b>Steps:</b></p> <div style="display: flex; justify-content: space-between; align-items: flex-start;"> <div style="width: 45%;">  </div> <div style="width: 50%; border: 1px solid #ccc; padding: 10px; border-radius: 10px;"> <div style="text-align: right; font-weight: bold; font-size: 24px; margin-bottom: 10px;">1</div> <ul style="list-style-type: none"> <li>Orientate yourself on the map.</li> <li>Where are you?</li> <li>Where is your destination?</li> </ul> </div> </div> <div style="display: flex; justify-content: space-between; align-items: flex-start; margin-top: 20px;"> <div style="width: 45%;">  </div> <div style="width: 50%; border: 1px solid #ccc; padding: 10px; border-radius: 10px;"> <div style="text-align: right; font-weight: bold; font-size: 24px; margin-bottom: 10px;">2</div> <ul style="list-style-type: none"> <li>Decide whether you have to leave the intersection to your left or right in order to get to the appointment at Dr. Schmidt's on the fastest and most direct way.</li> </ul> </div> </div>		
<b>Optimal solution:</b>	Get off the bus and determine the location on the map. Decide whether to go left or right.	
<b>Task completed:</b>	Name the correct direction, "right".	
<b>Measurement:</b>	Interval from looking at the map until the correct direction is named right. (right)	

Table 27: Task and Measurement Descriptions of T 2-1-4

Setup: I	No.: T 2-1-5	Task Name: Check timelines
<div style="text-align: right; font-size: small;">Check timelines 1/2-1-5</div> <div style="background-color: #004a87; color: white; padding: 10px; border-radius: 15px; display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">Checking the timetables</h2>  </div> <p><b>Initial situation:</b> You left the bus at 11.24 a.m. at the Jägerstraße bus stop. After some minutes of walking, you would like to check whether you will arrive at your destination on time. It is now 11.32 a.m.</p> <p><b>Task:</b> Orientate yourself on the city map. Using the information on the detail drawing, work out how far you have already gone and how far you still need to go. According to this information, estimate whether you will be on time for your appointment at Dr. Schmidt's, which is located "Am Stadtpark".</p> <p><b>Steps:</b></p> <div style="display: flex; justify-content: space-between;"> <div style="width: 45%;">  <p style="text-align: center; font-size: small;">• Stadtplan</p> </div> <div style="width: 50%; border: 1px solid #ccc; border-radius: 10px; padding: 10px;"> <div style="text-align: right; font-size: 24px; font-weight: bold; color: #004a87; border: 1px solid #004a87; border-radius: 50%; width: 30px; height: 30px; display: flex; align-items: center; justify-content: center; margin: 0 auto 10px auto;">1</div> <ul style="list-style-type: none"> <li>Orientate yourself on the city map and find the exit stop.</li> <li>Find the destination.</li> </ul> </div> </div> <div style="display: flex; justify-content: space-between; margin-top: 20px;"> <div style="width: 45%;">  <p style="text-align: center; font-size: small;">• Terminkalender</p> </div> <div style="width: 50%; border: 1px solid #ccc; border-radius: 10px; padding: 10px;"> <div style="text-align: right; font-size: 24px; font-weight: bold; color: #004a87; border: 1px solid #004a87; border-radius: 50%; width: 30px; height: 30px; display: flex; align-items: center; justify-content: center; margin: 0 auto 10px auto;">2</div> <ul style="list-style-type: none"> <li>Check the way you have already gone and how far you still need to go.</li> <li>Using the organizer and the watch, check your punctuality.</li> </ul> <div style="text-align: center; margin-top: 10px;"> <p style="font-size: small;">• Uhr</p>  </div> </div> </div>		
<b>Optimal solution:</b>	Determine the location on the map, check punctuality for appointment.	
<b>Task completed:</b>	Name that the appointment is punctually.	
<b>Measurement:</b>	Interval from looking at the map until punctuality information has been given.	

Table 28: Task and Measurement Descriptions of T 2-1-5






Setup: I	No.: T 2-1-6	Task Name: Acknowledgement via telephone
<div style="text-align: right; font-size: small;">Acknowledgement via telephone I/2-1-6</div> <div style="text-align: center; border: 2px solid blue; border-radius: 15px; padding: 10px; margin-bottom: 10px;"> <h2 style="margin: 0;">Appointment confirmation by phone</h2> </div> <p><b>Initial situation:</b> After you have been walking for 3 minutes, the telephone rings. Answer the call and say "Hello". The caller is the secretary's office of Dr. Schmidt.</p> <p><b>Task:</b> Accept the call and answer the questions asked by Dr. Schmidt's secretary.</p> <p><b>Steps:</b></p> <div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;">  </div> <div style="text-align: center;">  </div> <div style="border: 1px solid gray; border-radius: 10px; padding: 10px; width: 250px;"> <div style="text-align: right; background-color: #0070C0; color: white; border-radius: 50%; width: 20px; height: 20px; line-height: 20px; margin: 0 auto 10px auto;">1</div> <ul style="list-style-type: none"> <li>• Accept the call (by swiping).</li> <li>• Say your last name.</li> <li>• The caller is Dr. Schmidt's secretary's office.</li> </ul> </div> </div> <div style="display: flex; justify-content: space-around; align-items: flex-start; margin-top: 20px;"> <div style="text-align: center;">  </div> <div style="border: 1px solid gray; border-radius: 10px; padding: 10px; width: 250px;"> <div style="text-align: right; background-color: #0070C0; color: white; border-radius: 50%; width: 20px; height: 20px; line-height: 20px; margin: 0 auto 10px auto;">2</div> <ul style="list-style-type: none"> <li>• Dr. Schmidt's secretary would like to know whether you will be on time.</li> <li>• Confirm the question asked and terminate the call by clicking the "Terminate" icon.</li> </ul> </div> </div>		
<b>Optimal solution:</b>	The phone rings (shortly after 2-1-5) and the caller asks for punctuality.	
<b>Task completed:</b>	Punctual appointment is confirmed via phone call.	
<b>Measurement:</b>	Interval from first ring until the receiver has hung up.	

Table 29: Task and Measurement Descriptions of T 2-1-6

The following six tables (Table 30 to Table 35) describe the tasks with UCM support and the criteria for the optimal task completion of the probands with start and end points for the measurements. The tasks validate the sub-hypothesis H 2-2:

- 1) Task 2-2-1 based on Setup J, (Table 30):  
Select a suitable bus line with technical assistance of a smart device. The function “plan my day” is called and the displayed information help to determine the suitable bus line. The measured interval is defined from taking the smartphone until the right bus line is named.
- 2) Task 2-2-2 based on Setup J, (Table 31):  
Plan a trip with technical assistance of a smartphone. The prepared information help to solve the question about the trip length and departure time. The interval to measure is defined from taking the smartphone until naming the correct time for departure and the total duration of trip.
- 3) Task 2-2-3 based on Setup K, (Table 32):  
Riding the bus with multimodal information beaming and find out, when and where to get off the bus. The smartphone gives text and audio information when and where to leave the bus. The measured interval is defined taking the smartphone until the information is named when and where to leave the bus.
- 4) Task 2-2-4 based on Setup K, (Table 33):  
Get off the bus locate on the bus stop via NFC and the smartphone gives multimodal assistance by text, graphic, and audio information to turn right on the cross-way. The measured interval is defined from taking the smartphone until the information is given whether to go right or left.
- 5) Task 2-2-5 based on Setup L, (Table 34):  
Check timelines with the smartphone or smartwatch. The devices give audio and text information underway that the appointment will be reached on time. The measured interval is defined from taking the smartphone until the information is named that the location will be reached on time.
- 6) Task 2-2-6 based on Setup L, (Table 35):  
While on the way, the device connects to the friend’s smart device and confirms the punctual arrival. The acknowledgement has to be confirmed by pressing the button on the smartwatch or smartphone. The measured

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interval is defined from touching icon until information sending is completed.

Setup: J	No.: T 2-2-1	Task Name: Select a bus line, smartphone
<div style="text-align: right; font-size: small;">Select a bus line   Smartphone J/2-2-1</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 10px; display: inline-block; margin-bottom: 10px;"> <b>Selecting the right bus line using the smartphone</b>  </div> <p><b>Initial situation:</b> Today, you have arranged to meet a friend who lives in the same city. Plan to go there using public transport. There is a smartphone in front of you with information stored about your meeting with Wilfried Zahn.</p> <p><b>Task:</b> Start the "Plan my day" application. Using the smartphone, find the best bus to get directly from A to D.</p> <p><b>Steps:</b></p> <div style="border: 1px solid #ccc; padding: 10px; margin: 10px 0;"> <div style="display: flex; align-items: center;">  <div style="margin-left: 20px;"> <p><b>1</b></p> <ul style="list-style-type: none"> <li>• Start the "Plan my day" application.</li> <li>• Get a quick overview of the information on the screen, displayed by the application</li> </ul>  </div> </div> <div style="display: flex; align-items: center; margin-top: 10px;">  <div style="margin-left: 20px;"> <p><b>2</b></p> <ul style="list-style-type: none"> <li>• Find the best bus line to get directly from A to D.</li> </ul> </div> </div> </div>		
<b>Optimal solution:</b>	Call the function, check the displayed information and determine the suitable bus line.	
<b>Task completed:</b>	Name the suitable bus line, "579".	
<b>Measurement:</b>	Interval from taking the smartphone until the right bus line is named. (579)	

Table 30: Task and Measurement Descriptions of T 2-2-1


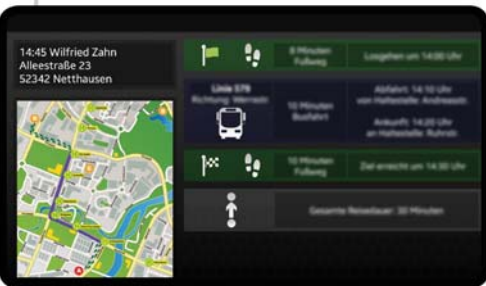
Setup: J	No.: T 2-2-2	Task Name: Plan a trip, smartphone
<div style="text-align: right; font-size: small;">Plan a trip  Smartphone J/2-2-2</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 10px; display: flex; justify-content: space-between; align-items: center;"> <span style="font-size: 1.2em; font-weight: bold;">Planning the bus trip using the smartphone</span>  </div> <p><b>Initial situation:</b> There is a smartphone in front of you, with the information about your meeting with Wilfried Zahn.</p> <p><b>Task:</b> Calculate the duration of the bus trip and the departure time of the bus.</p> <p><b>Steps:</b></p> <div style="border: 1px solid #ccc; padding: 10px; margin-bottom: 10px;"> <div style="display: flex; align-items: center;">  <div style="margin-left: 20px;"> <p style="font-size: 1.5em; font-weight: bold; border: 1px solid #0056b3; border-radius: 50%; width: 25px; height: 25px; display: flex; align-items: center; justify-content: center;">1</p> <ul style="list-style-type: none"> <li>Get a quick overview of the information displayed by the application.</li> </ul> </div> </div> </div> <div style="border: 1px solid #ccc; padding: 10px;"> <div style="display: flex; align-items: center;"> <p style="font-size: 1.5em; font-weight: bold; border: 1px solid #0056b3; border-radius: 50%; width: 25px; height: 25px; display: flex; align-items: center; justify-content: center;">2</p> <ul style="list-style-type: none"> <li>At what time do you have to leave home to go to the bus stop by foot?</li> <li>Calculate the complete duration of the bus trip to your meeting.</li> </ul> </div> </div>		
<b>Optimal solution:</b>	Use the smartphone and find the prepared information.	
<b>Task completed:</b>	Name the correct length of the trip and departure time “28 minutes, 02:02 p.m.”	
<b>Measurement:</b>	Interval from taking over the smartphone until the correct time for departure and total duration of trip is named (2:02 p.m., 28 minutes).	

Table 31: Task and Measurement Descriptions of T 2-2-2









Setup: K	No.: T 2-2-3	Task Name: Riding the bus, multimodal information
<div style="text-align: right; font-size: small; margin-bottom: 5px;">Riding the bus   Multimodal information K/2-2-3</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 10px; display: flex; justify-content: space-between; align-items: center;"> <div style="flex: 1;"> <h2 style="margin: 0;">Determining where you are during the bus trip using the smartphone</h2> <p><b>Initial situation:</b> You are on the bus and have passed some stops already.</p> <p><b>Task:</b> While on the bus, look at the smartphone and retrieve the current information of the bus ride up to this point by starting the "Travel companion" application.</p> <p><b>Steps:</b></p> <div style="display: flex; align-items: center; margin-top: 20px;"> <div style="border: 1px solid black; background-color: #333; color: white; padding: 10px; border-radius: 10px; display: flex; gap: 10px;"> <div style="text-align: center;">  Plane meinen Tag                 </div> <div style="text-align: center;">  Wegbegleiter                 </div> </div> <div style="margin-left: 20px;"> <p><b>1</b></p> <ul style="list-style-type: none"> <li>Start the "Travel companion" application.</li> <li>Get a quick overview of the information given by the application.</li> </ul> </div> </div> <div style="margin-top: 20px; text-align: center;">  <p><b>2</b></p> <ul style="list-style-type: none"> <li>In how many minutes do you have to leave the bus?</li> <li>At which bus stop do you have to get off?</li> </ul> </div> </div> </div>		
<b>Optimal solution:</b>	While on the bus, the smartphone gives text and audio information when and where to leave the bus.	
<b>Task completed:</b>	Name the time until leaving the bus, "4 minutes and 2 stations left, Ruhrstraße".	
<b>Measurement:</b>	Interval from taking the smartphone until the information is named when and where to leave the bus. (4 minutes, 2 stations left, Ruhrstraße)	

Table 32: Task and Measurement Descriptions of T 2-2-3

Setup: K	No.: T 2-2-4	Task Name: Navigate on a cross-way, multimodal assistance
<div style="text-align: right; font-size: small;">Navigate on a cross-way   Multimodal assistance K/2-2-4</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 15px; display: inline-block; margin-bottom: 10px;"> <h3 style="margin: 0;">Navigating at an intersection using smartwatch and smartphone</h3> </div>  <p><b>Initial situation:</b> You have left the bus. Use your smartphone for further orientation. You are also wearing a smartwatch.</p> <p><b>Task:</b> Hold the smartphone in front of the bus stop. You will be localized. The smartphone shows an up-to-date camera image of your surroundings. The system indicates the direction you have to go with an arrow. Decide whether you have to go to your left or right to get to your meeting on time.</p> <p><b>Steps:</b></p> <div style="display: flex; justify-content: space-between; align-items: flex-start;"> <div style="width: 45%;">   </div> <div style="width: 50%; border: 1px solid #ccc; padding: 10px;"> <div style="text-align: center; margin-bottom: 10px;">  <p>NFC-Symbol</p> </div> <div style="border: 1px solid #ccc; padding: 5px; margin-bottom: 10px; text-align: right; border-radius: 10px; font-weight: bold; font-size: 24px; color: white; width: 30px; margin: 0 auto;">1</div> <ul style="list-style-type: none"> <li>Using the smartphone, touch the NFC icon within the markings at the bus stop.</li> <li>You will be localized. Take the smartphone off the bus stop sign. An up-to-date camera image of your surroundings is displayed. An arrow indicates the direction you need to go.</li> </ul> <div style="border: 1px solid #ccc; padding: 5px; margin-bottom: 10px; text-align: right; border-radius: 10px; font-weight: bold; font-size: 24px; color: white; width: 30px; margin: 0 auto;">2</div> <ul style="list-style-type: none"> <li>Smartphone and smartwatch both indicate the direction you need to go. You will also get short voice information.</li> <li>Which direction is recommended?</li> </ul> </div> </div>		
<b>Optimal solution:</b>	Exit the bus. The smartphone gives text and audio information to turn right.	
<b>Task completed:</b>	Name the correct direction, "right".	
<b>Measurement:</b>	Interval from taking the smartphone until the information is given whether to go right or left. (right)	

Table 33: Task and Measurement Descriptions of T 2-2-4

Setup: L	No.: T 2-2-5	Task Name: Check timelines, smartphone & smartwatch
<div style="text-align: right; font-size: small; margin-bottom: 5px;">check timelines   smartphone and smartwatch L/2-2-5</div> <div style="background-color: #0056b3; color: white; padding: 10px; border-radius: 15px; display: inline-block; margin-bottom: 10px;"> <b>Checking your time schedule using the smartphone and the smartwatch</b>  </div> <p><b>Initial situation:</b> After a few minutes walking, check whether you will arrive at your meeting on "Alleestraße" on time.</p> <p><b>Task:</b> Using the smartwatch or smartphone, check whether you will reach your meeting on time.</p> <p><b>Steps:</b></p> <div style="display: flex; justify-content: space-between; align-items: flex-start;"> <div style="width: 45%;">    </div> <div style="width: 50%; border: 1px solid #ccc; padding: 10px;"> <div style="border-bottom: 1px solid #ccc; padding-bottom: 10px;"> <p style="text-align: right; font-weight: bold; font-size: 24px; border: 1px solid #0056b3; border-radius: 50%; width: 20px; height: 20px; display: flex; align-items: center; justify-content: center; margin: 0 auto;">1</p> <ul style="list-style-type: none"> <li>Press the watch icon to check whether you will reach your appointment on time.</li> </ul>  </div> <div style="padding-top: 10px;"> <p style="text-align: right; font-weight: bold; font-size: 24px; border: 1px solid #0056b3; border-radius: 50%; width: 20px; height: 20px; display: flex; align-items: center; justify-content: center; margin: 0 auto;">2</p> <ul style="list-style-type: none"> <li>A text and tone information is given, informing you that you will reach your appointment on time at 2.30 p.m.</li> </ul> </div> </div> </div>		
<b>Optimal solution:</b>	The device gives audio and text information underway that the appointment will be reached on time.	
<b>Task completed:</b>	Name that the appointment is punctual.	
<b>Measurement:</b>	Interval from taking the smartphone until the information is named that the location will be reached on time.	

**Table 34: Task and Measurement Descriptions of T 2-2-5**





Setup: L	No.: T 2-2-6	Task Name: Acknowledgement in the background, app
<div style="text-align: right; font-size: small; margin-bottom: 10px;">Acknowledgement in the background   App L/2-2-6</div> <div style="border: 1px solid #0056b3; padding: 10px; margin-bottom: 10px;"> <h3 style="margin: 0;">Automatic appointment confirmation via smartphone</h3>  </div> <p><b>Initial situation:</b> In a previous step, you checked your punctuality by pressing the watch icon. After the watch has confirmed your punctuality, you are asked whether you would like to confirm the meeting.</p> <p><b>Task:</b> Both screens display text information asking whether you would like to send Wilfried Zahn a message, letting him know that you will be on time.</p> <p><b>Steps:</b></p> <div style="display: flex; flex-direction: column; align-items: flex-start;"> <div style="margin-bottom: 20px;">  <div style="border: 1px solid #ccc; padding: 10px; margin-left: 20px; width: 300px;"> <div style="text-align: right; font-weight: bold; font-size: 24px; border-radius: 50%; width: 20px; height: 20px; line-height: 20px; margin-bottom: 5px;">1</div> <ul style="list-style-type: none"> <li>The smartphone and smartwatch display information. Both also vibrate and give a tone signal.</li> </ul> </div> </div> <div>  <div style="border: 1px solid #ccc; padding: 10px; margin-left: 20px; width: 300px;"> <div style="text-align: right; font-weight: bold; font-size: 24px; border-radius: 50%; width: 20px; height: 20px; line-height: 20px; margin-bottom: 5px;">2</div> <ul style="list-style-type: none"> <li>You are asked whether you would like to send Wilfried Zahn a message, letting him know that you will be on time.</li> <li>Confirm your timely meeting.</li> </ul> </div> </div> </div>		
<b>Optimal solution:</b>	While on the way, the device connects to the friend's smart device and confirms the punctual arrival.	
<b>Task completed:</b>	Punctual appointment is confirmed via smart device.	
<b>Measurement:</b>	Interval from touching icon until information sending is completed.	

Table 35: Task and Measurement Descriptions of T 2-2-6

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## 6.3 EXPERIMENTS

This section describes the evaluation method of the UCM with experiments and an additional questionnaire. The probands execute tasks in the context of the scenarios “Media Rich Communication” (cf. Section 6.2.1) and “Mobility” (cf. Section 6.2.2) without and with UCM-supported ICT devices and applications. The measured values are the basis for the statistical analysis in Chapter 7 to validate the UCM.

The probands are recruited on the criteria of the case study in Section 5.3.2 to ensure that user behavior and needs will fit to the research aims of the UCM use cases “Daughter and Father” (cf. Section 6.1.1) and “Grandma” (cf. Section 6.1.2). A qualitative questionnaire elaborates the research setting with the personal attitudes of the probands and is applied to support the drawn conclusions.

An overview of the research setting is given in Section 6.2 with a detailed description of the proband tasks of Scenario 1 “Media Rich Communication” (cf. Section 6.2.1.4) and Scenario 2 “Mobility” (cf. Section 6.2.2.4).

### 6.3.1 Selected Probands for the Experiment

The selection of the recruited probands is based on the ICT case study described in Section 5.3.3: The in scope Sinus Milieus clusters are B2 (partially), B3, C2, and C3 (cf. Figure 41, green frame). They represent the social middle-upper and upper class with a modern and innovative orientation in their life.

The use of ICT services is on a medium to advanced level and will be adopted from earlier work and private life experience into the retirement phase of the life course (cf. Section 5.3.2). Elderlies in 2030 will have to cope with the same physical and mental changes as nowadays elderlies (cf. Section 2.4) and similar challenges for the usage of ICT can be assumed (Section 5.1.1). The probands are recruited according to the attributes of the selected Sinus Milieus clusters (Figure 41, green frame).

sinus:

## Sinus-Milieus® in Germany

## Social Status and Basic Orientation

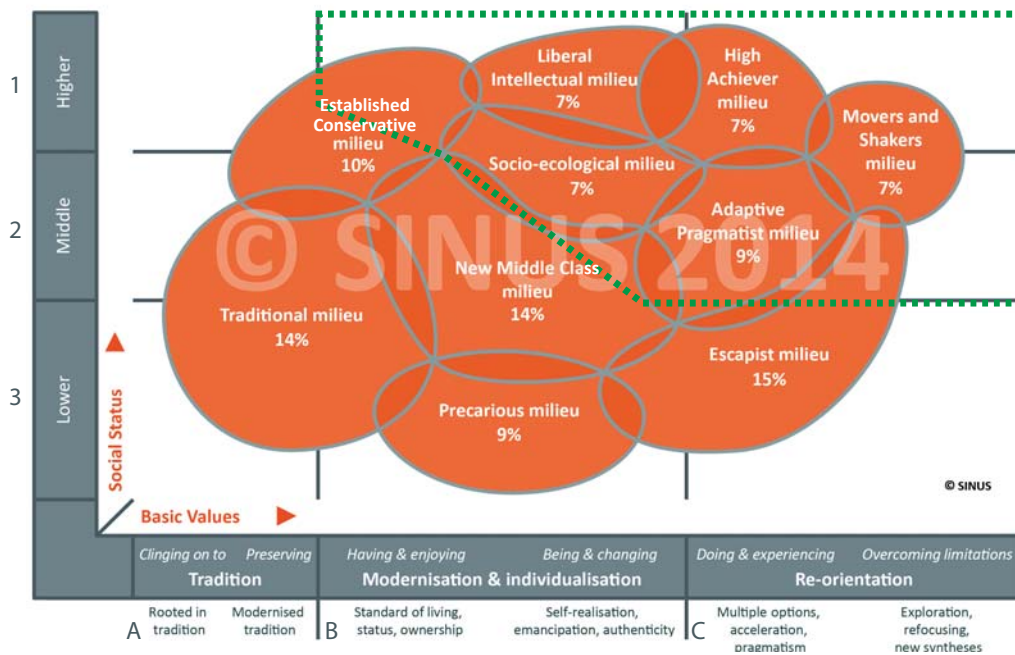


Figure 41: Selected Sinus Milieus Clusters for the Proband Experiment

Source: Sinus Markt- and Social Research (2014),  
Sinus Markt- und Sozialforschung, Heidelberg (2014)

A socio-demographic questionnaire validates the social affiliation and technical experience of the probands with several aspects like

- Gender
- Age
- Profession
- Usage of mobile communication devices
- Internet usage (frequency, duration, kind of services)
- Attitude to technical assistance services (today and future)

The selected 30 probands (both genders) are aged from 58 to 75 years, whereas 76.67% are pensioners and 23.33% are still on the job. The diversity of job distributions covers the middle and higher layer of the social status of the Sinus Milieus, e.g., housewives, office workers, teachers, self-employed persons,

managers, directors, doctors, and researchers (for further details see Appendix E-3).

The fraction (96.67%) has experience with ICT usage which is known by the last decade of the job or ICT is used as a leisure activity in retirement. The frequent use of the devices (some probands with several hours a day) shows the interest on using ICT. Tablet computers are used by 40% of the probands and smartphones with a share of 46.70%. Mobile phones are used by 96.70% and Computers are used of 90% of the probands.

The ICT usage of the probands can be clustered based on different attributes:

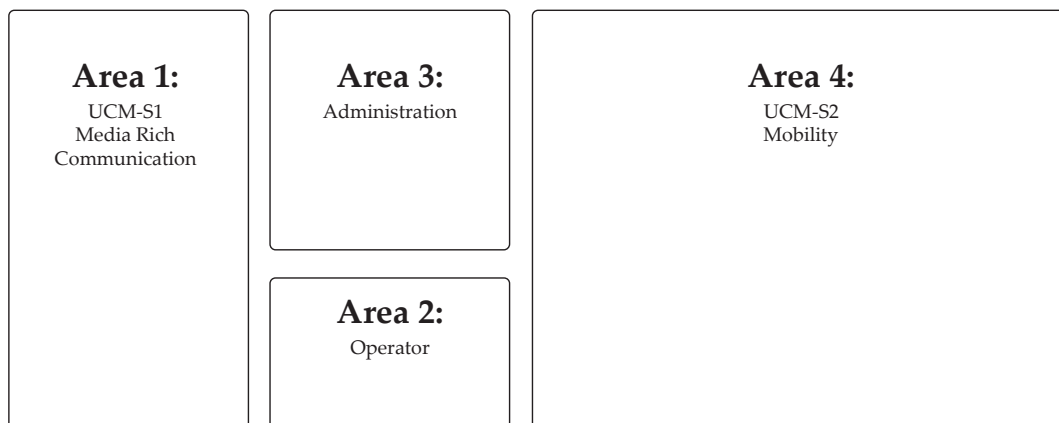
- Using Internet services several times a week, reading news on information platforms, or send an e-mail instead of sending a letter. The use of ICT is pragmatic and has to provide specific benefits (Figure 41, Coordinate B1, Established Conservative Milieu and Liberal Intellectual Milieu).
- Information platforms, as news portals or holiday checks are used in the same natural way as e-commerce, video conferencing or e-books. ICT is used stationary, or mobile for online communication, entertainment, and education on a high level (Figure 41, Coordinate C1, High Achiever Milieu and top segmentation of the Movers and Shakers Milieu).
- Planning trips with digital maps, view photos on a tablet computer, communicate via e-mail or chat, but e-commerce is mistrusted. The use of ICT is ambivalent (Figure 41, Coordinate B2, Socio-ecological Milieu).
- ICT is used several times a day on a diversity of devices, e.g. Smartphone, Tablet or PC. Playing games or consuming multimedia content and performing video conferences illustrates the hedonistic attitude of the users. Online shopping is accepted but the English language is a hurdle for some users (Figure 41, Coordinate C2, Adaptive Pragmatist Milieu and bottom segmentation of Movers and Shakers Milieu).

The highest usage on Internet services is on communication with 90.00% with e-mails and chats. News portals are used by 66.67% and research services by 80%

of the probands. Shopping and e-commerce are used with an amount of 46.67% (for further details see Appendix E-3.).

### 6.3.2 Experimental Laboratory Setup

The proband experiments are realized in a laboratory that is divided into four rooms (Figure 42): Area 1 (left side) is for the “Media Rich Communication” experiment with the application setup of UCM-S1. The evaluation of H2H communication requires an operator performing telephone or video calls (cf. Section 6.2.1.4) who is sited in Area 2 (middle bottom). The constructor performs several tasks with each proband and completes each of the two experiments with a qualitative questionnaire. The questionnaire is completed in Area 3 (middle top), as well as the introduction and administration of the probands. Area 4 (right side) is prepared for the experiment “Mobility” with the application setup for UCM-S2 (for further details see Appendices C-1 and C-2).



**Figure 42: Laboratory Area Setting of UCM Experiments**

The proband experiment starts in Area 3 with an introduction to the research topic and aims. A relaxed atmosphere is created with a personal welcome service (drinks and snacks are offered) and the administrative process is archived (Figure 43). The questionnaire about ICT usage and previous knowledge of the use of internet services and smart devices is performed in order to validate the categorization of the probands to the Sinus Milieus clusters.

Additional explanations “how to use tablets and smartphones” depending on the experience of the probands is provided by a special prepared learning app. As an example, easy sliding gesture, pressing button, speech recognition, and synthesis (for further details see Appendix D-3).



**Figure 43: Administration and Registration Area 3**

The experiments for Scenario 1 “Media Rich Communication” start with Tasks 1-1-1 to 1-1-6 and are continued with Tasks 1-2-1 to 1-2-6. The experiments of Scenario 1 “Media Rich Communication” finish with filling in the qualitative questionnaire (see Appendix E-4 for an overview of all questions). This evaluation elaborates the usability and experience during the task execution to finalize the drawn conclusions with the personal attitudes of the probands. The questions are based on the five attributes of usability engineering by Nielsen (cf. Section 5.1.3), i.e., learnability, efficiency, memorability, errors, satisfaction.

Table 36 shows as an example the questions of Scenario 1 “Media Rich Communication” without UCM support. These questions are also applied to the tasks of Scenario 1 with UCM support. The results are compared to each other for the described evaluation. The sequence of the experiment tasks of this scenario is applied to Scenario 2 “Mobility” (see Appendices E-4 and E-5 for an overview of all questions for both scenarios).

Task	Question	Attributes
1-1-1	Was it easy and comfortable to take the call?	Errors
1-1-2	Was the task fun for you?	Satisfaction
1-1-3	Was it easy to find the telephone app and start it?	Efficiency
1-1-4	Was it easy to make the call and convey the information?	Efficiency
1-1-5	How strenuous was it to start the "write message" dialogue-mask?	Learnability
1-1-6	Could you solve the task in an intuitive way?	Memorability

**Table 36: Example of Qualitative Questionnaire Scenario 1 for Tasks 1-1-1 to 1-1-6**

A detailed description of the experiment process is depicted in Sections 6.3.3 and 6.3.4.

Both experiments are recorded by external video cameras mounted in Area 1 and Area 4 to analyze the task executions afterwards. On the Media Rich Client<sup>9</sup> and the phablet<sup>10</sup> a screen capture software is running with audio and video capture functionality. The task procedure is attended by the constructor who measures the task execution time with a stopwatch. A final analyze is performed afterwards supported by a software for video transcription<sup>11</sup>. This software produces a text file with timestamps, that can be imported in the software for the statistical evaluation of the tasks.

In preparation of each proband task execution a checklist is applied of the constructor and the operator to reset and test all technical devices. This guarantees a consistent research setup for every run with each scenario and proband. A detailed checklist for Scenario 1 "Media Rich Communication" and Scenario 2 "Mobility" is depicted in Appendices B-1 and B-2. The individual setup of both scenarios is described in the following two Sections 6.3.3 and 6.3.4.

<sup>9</sup> Camtasia Studio, Version 7.0.1, <http://www.techsmith.de/camtasia.html>

<sup>10</sup> EASY screen recorder, Version 1.5, <http://www.recordable.mobi>

<sup>11</sup> F4, Version 2012, <http://www.audiotranskription.de/f4.htm>

### 6.3.3 Setup Scenario 1: Media Rich Communication

The Scenario 1 setup is built on the communication needs described in the scenario “Daughter and Father” (Section 6.1.1). The tasks represent nowadays use of ICT solutions and is transformed to examples for future use. In this experiment 30 probands execute the tasks described in Section 6.2.1.4 without and with UCM support. The probands are introduced in the test setting and the use of the devices. A first preview of one task is performed with the probands to validate the correct usage of the given experiment setting. A test of the functionalities of the technical infrastructure is passed by the operator and instructor before each test cycle (see Appendix B-1 for the technical checklist and preparation guide of this scenario). Figure 44 shows a photo of the experimental setup of Scenario 1 “Media Rich Communication”: The 27 inch screen with two video areas and a huge area for the video stream of the communication partner. The items “7” and “heart” are symbols printed on a sheet of paper (No. 1, Figure 44). They are used for the Tasks 1-1-6 and 1-2-6 to type the alphabetic character into the device or for STT recognition. The tasks are described on DIN A3 sheets of paper (No. 2, Figure 44) and the photos of persons (No. 3, Figure 44) are used for task 1-2-3. This setup is prepared for each proband in the same alignment.



Figure 44: Description of Scenario 1 “Media Rich Communication”



Figure 45 shows a proband performing Task 1-1-1 with UCM-S1.



**Figure 45: Proband Performs Task with UCM-S1**

Figure 46 gives an overview of the experiment sequence for Setup A with Tasks 1-1-1 and 1-1-2 (see Appendix C-2 for a detailed overview of all setups).

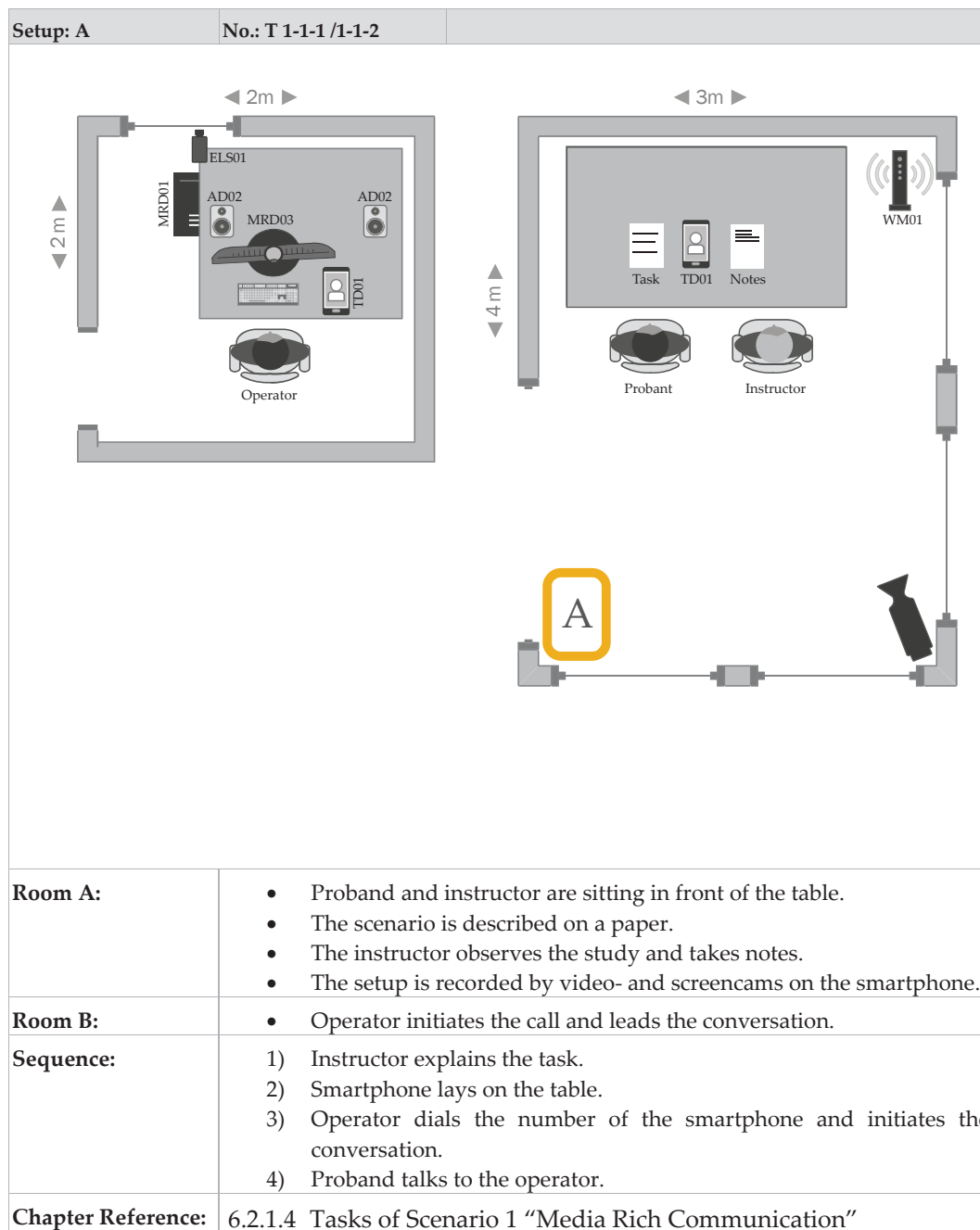


Figure 46: Task Setup Example of T 1-1-1 and T 1-1-2

### 6.3.4 Setup Scenario 2: Mobility

The Scenario 2 setup is built on the mobility needs described in the scenario “Grandma” (Section 6.1.2). The tasks of Hypothesis 2-1 (Tasks 2-1-1 to 2-1-6, Section 6.2.2.4) represent today’s mobility needs. They have to be performed without ICT support (except Task 2-1-6). These tasks are transformed to future ICT supported examples for mobility assistance. In this experiment the 30 probands execute the tasks described in Section 6.2.2.4 with and without UCM support. The probands are introduced in the test setting and the use of the devices (phablet and smartwatch). A test of the functionalities of the technical infrastructure is passed by the operator and instructor before each proband test cycle (see Appendix B-2 for the technical checklist and preparation guide of this scenario). Figure 47 shows a photo of the setup of Scenario 2 “Mobility”. On the left side of the picture the Tasks 2-1-1 to 2-1-6 are mounted on the ceiling with DIN A1 posters. On the right side the tasks with UCM support (Tasks 2-2-1 to 2-2-6) are shown.



Figure 47: Description of Scenario 2 “Mobility”

Figure 48 shows a proband using UCM-S2 with AR mobility assistance to decide to go left or right on a crossway.



Figure 48: A Proband Executes Task 2-2-4 with UCM-S2

Figure 49 shows a proband localize with NFC technology on a bus stop and checks if he is in time for the appointment.



Figure 49: A Proband Performs UCM-S2 to Localize a Bus Stop

Figure 50 gives an overview of the experiment sequence for Setup G with the Tasks 2-1-1 and 2-1-2 (see Appendix C-2 for a detailed overview of all setups).

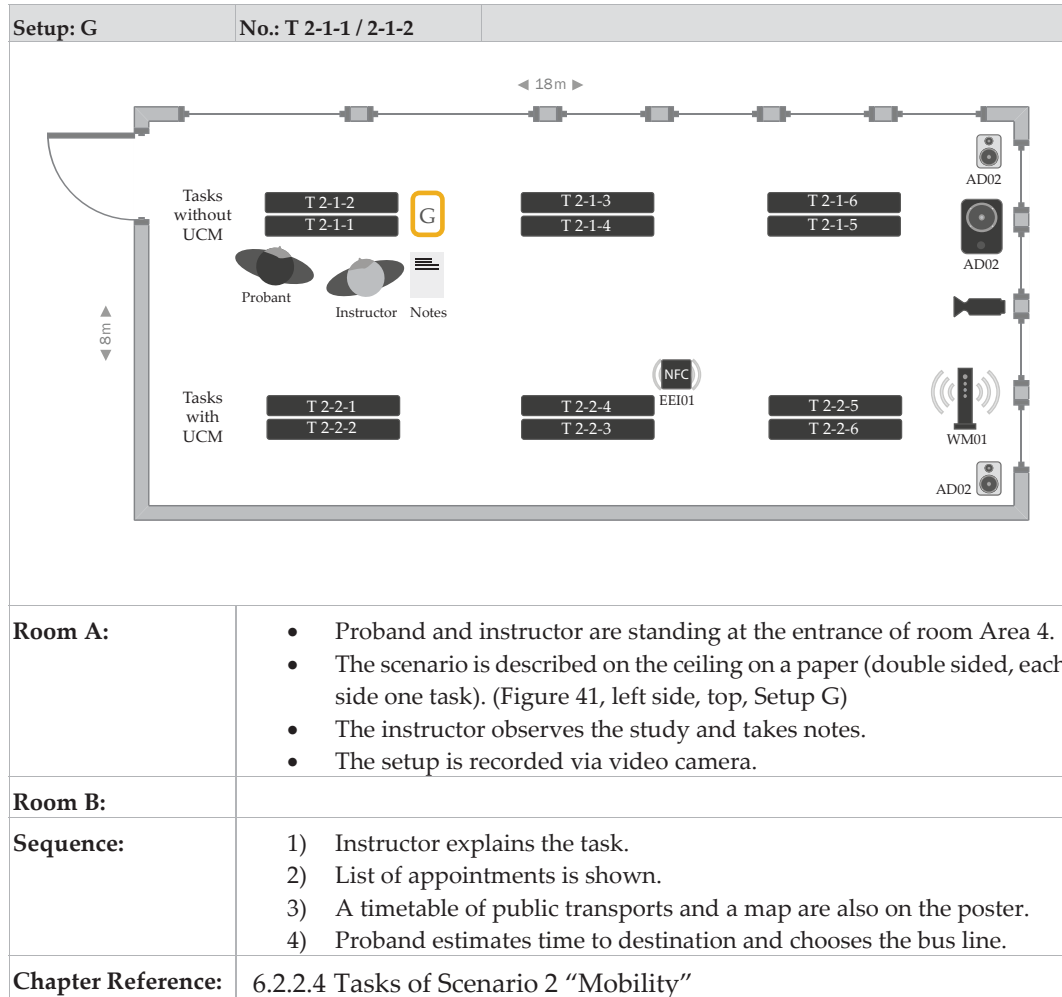


Figure 50: Task Setup Example of T 2-1-1 and T 2-1-2

The statistical evaluation of the measurements with the applied prototypes of the UCM scenarios “Media Rich Communication” and “Mobility” is presented in Chapter 7.



## 7 STATISTICAL MODEL, MEASUREMENTS AND EVALUATION

In this chapter the theoretical framework for the measurement data representation is presented. The measurements are prepared for further processing and converted into frequency and probability distributions (cf. Section 7.1). Then, in Section 7.2 statistical evaluation methods for curve fitting are investigated, namely resampling and parametric tests. Finally, the developed evaluation method is applied to both scenarios “Media Rich Communication” and “Mobility” (Section 7.3).

### 7.1 MATHEMATICAL MEASUREMENT AND DATA PREPARATION

Notation	Meaning
$l$	number of tasks (24 in total)
$n$	number of probands (30)
$T_i$	task i
$M(T_i)$	time measurement to solve task $T_i$ for all probands
$F(M_i)$	frequency distribution of $M_i$
$P(X_i)$	probability distribution of $F_i$

**Table 37: Notation and Meaning for the Mathematical Representation of the Measurements and Data Preparation for the Statistical Evaluation**

In order to apply the measurements  $M_j$  to statistical evaluations, a conversion to probabilities is required. Therefore, in a first step the measurement  $M(T_j)$  is aggregated to a frequency distribution  $F(M_j)$  (for all  $j = 1, \dots, l$ ):

$$M(T_j) = (t_1, \dots, t_n) \rightarrow F(M_j) = (ts_1, \dots, ts_{(n,j)}), \quad (1)$$

where  $ts_i = \sum_{k=1, t_k=i}^n 1$  is the summed up number of probands that needed  $i$  seconds to solve task  $T_j$ , and  $(n, j)$  is the length of  $F(M_j)$ , i.e., the number of parameters of  $F(M_j)$ . Hence, the vector  $F(M_j)$  is expected to be shorter than the vector  $M(T_j)$ , and only if each proband needs another time to solve the task, then

both vectors have the same length, i.e., the measurement and the frequency distributions are the same.

Then, in a second step each frequency distribution  $F(M_j)$  is converted to a probability distribution  $P_j(X)$ , where  $X$  is a random variable (probabilistic representation of the frequency distribution  $F(M_j)$ ):

$$M(T_j) = (tc_1, \dots, tc_{n,j}) \rightarrow P(X_j) \text{ with } X = \left(\frac{tc_1}{n}, \dots, \frac{tc_{n,j}}{n}\right), \quad (2)$$

where  $P(X_j)$  is the probability distribution of the measurement  $M_j$ , with  $p(x_i) = \frac{tc_i}{n}$ , for  $i = 1, \dots, (n, j)$ , represents the probability that a proband needs  $i$  seconds to solve the task. The factor  $\frac{1}{n}$  in Formula (2) normalizes the measured data  $T_j$  to  $\sum_{i=1}^n p(x_i) = 1$ . Hence,  $0 \leq p(x_i) \leq 1$  holds for all  $i$ .

Example: Assume  $T_1$  is "Take a phone call by sliding a green button from the left side to the right side on the display of your smartphone" and the measurements for  $n = 30$  probands are

$$M(T_1) = (2, 4, 6, 7, 3, 5, 5, 6, 6, 8, 3, 4, 6, 10, 11, 11, 7, 7, 8, 5, 5, 7, 3, 6, 6, 6, 6, 8, 12, 10).$$

Then, the frequency distribution of  $M(T_1)$  is  $F(M_1) = (0, 1, 3, 2, 4, 8, 4, 3, 0, 2, 2, 1)$  and the probability distribution of  $F(M_1)$  is

$$P(X_1) = \left(0, \frac{1}{30}, \frac{1}{10}, \frac{1}{15}, \frac{2}{15}, \frac{4}{15}, \frac{2}{15}, \frac{1}{10}, 0, \frac{1}{15}, \frac{1}{15}, \frac{1}{30}\right) \text{ with } \sum_{i=1}^{12} p(x_i) = 1.$$

Figure 51 shows the measurement  $M(T_1)$  (green), and Figure 52 shows the frequency distribution  $F(M_1)$  (yellow) and the probability distribution  $P(X_1)$  (blue) of the measurements of Task  $T_1$ .

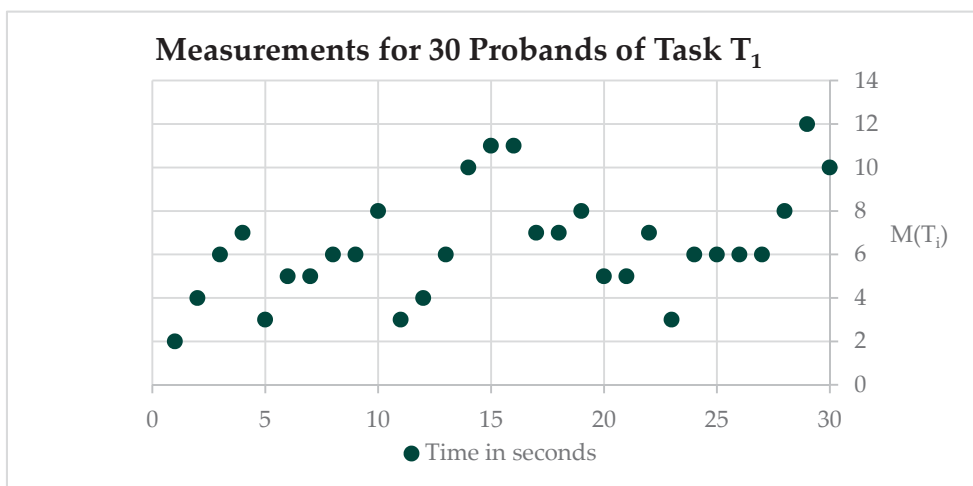


Figure 51: Measurement  $M(T_1)$  of Task  $T_1$



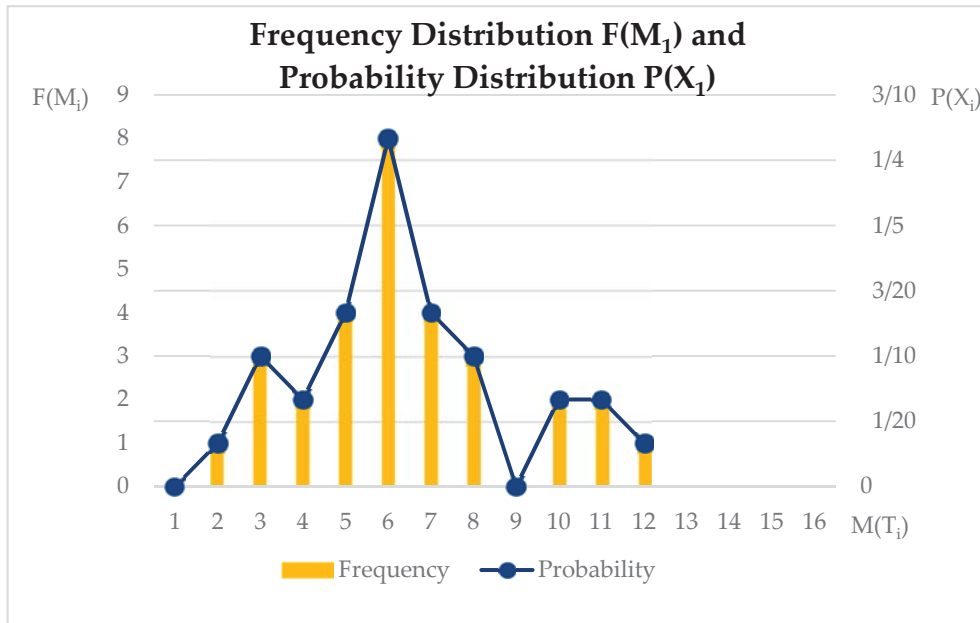


Figure 52: Frequency Distribution  $F(M_1)$ (yellow) and Probability Distribution  $P(X_1)$  (blue), both based on the Measurement  $M_1$

The following section contains a discussion of evaluation methods in order to compare two probability distributions with each other.

## 7.2 EVALUATION METHODS

Two methods are possible for the statistical evaluation (Hayes, 1969; Yu, 2003):

- 1) Resampling, and
- 2) Parametric tests.

Both methods are described in the following including a discussion of how to apply them to the UCM evaluation.

### 7.2.1 Resampling

Resampling can be done in general by applying four different methods, which are described and discussed in the following (Yu, 2003):

**Randomization test:** The sample is modified into a random order, i.e., a permutation of the original sample is done. However, the sample remains the same, and thus, the resulting distribution is the same as the origin distribution.

**Cross-validation (CV):** The idea of CV is to partition the measurement into a sample set and a test set. Both sets are chosen randomly, and in order to reduce variability, multiple rounds of cross-validation are performed, and finally, their average is computed. The application to the evaluation of the UCM tasks is not recommended, since the sample is with  $n = 30$  too small for CV: Using a partitioning of  $\frac{2}{3}$  for the sample set and  $\frac{1}{3}$  for the test set results in 20 measurements for the sample set and 10 measurements for the test set. Thus, the distribution of the test set is expected to have a small number of data points, since measurements with the same time duration are summed up for the representation as a distribution.

**Bootstrap:** Is used to construct resamples from the measurements by random sampling with replacement. For small samples this may lead to constructed samples whose distributions may differ from the measured distribution. In the worst case the same data point occurs  $n = 30$  times. This artefact limits the application of bootstrapping only to large samples much bigger than  $n = 30$ .

**Jackknife:** The sample is modified by leaving  $d$  measurements out (deletion) and calculating the mean and the variance. This is done several times and the average of the calculated means and variances is taken for the estimation of distribution. Let  $d = 1$ , then the mean of the reduced Jackknife sample  $i$  by deleting the value  $x_i$  is ( $k$  is the size of the distribution)

$$\mu_i = \frac{1}{k-1} \cdot \sum_{j \neq i} x_j \quad (3)$$

Then, the average mean  $\mu_*$  of the  $k$  Jackknife samples is

$$\mu_* = \frac{1}{k} \cdot \sum_{j=1}^k \mu_j \quad (4)$$

and the Jackknife variance  $\sigma^2$  of the Jackknife samples can be estimated by

$$\sigma^2 = \frac{k-1}{k} \cdot \sum_{i=1}^k (\mu_i - \mu_*)^2 \quad (5)$$

since each data point occurs  $k - 1$  times in the  $k$  Jackknife samples. Formula (4) is exactly the arithmetic mean. The following example illustrates this consideration: Assume a measurement with three probands leads to the data points  $x_1$ ,  $x_2$ , and  $x_3$  and to the three Jackknife samples  $(\{x_1, x_2\})$ ,  $(\{x_1, x_3\})$ , and  $(\{x_2, x_3\})$ , with the deletion  $d = 1$ . Then, the average mean is  $\mu_* = \frac{1}{3} \cdot \frac{1}{3} \cdot (2 \cdot x_1 + 2 \cdot x_2 + 2 \cdot x_3)$ , which is exactly the arithmetic mean. Formula (5), the Jackknife variance based on differences of mean values, is similar to the variance of the sample mean and differs by the factor  $k - 1$ , which reflects the dependency of the  $\mu_i$ 's. They are dependent on each other due to the resampling from one sole sample. Jackknife is recommended for large samples in order to reduce the sample size by applying a big deletion  $d$ .

In the following the focus is on the application of parametric tests.

### 7.2.2 Parametric Tests

Evaluation based on parametric tests takes the sample distribution and compares it with a theoretical sampling distribution:

- The unique distribution  $U(X)$  in the case of an unknown bias, since each data (representing an event; here: time to solve a task) has the same probability:

$$U(X) = \left(\frac{1}{n}, \dots, \frac{1}{n}\right) \quad (6)$$

- Or, with the Gaussian distribution  $G(X)$ , assuming that the data are Gaussian distributed, i.e. it will be assumed that the capabilities of the probands to solve the tasks are Gaussian distributed. However, the mean  $\mu = \frac{1}{n} \sum X_i$  and the variance  $\sigma^2 = \frac{1}{n} \sum (X_i - \mu)^2$  of  $X$  need to be calculated, in order to apply the Gaussian distribution:

$$G(X) = \left(\frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x_1-\mu)^2}{2\sigma^2}}, \dots, \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x_n-\mu)^2}{2\sigma^2}}\right) \quad (7)$$

To complete the comparison, the distance based on a metric or divergence between the sample and the theoretical sampling distribution needs to be

calculated. This leads to the average distance, respectively average divergence of the sample distribution to the theoretical sampling distribution.

### 7.2.2.1 Metrics

Metrics are based on the norm of a real-valued vector space  $V$ . A *norm*  $\|\cdot\|$  is defined by a mapping (Forster, 1977)

$$\|\cdot\|: V \rightarrow \mathbb{R} \text{ with } x \in V \rightarrow \|x\| \quad (8)$$

and with the following three properties:

1.  $\|x\| = 0 \Leftrightarrow x = 0$
2.  $\|\alpha \cdot x\| = |\alpha| \cdot \|x\|$  with  $\alpha \in \mathbb{R}$
3.  $\|x + y\| \leq \|x\| + \|y\|$  with  $y \in V$

If the vector space  $V$  is normalized, i.e. the sum of all vector lengths of the vector space  $V$  equals 1, then the pair  $(V, \|\cdot\|)$  is called *normalized vector space* and is applied to construct a *metric*  $d$ :

$$d(x, y) = \|x - y\| \text{ with } x, y \in V \quad (9)$$

Metrics have the property that they are symmetric. If metrics are applied to functions, then they are called *distance functions*. An example for a distance function is the *Euclidean distance*  $E(x, y) = \|x, y\|$ , which is in one dimension the absolute value of the difference of  $x$  and  $y$  for all  $x, y \in V$ . Then, the Euclidean distance for two discrete probability distributions  $P(X)$  and  $Q(Y)$  is  $E(P(X), Q(Y)) = \sum_{x \in X, y \in Y} E(x, y)$ . Unfortunately, the Euclidean distance is sensitive to outliers and is thus only a measure with limited expressiveness for the distance of two distributions. A survey of distance functions can be found in (Devroye, Györfi and Lugosi, 1996).

### 7.2.2.2 Divergence

Divergences do not fulfill all properties of a norm, but they provide valuable information about distributions. For example, the *entropy*  $H(X)$ , with  $X$  is a random variable, measures the uncertainty of a distribution (Cover and Thomas, 1991):

$$H(X) = \sum_{x \in X} p(x) \cdot \log \frac{1}{p(x)} \quad (10)$$

The entropy has the following two properties:

1.  $H(X) \geq 0$
2.  $H(X) \leq \log n$  for the unique distribution with length  $n$

As an application of entropy to a divergence, consider the Kullback-Leibler divergence (KLD) which is defined by

$$D(P||Q) = \sum_{x \in X} p(x) \cdot \log_2 \frac{p(x)}{q(x)} \tag{11}$$

whereas  $P$  is the sample (measurement) and  $Q$  the theoretical sample distribution, and  $p(x)/q(x) > 0$  (if  $p(x)/q(x)$  is undefined, then the divergence is 0) (Cover and Thomas, 1991).

The interpretation of entropy here is, that a bigger entropy means more uncertainty for a distribution, i.e., a bigger deviation of both distributions. The KLD violates property 3 (cf. Formula 8) of a norm – the triangle inequality, and thus, it is not a metric. Summarizing, this entropy-based measure is an expressive measure to investigate the divergence between two distributions.

In the following the average distance and average divergence of two distributions are considered.

### 7.2.2.3 Average Distance and Average Divergence

The *average distance*  $A(E(\cdot, \cdot))$ , respectively *average divergence*  $A(D(\cdot || \cdot))$  (or *average KLD*), of two distributions is a relative number due to the normalization and the average calculation:

$$A(E(\cdot, \cdot)) = \frac{E(\cdot, \cdot)}{(n, j)} \text{ and } A(D(\cdot || \cdot)) = \frac{D(\cdot || \cdot)}{(n, j)} \tag{12}$$

These average values are always less than or equal to 1. The reason is as follows due to the data normalization: Figure 53 shows the degenerated distributions  $P(X) = (0,0,0,0,0,0,0,0,0,0,1)$  and  $Q(X) = (1,0,0,0,0,0,0,0,0,0,0)$  with an Euclidean distance  $E(P,Q) = 2$  and a KLD  $D(P||Q) = 0$ . Thus, the average distance is  $A(E(P,Q)) = 2/2 = 1$  and the average divergence is  $A(D(P||Q)) = 0$ , since most points are similar, except the two outliers which provide with their probability of 1 a maximum uncertainty related to the distribution. But the average divergence has a minimum uncertainty (with 0), since nearly all data points (10 of 12) have the same probability for both distributions. Hence, the average numbers compare the quality of the measurement points.

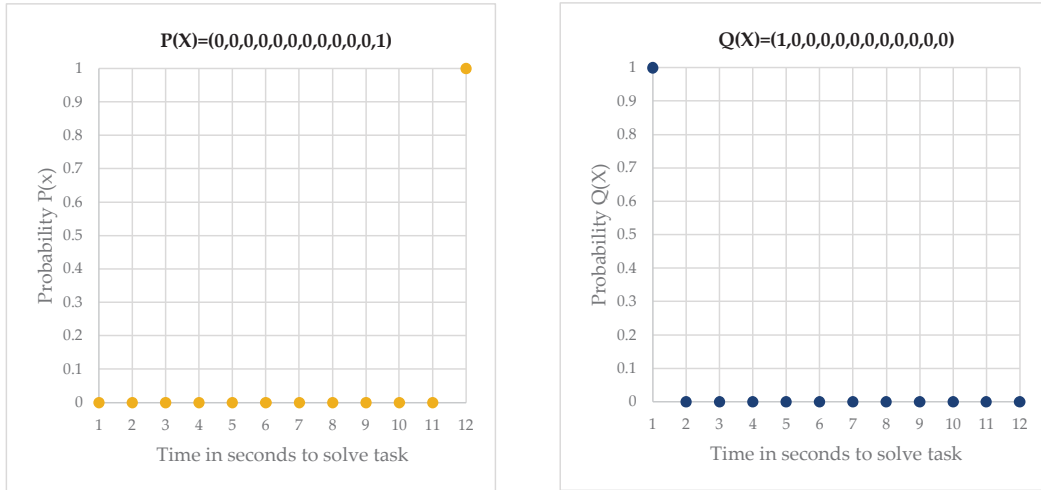


Figure 53: Degenerated Probability Distributions  $P(X)$  left-side in yellow and  $Q(X)$  right-side in blue

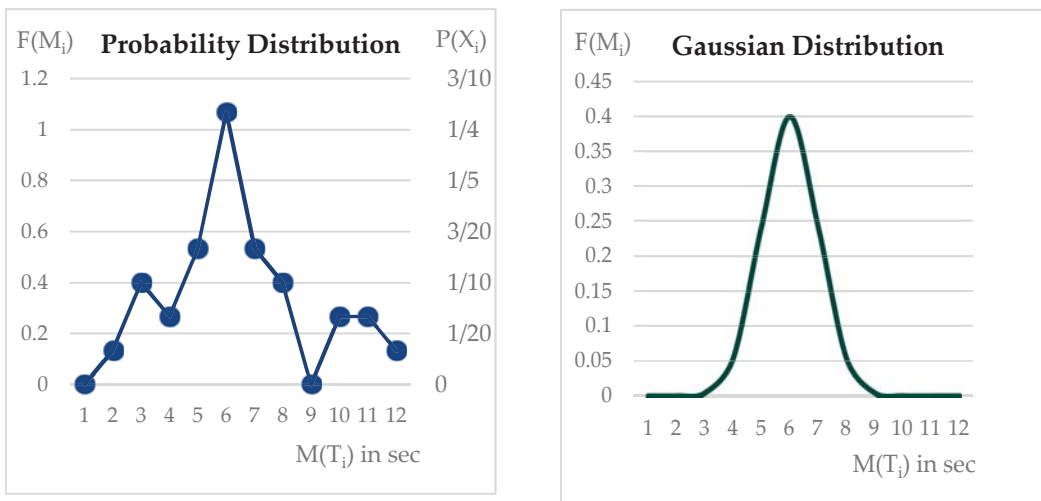


Figure 54: Probability and Gaussian Distributions of the Measurement  $M(T_1)$

To illustrate these averages consider the probability distribution  $P(X_1)$  of the example in Section 7.1:  $P(X_1) = (0, \frac{1}{30}, \frac{1}{10}, \frac{1}{15}, \frac{2}{15}, \frac{4}{15}, \frac{2}{15}, \frac{1}{10}, 0, \frac{1}{15}, \frac{1}{15}, \frac{1}{30})$ . For  $P(X_1)$  is the arithmetic mean  $\mu = \sum_{i=1}^{12} x_i \cdot p(x_i) = 6.43$  and the variance  $\sigma^2 = \sum_{i=1}^{12} p(x_i) \cdot (x_i - \mu)^2 = 10.49$ . It will be assumed, that the measurement is Gaussian distributed with the forehand mean and variance:  $Q(X) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(X-\mu)^2}{2\sigma^2}} = \frac{1}{\sqrt{10.49}\sqrt{2\pi}} \cdot e^{-\frac{(X-6.43)^2}{2 \cdot 10.49}}$ . Then, the Euclidean distance is  $E(P, Q) = 0.41$  and the KLD  $D(P||Q) = 0.39$ . Thus, the average distance is  $A(E(P, Q)) = 0.03$  and the average divergence is

$A(D(P||Q)) = 0.03$ . Both values are very similar indicating that the Euclidean distance of each measurement point of both distributions is small and also the uncertainty is small, indicating that both distributions are similar. This result is depicted in Figure 54 by the probability, and Gaussian distributions of the measurement  $M_1$ .

### 7.3 MEASUREMENTS, EVALUATION AND DISCUSSION

In this section measurements of the experiments “Media Rich Communication” and “Mobility” are provided. These measurements are represented as frequency and probability distributions as described in the former section. Subsequently, the probability distributions are fitted to Gaussian distributions with  $\mu$  and  $\sigma$  calculated from the measurements as described in the former section. Finally, the fitting is evaluated using the KLD between the probability and the Gaussian distribution. This section concludes with a discussion of the results.

In the following four evaluations are presented (cf. Figure 28, p.127, bottom, and Figure 29, p.128, bottom): The scenarios “Media Rich Communication without UCM” and “Media Rich Communication based on UCM”, then, the scenario “Mobility without UCM”, and finally, “Mobility based on UCM”.

#### 7.3.1 Scenario 1-1: Media Rich Communication without UCM

Figure 55 shows the measurements of the six tasks belonging to the scenario “Media Rich Communication without UCM”. The measurements can be summarized as follows:

- Task 1-1-1 shows measurements between 3 and 9 seconds, with one outlier (proband 2) with 19 seconds.
- Task 1-1-2 shows measurements between 18 and 42 seconds, where only probands 8, 9 and 22 needed more than 35 seconds to solve the task.
- Task 1-1-3 shows mainly measurements between 15 and 35 seconds, and only proband 13 needed 12 seconds, and proband 2 needed 40 seconds and proband 1 even 36 seconds.
- Task 1-1-4 contains measurements between 16 and 42 seconds.

- 
- Task 1-1-5 shows a greater scatter of the measurements compared to task 4 between 5 and 24 seconds.
  - Task 1-1-6 shows an inhomogeneous measurement between 48 and 150 seconds, where 4 probands, namely proband 1, 2, 3, and 9 needed between 155 and 210 seconds.



Each measurement was done for  $k = 30$  probands, where the task execution was measured in seconds. The maximum values are shown on the vertical axis.

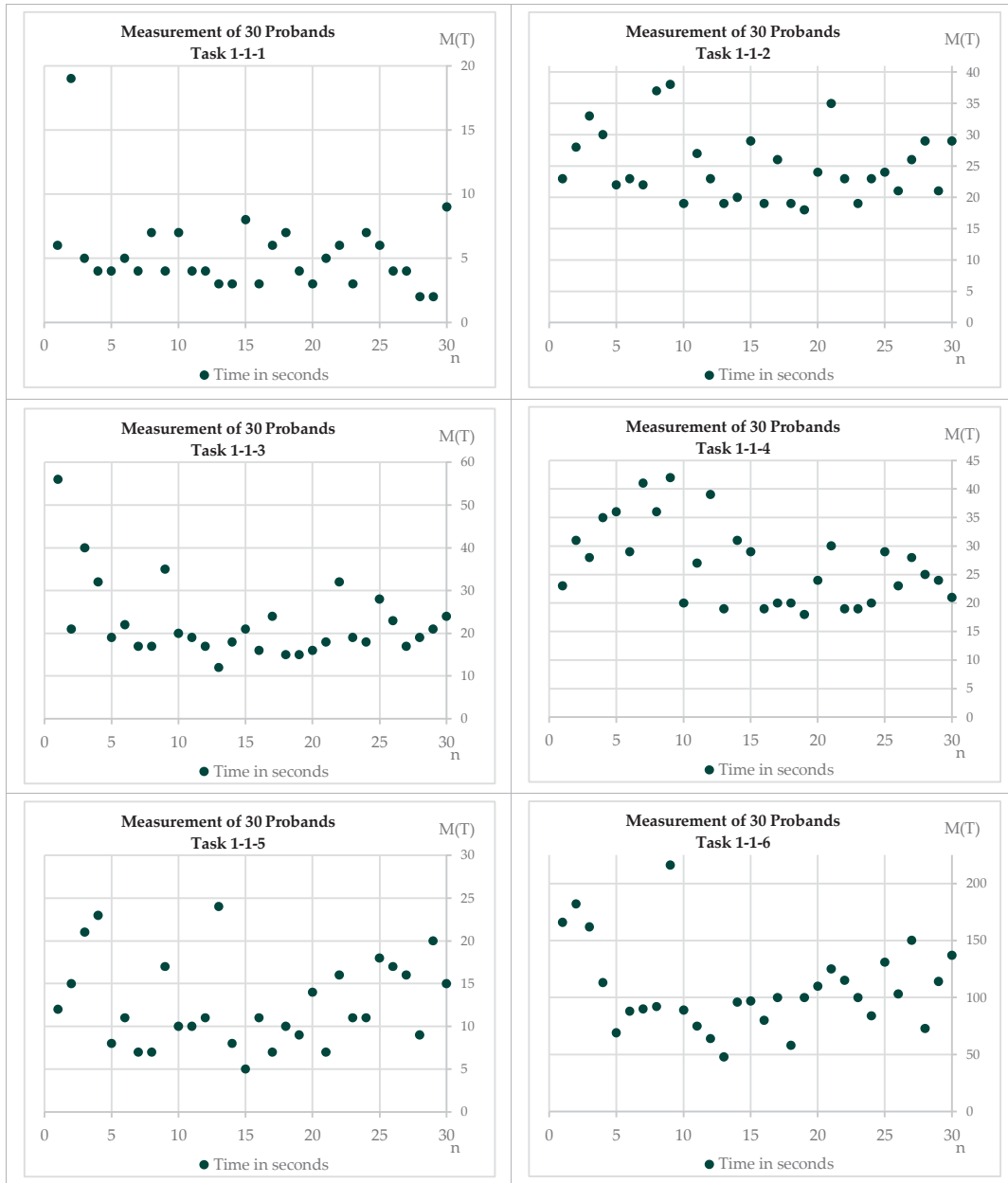


Figure 55: Measurements of Six Tasks of Scenario 1 without UCM.

The measurements are represented as a frequency distribution  $F(M)$  (yellow) and the corresponding probability distribution  $P(X)$  (blue).

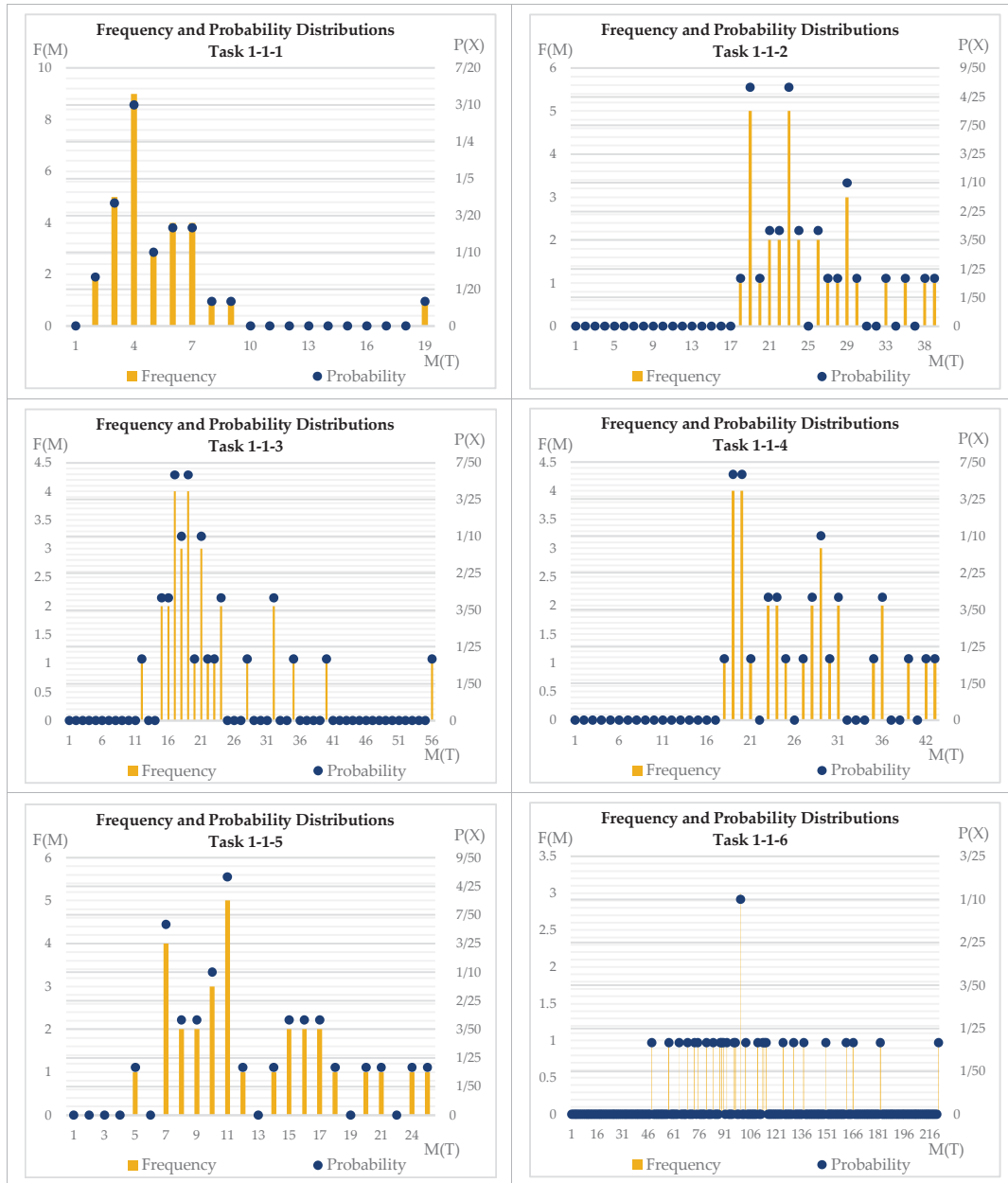


Figure 56:  $F(M)$  and  $P(X)$  of the Six Tasks of Scenario 1 without UCM

The probability distribution  $P(X)$  (blue), and additionally, the corresponding curve fittings with the Gaussian distribution  $N(\mu, \sigma)$  (red), are represented where  $\mu$  and  $\sigma$  are calculated from the measurements.

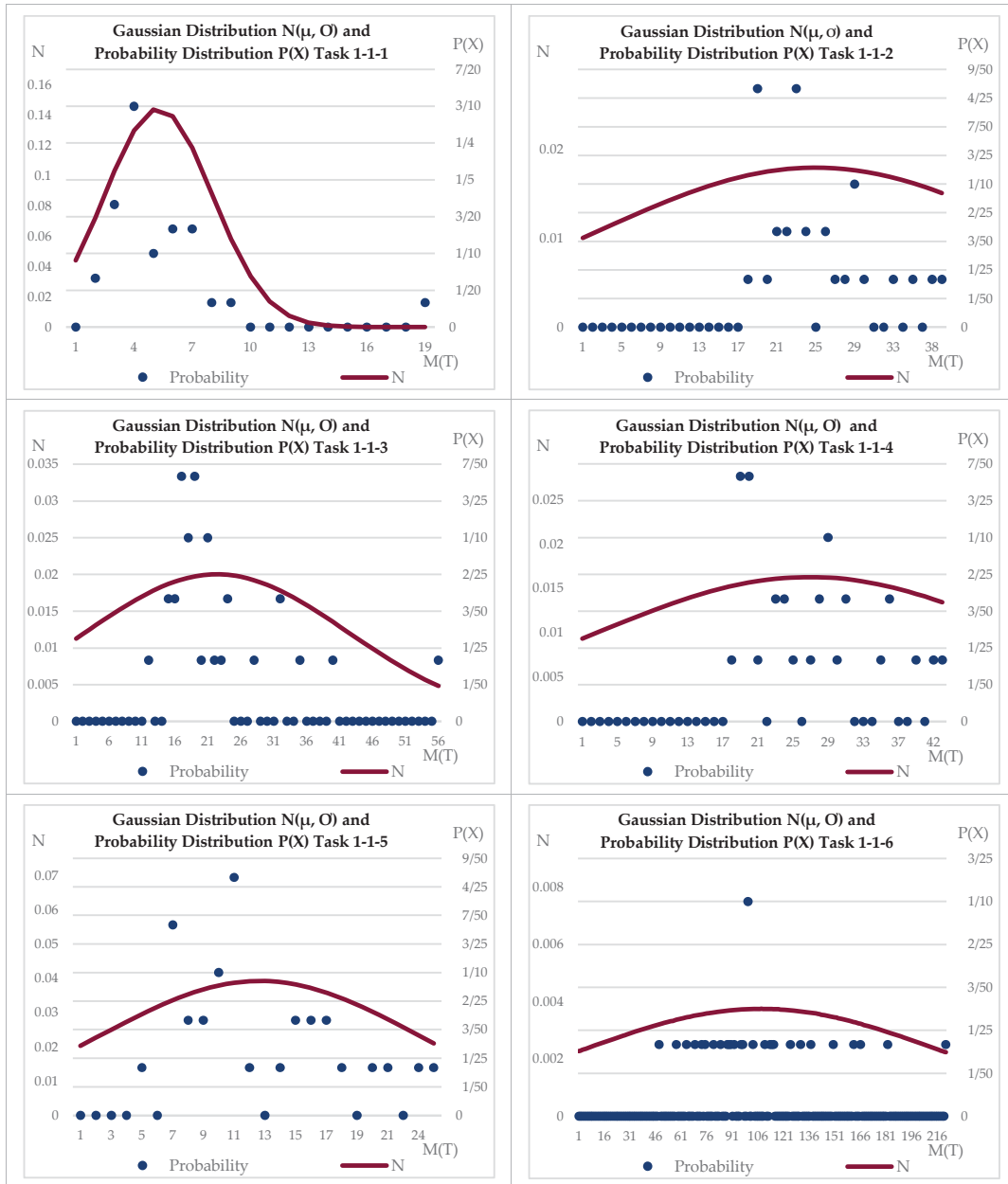


Figure 57:  $P(X)$  and  $N(\mu, \sigma)$  of Six Tasks of Scenario 1 without UCM

These measurements show that the tasks provided different demands to the probands. For example Task 1-1-3 indicates that the first probands needed more time to solve the tasks than the following probands. In contrast to this, Task 1-1-5 indicates that the probands 20 till 30 needed more time than the probands 10 till 19.

Subsequently, these measurements are represented as frequency distributions (yellow) and probability distributions (blue) as shown in Figure 56: the left vertical denotes the frequency distribution  $F(M)$  of a measurement  $M$ , the horizontal axis denotes the measured times to perform the task (in seconds) and, the vertical axis on the right side denotes the probability distribution  $P(X)$ . Most probability distributions of Figure 56 provide reasons to fit them with the Gaussian distribution as described in the former section. However, some presented probability distributions show coincide measurements for several probands like  $P(4) = \frac{3}{10}$  of Task 1-1-1 and  $P(29) = \frac{1}{10}$  of Task 1-1-4.

Figure 57 show the Gaussian distributions  $N(\mu, \sigma)$  (left vertical axis, red curve) and the corresponding probability distributions (right axis, blue dots). Note, the scales of the left and right axis differ in order to display both curves in the same diagram. Both curves are used to calculate the KLD between them (based on Formula (11,p.197)) and the average KLD for each data point (Formula (12, p.197)), which are represented in Table 38.

Task	$D(P  N)$	$A(D(P  N))$
1-1-1	0.881	0.097
1-1-2	2.136	0.133
1-1-3	1.995	0.124
1-1-4	2.119	0.124
1-1-5	1.085	0.067
1-1-6	3.995	0.121

**Table 38: KLD and Average KLD of the Probability Distribution  $P(X)$  and the Gaussian Distribution  $N(\mu, \sigma)$  for Tasks 1-1-1 to 1-1-6**

The KLD is an entropy-based calculation, and thus, a smaller number indicates a good estimation in the following sense: the smaller the KLD, the lesser

are the number of estimations that are possible using the Gaussian distribution. Hence, Task 1-1-1 fits much better to the Gaussian distribution, than Tasks 1-1-2, 1-1-3, 1-1-4, 1-1-5, and finally, Task 1-1-6.

### 7.3.2 Scenario 1-2: Media Rich Communication with UCM

Figure 58 shows the measurements of the six tasks belonging to the scenario “Media Rich Communication with UCM” (again, 30 probands, and the vertical axis denote the maximum measured values). The measurements are described as follows:

- Task 1-2-1 shows measurements between 3 and 7 seconds of 26 probands and only four probands need more time, namely, 8 till 10 seconds.
- Task 1-2-2 is a homogeneous measurement between 10 and 25 seconds, and only 2 probands required 30 and 34 seconds.
- Task 1-2-3 was completed quickly with 1 till 4 seconds, only 2 probands required 14 and 16 seconds to complete the task.
- Task 1-2-4 has only 1 outlier with 35 seconds and the remaining probands needed 16 till 30 seconds.
- Task 1-2-5 shows a very homogeneous measurement with 3 till 10 seconds for all probands.
- Task 1-2-6 contains a little bit more scattered measurement between 15 and 85 seconds, and 1 outlier with 115 seconds.

Each task was performed with  $k = 30$  probands. The duration of the task executions is measured in seconds.

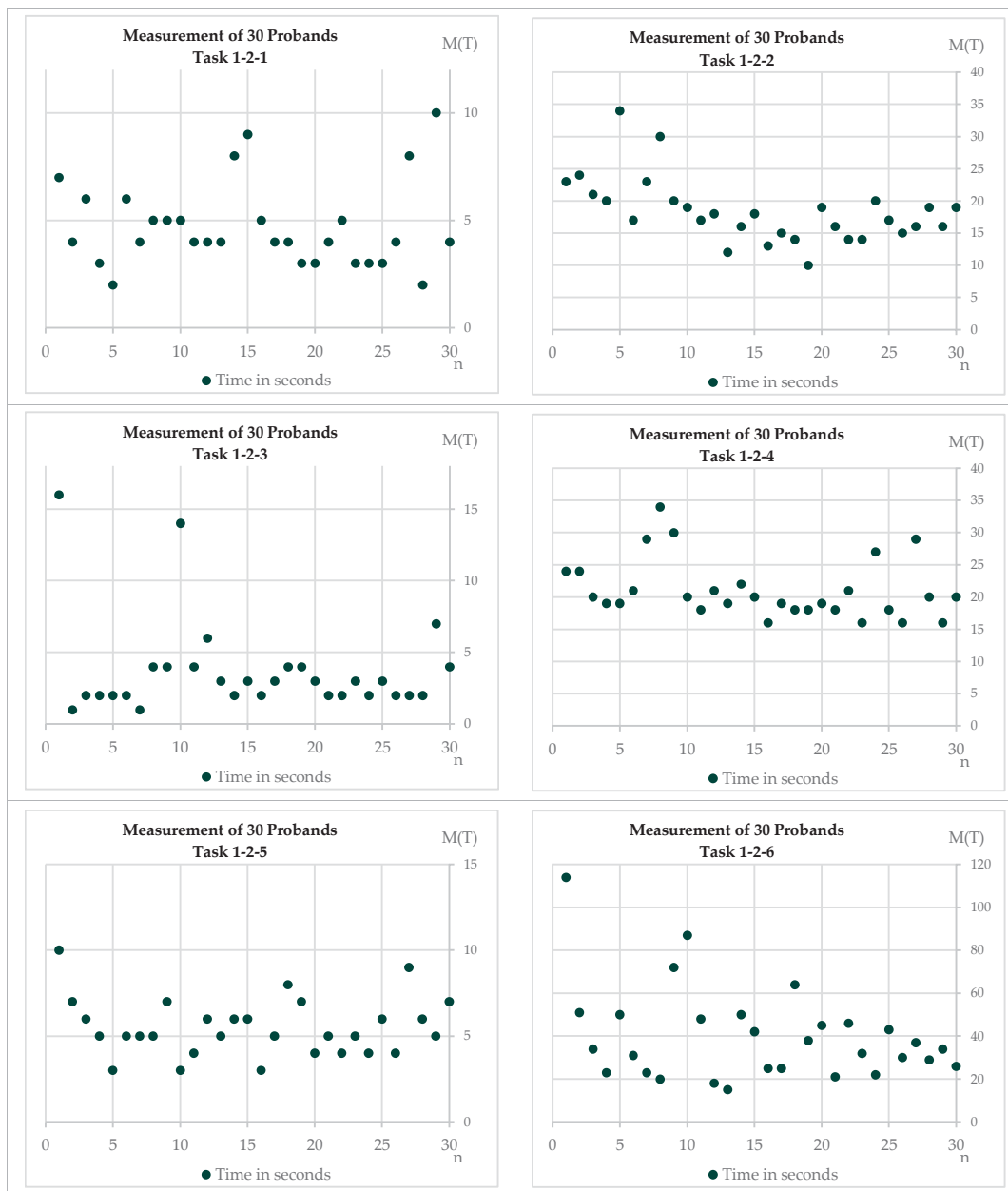


Figure 58: Measurements of Six Tasks of Scenario 1 with UCM

The measurements are represented as a frequency distribution  $F(M)$  (yellow) and the corresponding probability distribution  $P(X)$  (blue).

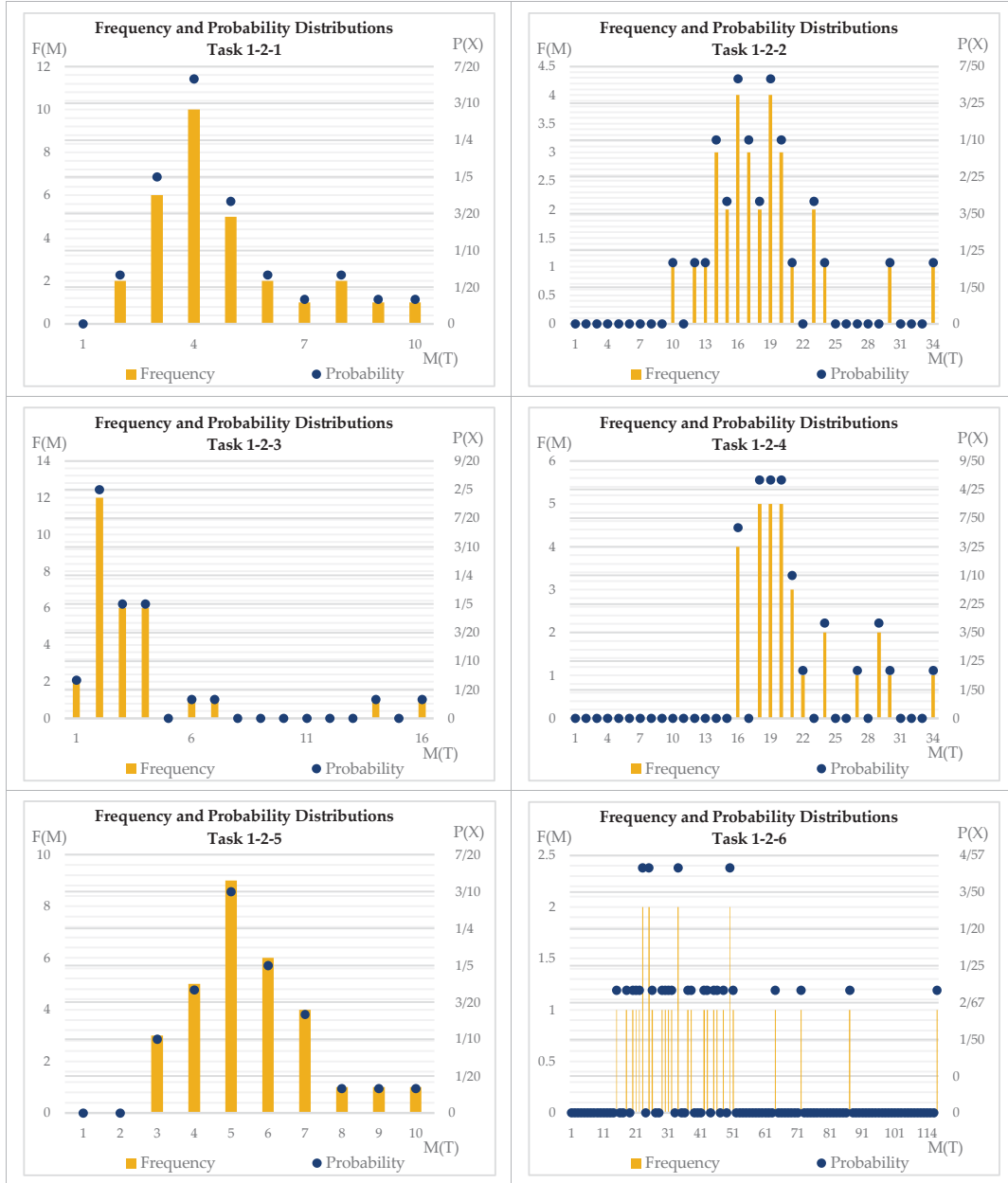


Figure 59:  $F(M)$  and  $P(X)$  of the Six Tasks of Scenario 1 with UCM

The probability distribution  $P(X)$  (blue), and additionally, the corresponding curve fittings with the Gaussian distribution  $N(\mu, \sigma)$  (red), are represented where  $\mu$  and  $\sigma$  are calculated from the measurements.



Figure 60:  $P(X)$  and  $N(\mu, \sigma)$  of Six Tasks of Scenario 1 with UCM



These measurements show that the Tasks 1-2-2 till 1-2-6 resulted in merely homogeneous measurements with different durations and some outliers (less than 4 per task). Only Task 1-2-1 is a little bit more inhomogeneous. However, these measurements indicate that most of the probands performed in a similar way with the UCM maintained tasks.

Subsequently, these measurements are represented as frequency distributions (yellow) and probability distributions (blue) as shown in Figure 59: the left vertical axis denotes the frequency distribution  $F(M)$  of the measurement  $M$ , the horizontal axis denotes the measured times of the 30 probands to perform the task (in seconds) and, the vertical axis on the right side denotes the probability distribution  $P(X)$ . Most probability distributions of Figure 59 provide reasons to fit them with the Gaussian distribution as described in the former section. However, some probability distributions show coincide measurements for several probands like  $P(2) = \frac{2}{5}$  of Task 1-2-4 and  $P(5) = \frac{3}{10}$  of Task 1-2-5.

Task	D(P  N)	A(D(P  N))
1-2-1	0.673	0.075
1-2-2	1.674	0.112
1-2-3	1.681	0.210
1-2-4	2.305	0.210
1-2-5	0.365	0.046
1-2-6	2.175	0.084

**Table 39: KLD and Average KLD of the Probability Distribution  $P(X)$  and the Gaussian Distributions  $N(\mu, \sigma)$  for Tasks 1-2-1 to 1-2-6**

Figure 60 show the Gaussian distributions  $N(\mu, \sigma)$  (left vertical axis, red curve) and the corresponding probability distributions (right axis, blue dots). Note, the scales of the left and right axis differ in order to display both curves in the same diagram. Both curves are used to calculate the KLD between them (based on Formula (11,p.197)) and the average KLD for each data point (Formula (12, p.197)), which are represented in Table 39. As result it is worth to mention that the KLD and average KLDs of Scenario 1 with UCM are smaller than without UCM (except for Task 1-2-4), and hence, they have a better fitting to the corresponding Gaussian

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distributions. This notable evaluation result will be discussed in detail at the end of this chapter.

### 7.3.3 Scenario 2-1: Mobility without UCM

Figure 61 contains the measurements of the six tasks belonging to the Scenario “Mobility without UCM”. The measurements can be summarized as follows:

- Task 2-1-1 shows measurements between 28 and 125 seconds, with two outliers (probands 4 and 8) with 138 and 155 seconds.
- Task 2-1-2 shows measurements between 20 and 105 seconds.
- Task 2-1-3 shows mainly measurements between 4 and 42 seconds, and only proband 19 needed 62 seconds.
- Task 2-1-4 contains measurements between 2 and 34 seconds, with one extreme outlier of 85 seconds (proband 10).
- Task 2-1-5 shows a homogeneous scatter of the measurements between 8 and 76 seconds.
- Task 2-1-6 shows measurements between 16 and 44 seconds, with one outlier of 55 seconds (proband 27).

Each measurement was done for  $k = 30$  probands, where the task execution was measured in seconds. The maximum values of the measurement are shown on the vertical axis.



Figure 61: Measurements of Six Tasks of Scenario 2 without UCM

The measurements are represented as a frequency distribution  $F(M)$  (yellow) and the corresponding probability distribution  $P(X)$  (blue).

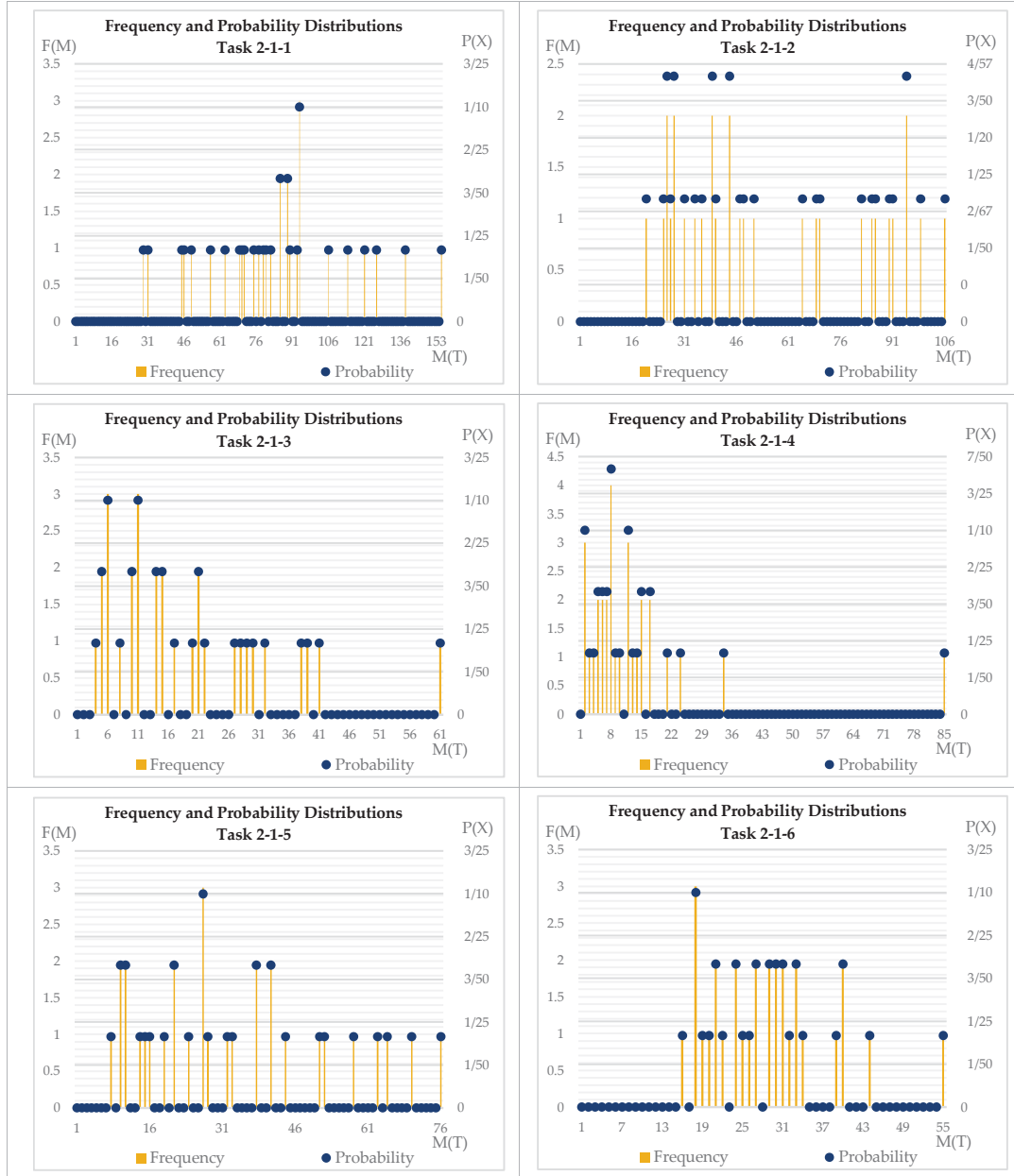


Figure 62:  $F(M)$  and  $P(X)$  of the Six Tasks of Scenario 2 without UCM

The probability distribution  $P(X)$  (blue), and additionally, the corresponding curve fittings with the Gaussian distribution  $N(\mu, \sigma)$  (red), are represented where  $\mu$  and  $\sigma$  are calculated from the measurements.



Figure 63:  $P(X)$  and  $N(\mu, \sigma)$  of Six Tasks of Scenario 2 without UCM

These measurements show that the tasks provided several challenges to the probands. For example Task 2-1-1 indicates that the probands needed twice the time to solve the tasks than the probands needed for Task 2-1-6. In contrast to this, indicates Task 2-1-4 that the probands needed only  $\frac{1}{5}$  of the time to solve the task compared to the measurements of Task 2-1-1.

Subsequently, these measurements are represented as frequency distributions (yellow) and probability distributions (blue) as shown in Figure 62: the left vertical denotes the frequency distribution  $F(M)$  of a measurement  $M$ , the horizontal axis denotes the measured times to perform the task (in seconds) and, the vertical axis on the right side denotes the probability distribution  $P(X)$ . Most probability distributions of Figure 62 provide reasons to fit them with the Gaussian distribution as described in the former section. Especially, the measurements of Tasks 2-1-3 and 2-1-4 support this idea intensively, even both measurements contain an outlier with 61 seconds, respectively 85 seconds.

Figure 63 contains the Gaussian distributions  $N(\mu, \sigma)$  (left vertical axis, red curve) and the corresponding probability distributions (right axis, blue dots). Note, the scales of the left and right axis differ in order to display both curves in the same diagram. Both curves are used to calculate the KLD between them (based on Formula (11, p.197)) and the average KLD for each data point (Formula (12, p.197)), which are represented in Table 40.

Task	$D(P  N)$	$A(D(P  N))$
2-1-1	3.154	0.121
2-1-2	2.691	0.108
2-1-3	1.611	0.077
2-1-4	2.157	0.120
2-1-5	2.157	0.094
2-1-6	1.932	0.097

**Table 40: KLD and Average KLD of the Probability Distribution  $P(X)$  and the Gaussian Distribution  $N(\mu, \sigma)$  for Tasks 2-1-1 to 2-1-6**

The KLD is an entropy-based calculation, and thus, a smaller number indicates a good estimation in the following sense: The smaller the KLD, the less are the number of estimations that are possible using the Gaussian distribution.

Hence, the measurements of Task 2-1-3 fit much better to the Gaussian distribution than to the measurements of Tasks 2-1-1, 2-1-2, 2-1-4, 2-1-5, and 2-1-6.

### 7.3.4 Scenario 2-2: Mobility with UCM

Figure 64 contains the measurements of the six tasks belonging to the scenario “Mobility with UCM”. Each measurement was done for  $k = 30$  probands, where the task execution was measured in seconds. The maximum values of the measurement are shown on the vertical axis. Again, the measurements can be summarized as follows:

- Task 2-2-1 shows measurements between 5 and 46 seconds, with one outlier (proband 1) with 62 seconds.
- Task 2-2-2 shows measurements between 5 and 57 seconds, with one outlier (proband 21) with 69 seconds.
- Task 2-2-3 shows mainly measurements between 12 and 35 seconds, and probands 21, 27, and 30 needed 48, 42, and 54 seconds.
- Task 2-2-4 contains measurements between 6 and 14 seconds, with two outliers of 17 and 19 seconds (probands 2 and 3).
- Task 2-2-5 shows an inhomogeneous scatter of the measurements between 5 and 16 seconds with two outliers of 2 and 18 seconds (probands 26 and 18).
- Task 2-2-6 shows measurements between 2 and 6 seconds, with three outliers of 10, 12, and 8 seconds (probands 3, 4, and 25).

Each task was performed with  $k = 30$  probands. The duration of the task executions is measured in seconds.

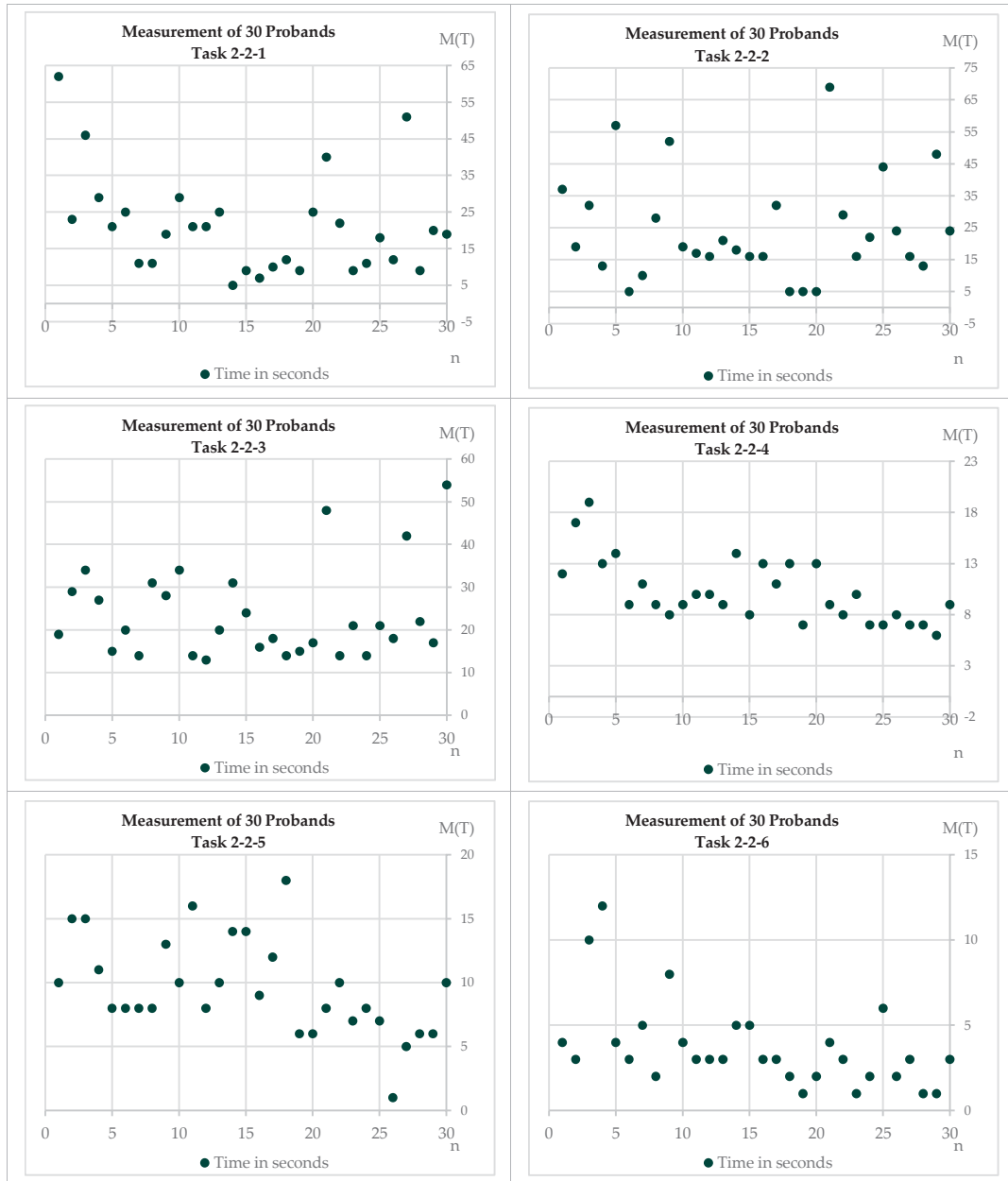


Figure 64: Measurements of Six Tasks of Scenario 2 with UCM



Measurements are represented as a frequency distribution  $F(M)$  (yellow) and the corresponding probability distribution  $P(X)$  (blue).

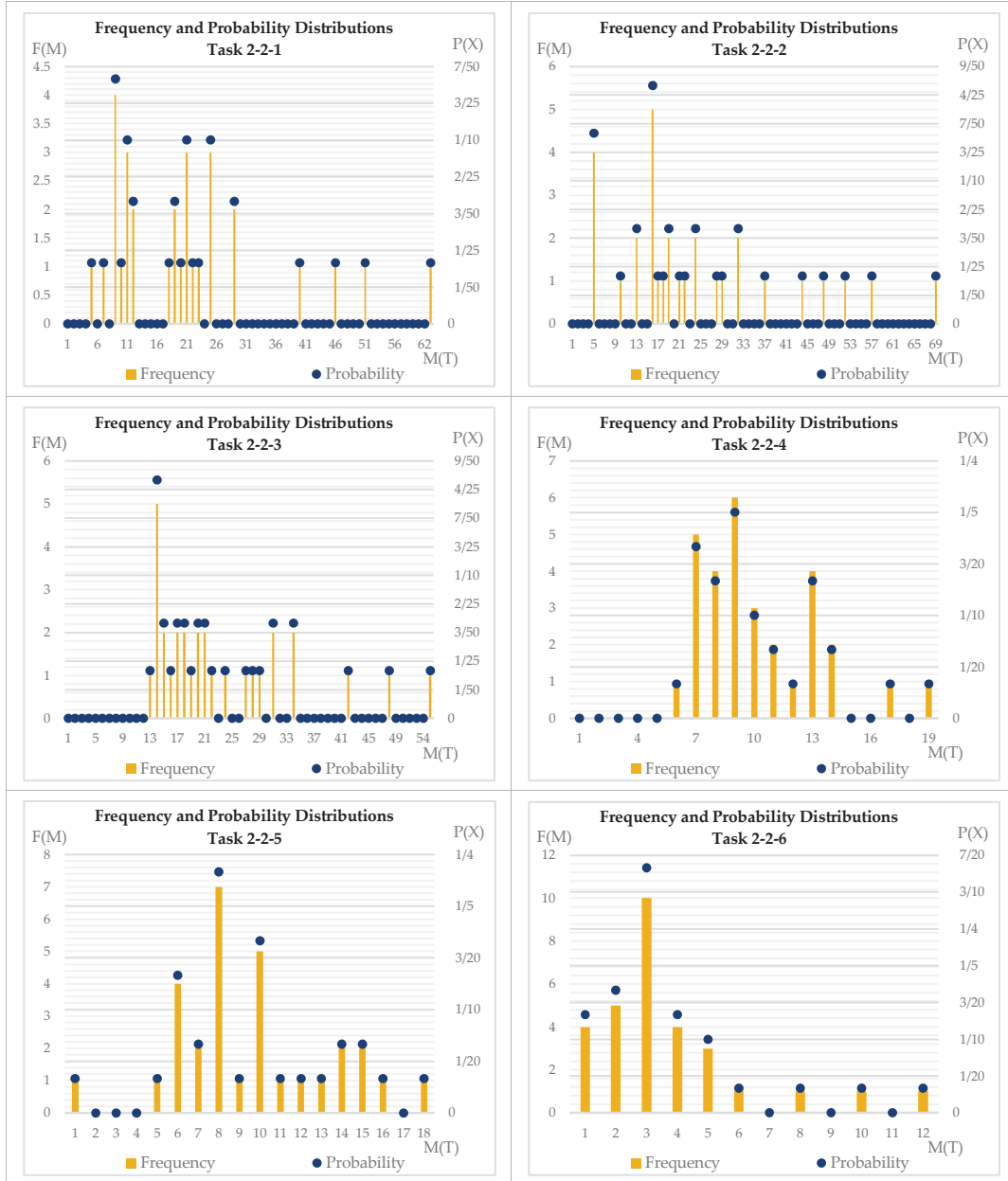


Figure 65:  $F(M)$  and  $P(X)$  of the Six Tasks of Scenario 2 with UCM

The probability distribution  $P(X)$  (blue), and additionally, the corresponding curve fittings with the Gaussian distribution  $N(\mu, \sigma)$  (red), are represented where  $\mu$  and  $\sigma$  are calculated from the measurements.



Figure 66:  $P(X)$  and  $N(\mu, \sigma)$  of Six Tasks of Scenario 2 with UCM

These measurements show that the tasks provided different challenges to the probands. For example Tasks 2-2-1 and 2-2-2 indicate that the probands needed fourth the time to solve the tasks than the probands needed for Tasks 2-2-5 and 2-2-6. In contrast to this indicates Task 2-2-4 that the probands needed only approximately  $\frac{1}{3}$  of the time to solve the task compared to Task 2-2-1 or Task 2-2-2.

Subsequently, these measurements are represented as frequency distributions (yellow) and probability distributions (blue) as shown in Figure 65: The left vertical denotes the frequency distribution  $F(M)$  of a measurement  $M$ , the horizontal axis denotes the measured times to perform the task (in seconds) and, the vertical axis on the right side denotes the probability distribution  $P(X)$ . Most probability distributions of Figure 65 provide reasons to fit them with the Gaussian distribution as described in the former section. Especially, the measurements of Tasks 2-2-4, 2-2-5 and 2-2-6 support this idea intensively, even these measurements contain a small number of outliers.

Figure 66 contains the Gaussian distributions  $N(\mu, \sigma)$  (left vertical axis, red curve) and the corresponding probability distributions (right axis, blue dots). Note, the scales of the left and right axis differ in order to display both curves in the same diagram. Both curves are used to calculate the KLD between them (based on Formula (11,p.197)) and the average KLD for each data point (Formula (12, p.197)), which are represented in Table 41.

Task	D(P  N)	A(D(P  N))
2-2-1	1.962	0.109
2-2-2	2.174	0.114
2-2-3	1.861	0.098
2-2-4	1.036	0.094
2-2-5	0.835	0.060
2-2-6	0.845	0.094

**Table 41: KLD and Average KLD of the Probability Distribution  $P(X)$  and the Gaussian Distribution  $N(\mu, \sigma)$  for Tasks 2-2-1 to 2-2-6**

The KLD is an entropy-based calculation, and thus, a smaller number indicates a good estimation in the following sense: The smaller the KLD, the lesser

are the number of estimations that are possible using the Gaussian distribution. Hence, the measurements of Tasks 2-2-4, 2-2-5, and 2-2-6 fit much better to the Gaussian distribution, than the measurements of Tasks 2-2-1, 2-2-2, and 2-2-3.

### 7.3.5 Discussion and Comparison of the Four Scenarios Results

In this section the task measurements and curve fittings of the four scenarios are compared and discussed. The results are also qualitatively justified (see Appendices E-4 and E-5 for a detailed overview of questionnaire values and evaluation of Scenario 1 and Scenario 2) using the questionnaires that are described in Section 6.3.2. A focus of the comparison is on the same scenarios without and with UCM, i.e., “Media Rich Communication” without and with UCM (cf. Figure 106, Appendix E-4), and “Mobility” without and with UCM (cf. Figure 107, Appendix E-5).

Scenario 1-1 “Media Rich Communication without UCM” (Section 7.3.1) shows five good fittings with  $D(P||N) \leq 2.2$  and only one task, namely 1-1-6, shows a less good KLD with  $D(P||N) \approx 3.9$ , which results in a difference of both KLDs of 1.7 (Table 38). Task 1-1-6 required an interactive communication with a smartphone, i.e., input of an “e-mail address” and of a “subject” into the e-mail app. Furthermore, questions like “your name?” and “color of your top?” had to be answered. During the actions the probands had to find the proper input fields in order to type their answers. However, the qualitative survey shows that people in average felt comfortable with Task 1-1-6 and scored an average value of three, which indicates moderate experience for the probands. A less good qualitative result gained Task 1-1-2 “Tell your name, the time, say goodbye and hang-up” with an average score of 4.7, which expresses a subjective desire of the probands for a more comfortable communication interaction. The remaining 3 tasks achieved an average score of approximately two indicating that the probands felt comfortable during the task solution.

Scenario 1-2 “Media Rich Communication with UCM” (Section 7.3.2) contains only good fittings with  $D(P||N) \leq 2.3$  and one very good fitting with  $D(P||N) \leq 0.4$ . But comparing these results with the values of Scenario 1-1, surprisingly the KLD of Task 1-1-4 (without UCM) is  $D(P||N) = 2.2$  and the KLD of Task 1-2-4 (with UCM) is  $D(P||N) = 2.3$ , thus, the latter is slightly higher with the

difference of 0.1. Task 1-1-4 is “Type telephone number, dial, tell your name, the quantity of present people, how the weather is, say goodbye and hang up using the screen button”. Obviously, the UCM cannot ease the task execution very much, even the convenience factor increased from 2.3 (Task 1-1-4) to 1.2 (Task 1-2-4) as expressed by the questionnaire. In contrast to this the UCM strongly supported the execution of Task 1-1-5 “Find the message app, start it, find the button to write a message” by multimodality with speech recognition: The  $D(P||N) = 1.1$  (without UCM) decreased to approximately  $\frac{1}{3}$ , namely  $D(P||N) = 0.4$  (with UCM).

Scenario 2-1 “Mobility without UCM” (Section 7.3.3) shows four good fittings with  $D(P||N) \leq 2.2$  and only two tasks measurements have a less good fitting with  $D(P||N) \approx 3.2$  (Task 2-1-1) and  $D(P||N) \approx 2.7$  (Task 2-1-2). The latter tasks reached a high score in the questionnaire with 3.8 and 4.7 expressing that the probands felt less comfortable during the task solution. This result relies on the long task execution durations with maximum 165 seconds, respectively 105 seconds, which requires patience and persistence from the probands.

Finally, Scenario 2-2 “Mobility with UCM” (Section 7.3.4) consists only of good fittings with  $D(P||N) \leq 2.2$  and two tasks, namely 2-2-5 and 2-2-6, show a pretty good KLD with  $D(P||N) \leq 0.85$ . Applying the Tasks 2-1-1 and 2-1-2 (former paragraph) to the UCM lead to an improved situation, where the probands felt much more comfortable with a score of approximately 1.1 for both tasks. Due to the UCM a qualitative improvement of factor 3.5 could be achieved (Task 2-2-1 compared to Task 2-1-1), respectively a factor of 4.3 (Task 2-2-2 compared to Task 2-1-2).

But comparing these results with the values of Scenario 2-1, surprisingly the KLD of Task 2-1-3 (without UCM) is  $D(P||N) = 1.6$  and the KLD of Task 2-2-3 (with UCM) is  $D(P||N) = 1.8$ , thus, the latter is slightly higher with the difference of 0.2. Task 2-1-3 is “During the journey, find out when and where to leave the bus”. Obviously, the UCM didn’t ease the task execution very much, even the probands were automatically informed about when and where to leave the bus. The efficiency increased in the questionnaire from the low factor 3.9 (Task 2-1-3) (see Appendices E-4 and E-5 for a detailed overview of questionnaire values and evaluation of Scenario 1 and Scenario 2) to the good value 1.4 (Task 2-2-3). The reason for this might be that all probands are living in the German City Bochum,

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and thus, they are using the public bus transportation frequently. On the other hand nearly all of them acknowledged the comfortable support of the UCM.

To summarize, the application of the UCM shows efficient task solutions for nearly all twelve tasks of Scenario 1 and Scenario 2. Only the two above described surprising results with UCM were slightly less good compared to the scenarios without UCM. All task execution durations were reduced by a factor of one till six (only the execution duration of Task 1-1-4 remained nearly the same), and the (qualitative) convenience factor increased by factors 0.7 till 4.0 for all tasks due to the seamless and multimodal UCM.

## 8 CONCLUSION AND OPEN ASPECTS

The contributions of the thesis are summarized in Section 8.1. Afterwards, in Section 8.2 open aspects of the thesis are presented and discussed.

### 8.1 CONCLUSION

The UCM is the architecture for future communication systems that support humans with their communication needs. The number of elderlies is growing fast and based on two scenarios it has been shown that physical abilities needed for communication can be compensated for (a) living (alone) at home, and (b) assisted navigation to a medical clinic.

The UCM architecture enables widespread possibilities to interact with the environment and persons. This emphasizes the flexibility and modularity of the UCM:

- Speech synthesis, for ease of use with textual interaction,
- Touch gestures, on a phablet and context-dependent information additional on a smartwatch,
- Sound and vibration signals, for multimodal and convenient user interaction,
- AR support for easy and high emotional experience to communicate with the environment,
- Diversity of devices are located and synchronized with the environment over wireless technologies, to provide contextually information and LBS,
- Wireless integration of devices for data transmission with high bandwidth and low latency or flexible, energy saving device integration for a smartwatch or loudspeakers, and
- Integration of additional external information, i.e., bus line or time information services.

The UCM is extendible and allows future technological developments to be incorporated. Furthermore, the model integrates heterogeneous network technologies, diverse devices, and supportive services into one homogeneous architecture model allowing a user the selection of favored and needed items.

The evaluation is based on the two hypotheses which represent the WHO claim for participation of elderly people. Two use cases and scenarios “Media Rich Communication” and “Mobility” are developed for daily life situations of elderlies, where a daughter communicates with her elderly father and a grandma needs to visit her doctor in a medical clinic. These scenarios are implemented as prototypes that apply the above described technologies and a variety of devices. Both prototypes demonstrate the UCM in a powerful way:

Comprehensive experiments with 30 probands and 24 tasks resulting in 1440 measurements and their statistical evaluation shows that the application of the UCM provides efficient task solutions for the twelve tasks of the scenarios “Media Rich Communication” and “Mobility”: The task execution durations were reduced by a factor of up to six due to the application of the UCM (compared to the situation without UCM). And the (qualitative) satisfaction factor of the probands increased by a factor of approximately four for all tasks due to the seamless and multimodal UCM (for a detailed description and discussion see the former Section 7.3.5).

These results lead to the conclusion that the UCM supports in a seamless and intuitive way the basic requirement “social participation of elderly people based on communication” of the WHO (2002) including heterogeneous network technologies and devices. Thus, the UCM supports participation and an active lifestyle for elderlies by H2H, M2M, H2M and M2H communication.

## 8.2 OPEN ASPECTS AND OUTLOOK

A central key factor for applying the UCM to communication is an easy-to-use development of devices that covers a satisfying usability (Sections 5.1 and 6.2). Devices will include wearable computing systems from watches, smartphones, tablet computers, up to embedded systems, which are not at all recognizable as computer or technology to the user. Till today no unique design and UX guidelines for devices or technology exist. However, an individual design, especially of user interfaces, is intended in order to define unique propositions and to stick users to



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the same (graphical) interface. Hence, the UCM needs to be compatible to nearly all devices and technologies.

The initial hurdles to technology use, which were apparent to today's generation 60+, are already diminishing and hardly noticeable for people born from 1970 onward (Digital Natives, cf. Section 5.3). The challenge to the development of devices, user and service concepts in the future will be to define how different user groups handle new technologies and which usage approaches are upcoming. This limitation is expected to be solved by continuously investigating the society and their ICT usage as is done by, e.g., Sociovision (cf. Sections 5.2 and 5.3).

The two developed prototypes, namely "Media Rich Communication" and "Mobility", allow their maintenance and further development including the incorporation of upcoming technologies and devices. This advantage enables a continuous development and adaptation of the UCM, and thus, to bring the UCM into daily life application by an increasing user acceptance and fulfilling Weiser's vision of Ubiquitous Computing.



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**APPENDIX**

### A-1. TECHNICAL SPECIFICATION OF MEDIA RICH DEVICE

<b>MRD01, Client, Media Rich Device, HP Compaq Elite 8300 Ultra-Slim Desktop (H4P20ET)</b>	
Dimensions:	Height: 66 mm Width: 252 mm Depth: 254 mm
Weight:	3.1 kg
Operation System:	Windows 7.0 Professional
Graphic System:	Intel HD Graphics 2500
CPU:	Intel Core i5-3470S (4x 2.90 GHz)
RAM:	4 GB
HDD Storage:	500 GB HDD
Connectivity:	Ethernet LAN: 10, 100, 1000 Mbit/s

**Table 42: MRD01, Client, Media Rich Device, HP Compaq Elite 8300 Ultra-Slim Desktop**  
Source: HP, 2014

<b>MRD02, Client, Connectivity - Wi-Fi, Asus USB-AC56 Wi-Fi Stick</b>	
Dimensions:	Height: 115 mm Width: 28 mm Depth: 19 mm
Weight:	50 g
Data rate:	802.11ac (5 GHz): Up to 867 Mbit/s 802.11n (2.4 GHz/5 GHz): Up to 300 Mbit/s 802.11a/g (2.4 GHz/5 GHz): Up to 54 Mbit/s 802.11b (2.4 GHz): Up to 11 Mbit/s
Security:	Supports 64/128 bit WEP, WPA-PSK, WPA2-PSK
Connectivity:	USB 3.0

**Table 43: MRD02, Client, Connectivity - Wi-Fi, Asus USB-AC56 Wi-Fi Stick**  
Source: Asus, 2014b

<b>MRD03, Client, Screen - 27" Samsung Screen (A550HS)</b>	
Dimensions:	Height: 483 mm Width: 648 mm Depth: 258 mm
Display:	27 inch Samsung S27A550 Full HD 1080p (1080*1920 pixel) LED 170°/160° Viewing Angle

**Table 44: MRD03, Client, Screen - 27" Samsung Screen (A550HS)**

Source: Samsung, 2014a

<b>MRD04, Client, Video / Audio Sensor, Logitech C920 USB HD Pro</b>	
Dimensions:	Height: 29 mm Width: 94 mm Depth: 24 mm
Weight:	162 g
Camera: (Video / Audio Sensor)	Video: 1080p (H.264) Diagonal Field of View (FOV): 78° Audio: Stereo Microphone
Connectivity:	USB 2.0

**Table 45: MRD04, Client, Video / Audio Sensor, Logitech C920 USB HD Pro**

Source: Logitech, 2014

<b>MRD05, Client, Connectivity - Bluetooth, Hama - USB-Adapter V.4</b>	
Dimensions:	Height: 5 mm Width: 12 mm Depth: 23 mm
Connectivity:	Data Transfer Rate: 3 Mbit/s Max. Range: 10 m USB Standard: USB 2.0 Bluetooth Class: Class 2 Bluetooth Version: 4.0

**Table 46: MRD05, Client, Connectivity - Bluetooth, Hama - USB Adapter V.4**

Source: Hama, 2014

**A-2. TECHNICAL SPECIFICATION OF TOUCH DEVICE**

<b>TD01, Client, Phablet, Samsung Galaxy Note 3</b>	
Dimensions:	Height: 151.2 mm Width: 79.2 mm Depth: 8.3 mm
Weight:	168 g (incl. battery)
Operation System:	Android OS 4.4
Display:	5.7 inch Full HD 1080p (1080*1920 pixel) Super AMOLED
SoC:	Snapdragon 800
CPU:	1.9GHz octacore
RAM:	3 GB
Storage:	32 GB, expandable with micro SD
Connectivity:	2G: GSM, GPRS, EDGE 3G: WCDMA/HSPA 4G: LTE  Wi-Fi: 802.11 a/b/g/n/ac Bluetooth: 4.0 +LE NFC: yes
Sensors:	Accelerometer, Gyroscope, Proximity, Ambient Light, Compass, Barometer, Temperature, Humidity, Gesture
Camera:	Back camera: 13 Mega Pixel camera 4K and 1080p HD video recording Front camera: 2 Mega Pixel camera 1080p HD video recording

**Table 47: TD01, Client, Phablet, Samsung Galaxy Note 3**

Source: Samsung, 2014c

<b>TD02, Touch Device, android.nfc Service</b>	
Package:	android.nfc
Required permissions:	NFC

**Table 48: TD02, External Environment Information, android.nfc Service**

Source: developer.android.com, 2014a

**A-3. TECHNICAL SPECIFICATION OF ADDITIONAL DEVICES**

<b>AD01, Additional Device, Smartwatch, Sony Smartwatch 2</b>	
Dimensions:	Height: 9 mm Width: 42 mm Depth: 41 mm
Weight:	122.5 g
Graphic System:	1.6 inch LCD 220*176 pixel
Connectivity:	NFC: yes Bluetooth: 3.0
Supported Operation Systems:	Android 4.0 and above

Table 49: AD01, Additional Device, Smartwatch, Sony Smartwatch 2

Source: Sony, 2014

<b>AD02, Additional Device, Loudspeaker System, Harman Kardon Soundsticks Wireless 2.1</b>	
Dimensions:	Height: 450 mm Width: 250 mm Depth: 250 mm
Weight:	2.2 kg
Amplification power:	140 W
Connectivity:	Bluetooth Cable: 3.5 mm Stereo
Frequency:	44 Hz – 20kHz

Table 50: AD02, Additional Device, Loudspeaker System, Harman Kardon Soundsticks Wireless 2.1

Source: Harman / Kardon, 2012

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**A-4. TECHNICAL SPECIFICATION OF WIRELESS MEDIA**

<b>WM01, Media, Wireless Access Point, Asus RT-AC68U</b>	
Dimensions:	Height: 220 mm Width: 160 mm Depth: 83.3 mm
Weight:	640 g
Data rate:	802.11ac (5 GHz): Up to 1300 Mbit/s 802.11n (2.4/5 GHz): Up to 600 Mbit/s 802.11a/g: Up to 54 Mbit/s 802.11b: Up to 11 Mbit/s
LAN:	4x Gigabit Ethernet
USB Ports:	1x USB 2.0 1x USB 3.0
Security:	Supports 64/128-bit WEP, WPA-PSK, WPA2-PSK, WPA-Enterprise, WPA2-Enterprise, Radius with 802.1x

**Table 51: WM01, Media, Wireless Access Point, Asus RT-AC68U**

Source: Asus, 2014a



**A-5. TECHNICAL SPECIFICATION OF EXTERNAL LIVE STREAMS**

<b>ELS01, External Live Streams, Video/Audio, D-Link DCS-2332L/E Wireless N</b>	
Dimensions:	Height: 210 mm Width: 140 mm Depth: 94 mm
Weight:	235 g
Resolution:	1.3 MP (720p)
Video Compression:	H.264
Framerate:	30 fps
Nightvision:	IR-LED, ICR, PIR
SD card:	MicroSD
Connectivity:	Wireless N 10/100 Fast Ethernet

**Table 52: ELS01, External Live Streams, Video/Audio, D-Link DCS-2332L/E Wireless N**

Source: D-Link, 2014

## A-6. TECHNICAL SPECIFICATION OF EXTERNAL INFORMATION

<b>EI01, External Information, Web Service, Wetter.com openweather API</b>	
Request format:	HTTP Request
Path:	http://api.wetter.com/
Return format:	XML JSON
Authentication:	API key Checksum Project name

**Table 53: EI01, External Information, Web Service, Wetter.com**

Source: [wetter.com](http://wetter.com), 2014

<b>EI02, External Information, Web Service, TimeAPI.ORG</b>	
Request format:	RESTful HTTP Request
Path:	http://timeapi.org
Return format:	JSON(p)
Authentication:	None

**Table 54: EI02, External Information, Web Service, Time Information**

Source: Lindsay, 2014

<b>EI03, External Information, Bus line Information</b>	
Request format:	Localhost Request
Path:	Static local information for prototype scenario
Return format:	CSV Data
Authentication:	None

**Table 55: EI03, External Information, Bus line Information**

<b>EEI01, External Environment Information, NFC Tag</b>	
Dimensions:	Height: 12 mm Width: 19 mm
Connectivity:	Operating Frequency: 13.56MHz Integrated Circuit (IC): NXP NTAG213 International Standards: ISO 14443 A Memory: 1152 bit / 144 byte

**Table 56: EEI01, External Environment Information, NFC Tag**

Source: Smartrac Technology Group, 2014

## A-7. TECHNICAL SPECIFICATION OF EXTERNAL SERVICES

<b>ES01, External Services, WebRTC</b>	
Protocol:	(S)RTP
Technology:	HTML5, JavaScript XMPP-Extension "Jingle" JSEP (JavaScript Session Establishment Protocol)
Service:	Secured (encrypted) real time communication

**Table 57: ES01, External Services, WebRTC**

Source: Westerlund, Jennings and Hardie, 2014

<b>ES02, External Services, STT (Speech To Text Input) - SpeechRecognizer Service</b>	
Package:	android.speech
Required permissions:	RECORD_AUDIO INTERNET

**Table 58: ES02, External Services, STT - SpeechRecognizer Service**

Source: developer.android.com, 2014d

<b>ES03, External Services, TTS (Text To Speech Output)- android.speech.tts Service</b>	
Package:	android.speech.tts
Required permissions:	None

**Table 59: ES03, External Services, TTS - android.speech.tts Service**

Source: developer.android.com, 2014b

<b>ES04, External Services, Maps - Service</b>	
Package:	com.google.android.gms.maps
Required permissions:	MAPS_RECEIVE READ_GSERVICES INTERNET ACCESS_NETWORK_STATE WRITE_EXTERNAL_STORAGE

**Table 60: ES04, External Services, Maps - Service**

Source: developer.android.com, 2014c

**B-1. EXPERIMENT PREPARATION - INTRODUCTION**

<b>Introduction</b>
<p><b>Test objectives:</b></p> <ul style="list-style-type: none"> <li>• Communication evaluation and mobility of tomorrow (comparison: present vs. UCM) Scenarios show ideas and approaches, but no product maturity solutions.</li> </ul> <p><b>Data collection:</b></p> <ul style="list-style-type: none"> <li>• Allocation proband to number (anonymization)</li> <li>• Data in questionnaires and times of performing are recognized/measured.</li> <li>• No exam situation, scenario-based testing.</li> <li>• Additional video recording for reproduction and later evaluation.</li> </ul> <p><b>Process:</b></p> <ul style="list-style-type: none"> <li>• Two categories (communication and mobility), each with 3 scenarios (in pairs).</li> <li>• Each task includes two subtasks.</li> <li>• Each task (each task pair) is read and explained prior to start</li> </ul>

**Table 61: Experiment Preparation - Introduction**

**B-2. EXPERIMENT PREPARATION-EVALUATION GUIDE UCM-S1**

<b>Technical Experiment Preparation: Scenario 1, Without UCM (Tasks 1-1-1 to 1-1-6)</b>	
1.	Battery check: smartphone and smartwatch.
2.	Make sure: Task description correctly sorted, symbol, NFC photos, number, pencils (sharpened), stopwatch.
3.	Make sure: Auto complete runs smoothly in mail app, no unread mails.
4.	Make sure: The call app is preset in the tab dial. Phone display is permanently enlightened.
5.	Make sure: Smartphone is connected to Wi-Fi.
6.	Turn on external speakers and couple to smartphone via Bluetooth.
7.	Start recording: PC ScreenCam, Smartphone ScreenCam (recordable, possibly PC sync).
8.	Open browser, call communication link, full screen f-11, hide keyboard/mouse, switch off screen.
9.	Read both task sheets prior to start.
10.	Place smartphone on the probands table only upon start.
<b>Technical Experiment Preparation: Scenario 1, With UCM (Tasks 1-2-1 to 1-2-6)</b>	
1.	Switch on screen.
2.	Start app communication and pair smartwatch with phone via Bluetooth.

**Table 62: Experiment Preparation - Guide UCM-S1**

Tasks	Scenarios (present):	Measuring points:	M	Value
1-1-1	A <b>Answering the call</b> Wipe green icon from left to right. <i>Signal to operator via webcam on start of call</i>	Interval from first ring until phone-dialogue screen is displayed.	U	
1-1-2	A <b>Talking on the phone and terminating the call</b> Say name, time, good-bye and terminate with icon.	Interval from displaying phone dialogue until "Terminate" icon is pressed.	U	
	<i>Make sure: tab dial is preset in call app.</i>			
1-1-3	B <b>Starting the phone call application</b> Find the phone application and start it. Enter the phone number and dial. <i>0234 - 54607455</i> <i>Important: Stop time during dialing.</i>	Interval from taking smartphone off the table until the dialing process is started.	U	
1-1-4	B <b>Making a call</b> Say last name, number of people, weather, good-bye and terminate with icon.	Interval from dialogue start until the "Terminate" icon is pressed.	U	
1-1-5	C <b>Starting the e-mail application</b> Find the e-mail application, start it and find icon to write new e-mail.	Interval from taking smartphone off the table until the "Write e-mail" dialogue is displayed.	U	
1-1-6	C <b>Writing and sending an e-mail</b> Enter e-mail address (name), subject (symbol), date and number. Then send e-mail. <i>Hint: Blue number (numerical value)</i> <i>Hint: Select mail address after entering "Dennis"</i>	Interval from displaying "Write e-mail" dialogue until e-mail is sent.	U	

**Table 63: Experiment - Evaluation Guide UCM-S1 - Tasks 1-1-1 to 1-1-6**

Tasks	Scenarios (future):		M	Values
1-2-1	D <b>Answering the call</b> Press the caller's picture on the smartwatch or smartphone. <i>Give signal to operator via webcam to start call</i>	Interval from first ring until phone dialogue screen is displayed.	S U	
1-2-2	D <b>Talking on the phone and terminating the call</b> Name is read by caller, proband is asked for the time, call is terminated by waving. <i>Hint: Dialogue via screen only, no display on smartphone or smartwatch</i>	Interval from displaying phone dialogue until call is terminated by waving.	S U	
1-2-3	E <b>Starting the phone call application (NFC)</b> Place the smartphone on the photo of the person you would like to call. <i>Hint: Back towards tag, display towards proband</i> <i>Important: Stop time during dialing.</i>	Interval from taking smartphone off the table until dialing process is started.	S U	
1-2-4	E <b>Making a video call</b> Dialogue partner says name, number of persons, weather, confirmation, good-bye, Then terminate (waving).	Interval from dialogue start until termination after waving.	S U	
	<i>Stopping the ScreenCam recording on smartphone</i>			
1-2-5	F <b>Starting the e-mail application (voice command)</b> Starting the application via voice command. <i>Hint: Time limit via voice command, immediately start speaking after pressing the microphone icon</i>	Interval from taking smartphone off the table until "Write e-mail" dialogue is displayed.	U	
1-2-6	F <b>Writing and sending an e-mail (voice command)</b> Enter subject (icon) and number, then send e-mail.	Interval from displaying "Write e-mail" dialogue until e-mail is sent.	U	

Table 64: Experiment - Evaluation Guide UCM-S1 - Tasks 1-2-1 to 1-2-6

**B-3. EXPERIMENT PREPARATION-EVALUATION GUIDE UCM-S2**

Technical Experiment Preparation: Scenario 2, Without UCM (Tasks 2-1-1 to 2-1-6)	
1.	Make sure: Task descriptions are sorted correctly, pencil, stop watch.
2.	Room camera: delete memory card, connect power cable, orient and start recording.
3.	Give second smartphone to proband.
4.	Explain task first before switching to task poster. Then start timekeeping.

Technical Experiment Preparation: Scenario 2, With UCM (Tasks 2-2-1 to 2-2-6)	
1.	Make sure: Task descriptions correctly sorted, pencil (sharpened), stop watch.
2.	Start smartphone ScreenCam (Recordable).
3.	Switch on external loudspeakers and couple to smartphone via Bluetooth. Check sound.
4.	Start navigation app and pair smartwatch with smartphone via Bluetooth.
5.	Check smartphone before each task and hand over to the proband at start.

**Table 65: Experiment Preparation - Guide UCM-S2**



Tasks		Scenarios (present):		M	Values	
2-1-1	G	<b>Selecting a suitable bus line</b> Find suitable bus line using the maps.	Interval from looking at the tools on the poster until the suitable bus line is named (579).	U		
		<i>Name task: Doctor's appointment downtown, travel planning with public transport</i> <i>Describe tools: Calendar, map with locations and bus stops, bus route map and show same on poster.</i> <i>Clearly announce start of measurement.</i>				
2-1-2	G	<b>Planning the bus trip</b> Take calendar, find today's appointment, determine required length of the trip and the departure time using public transport.	Interval from looking at the tools on the poster until the correct length of the trip and departure time are named (38 mins, 11:10 a.m.)	U		
		<i>Name task: Calculation of length of the trip and departure time of the bus</i> <i>Describe tools: Notepad, calendar, map, route map and show same on poster.</i> 1. Calculate length of the trip 2. Determine departure time <i>Clearly announce start of measurement.</i>				
2-1-3	H	<b>Determining where you are during the bus trip</b> Find out during the bus trip, when and where to get off the bus.	Interval from looking at the information sign until time and location of leaving the bus are named (6).	U		
		<i>Name task: Determine during the bus trip (after you have passed some stops) when and where to get off.</i> <i>Describe tools: Bus route plan, map and show on poster. Clearly announce start of measurement.</i>				
2-1-4	H	<b>Navigating at an intersection</b> Get off the bus and determine the location on the map. Decide whether to go left or right.	Interval from looking at the map until the correct direction is named.	U		
		<i>Name task: After having left the bus, determine position and decide whether to go left or right.</i> <i>Describe tools: Map</i> <i>Clearly announce start of measurement.</i>				
2-1-5	I	<b>Checking the timetable</b> Determine the location on the map, check punctuality for appointment.	Interval from looking at the map until punctuality information has been given.	U		
		<i>Name task: Along the way after having left the bus. Check whether target/appointment will be reached on time. Describe tools: Map</i> <i>Clearly announce start of measurement.</i>				
2-1-6	I	<b>Appointment confirmation by phone</b> The phone rings (shortly after 2-1-5) and the caller asks for punctuality.	Interval from first ring until the receiver has been hung up.	U		
		<i>Name task: Call from the doctor's secretary. Take call and confirm punctuality.</i> <i>Signal call to Mathias by ringing.</i>				

Table 66: Experiment - Evaluation Guide UCM-S2 - Tasks 2-1-1 to 2-1-6

Tasks		Scenarios (future):		Values
2-2-1	J	<b>Selecting the right bus line (smartphone)</b> Call the function, check the displayed information and determine the suitable bus line.	Interval from taking over the smartphone until the right bus line is named. (579)	S U
		<i>Name task: Appointment with friend, trip planning using public transport.</i> <i>Tools: Smartphone</i> <i>"Plan my day" application</i> <i>Start app, hand over the phone upon start of task.</i>		
2-2-2	J	<b>Planning the bus trip using the smartphone</b> Use the smartphone and find the prepared information.	Interval from taking over the smartphone until the correct time for departure and total duration of trip is named (2:02 p.m., 28 mins).	S U
		<i>Name task: Determine duration of trip and departure time of bus.</i> <i>Tools: Smartphone.</i> <i>Take the phone and hand it over upon start of task.</i>		
2-2-3	K	<b>Determining where you are during the bus trip</b> While on the bus, the smartphone gives text and audio information when and where to leave the bus.	Interval from taking the smartphone until the information is named when and where to leave the bus. (4 mins, 2 stations left, Ruhrstraße)	S U
		<i>Name task: Determine remaining journey time and exit bus stop.</i> <i>Tools: Smartphone</i> <i>Application: "Wegbegleiter"</i> <i>Take the phone and hand it over upon start of task.</i> <i>Important: Make sure that sound is on and home screen of the app is displayed.</i>		
2-2-4	K	<b>Navigating at an intersection (NFC support)</b> Exit the bus. The phone gives text and audio information to turn right.	Interval from taking the smartphone until the information is given whether to go right or left.	S U
		<i>Name task: Orientation at exit bus stop with active localisation via NFC, determine in which direction to go.</i> <i>Tools: smartphone</i> <i>Important: Give instruction. Avoid touching the following icon (check).</i>		
2-2-5	L	<b>Checking time schedule (smartphone and - watch)</b> The device gives audio and text information underway that the appointment will be reached on time.	Interval from taking the smartphone until the information is named that the location will be reached on time.	S U
		<i>Name task: Check punctual arrival on the footpath.</i> <i>Tools: smartphone or smartwatch</i> <i>Hint: Describe together with 2-2-6 as it is continuous task.</i>		
2-2-6	L	<b>Automatic appointment confirmation in the background</b> While on the way, the device connects to the friends smart device and confirms the punctual arrival.	Interval from touching icon until information sending is completed.	S U
		<i>Name task: Perform appointment confirmation ; Tools: smartphone or smartwatch</i>		

Table 67: Experiment - Evaluation Guide UCM-S2 - Tasks 2-2-1 to 2-2-6

**B-4. QUESTIONNAIRE**

Questionnaire 0: General experiences										Proband: ___		
<a href="http://survey.ucm.io/index.php/survey/index/sid/251692/newtest/Y/lang/de">http://survey.ucm.io/index.php/survey/index/sid/251692/newtest/Y/lang/de</a>												
Q 0-0-1	<b>Please specify your age.</b>											
Answer	Number input											
Q 0-0-2	<b>Please specify your gender. (F/M)</b>											
Answer	Female								Male			
Q 0-0-3	<b>Please specify whether you are pensioner or worker.</b>											
Answer	Pensioner								Worker			
Q 0-0-4	<b>Please specify your profession.</b>											
Answer												
Q 0-1-1	<b>Have you already gained experiences with computers, smartphones, mobiles, tablets, smartwatches? (1-6)</b>											
Answer	(1) No Experience											
	(2) Computer											
	(3) Mobile Phone											
	(4) Smartphone											
	(5) Tablet											
	(6) Smartwatch											
Q 0-1-2	<b>How would you assess your computer knowledge? (1-9)</b>											
Answers	Hardly any knowledge	2	3	4	Good knowledge	6	7	8	Expert knowledge			
Q 0-1-3	<b>What kind of devices are you using currently?</b>											
Answer	Text input											
Q 0-1-4	<b>How often do you use the named devices? (1-6)</b>											
Answers	(1) Less than once a month											
	(2) Approx. once a month											
	(3) Approx. once a week											
	(4) Several times per week											
	(5) Daily											
	(6) Several hours per day											
Q 0-1-5	<b>How often do you use the internet (services)? (1-7)</b>											
Answers	(1) Not at all											
	(2) Less than once a month											
	(3) Approx. once a month											
	(4) Approx. once a week											
	(5) Several times per week											

	(6) Daily									
	(7) Several hours per day									
Q 0-1-6	<b>For which purpose do you use the named devices? (1-11)</b>									
Answers	(1) Communication (e-mails, video phoning, chat, etc.)									
	(2) Shopping									
	(3) Online banking									
	(4) News websites (Tagesschau, BILD, Spiegel-Online, etc.)									
	(5) Calendar management									
	(6) Gaming									
	(7) Auxiliary means (calculator, torch, reminders, etc.)									
	(8) Photography									
	(9) Multimedia (watch movies and pictures, audio books, e-books, etc.)									
	(10) Researches (persons, questions, etc.)									
	(11) Navigation / travel planning									
Q 0-2-1	<b>Where do you see areas of improvement concerning computer usability? (1-11)</b>									
Answers	(1) Communication (e-mails, video phoning, chat, etc.)									
	(2) Shopping									
	(3) Online banking									
	(4) News websites (Tagesschau, BILD, Spiegel-Online, etc.)									
	(5) Calendar management									
	(6) Gaming									
	(7) Auxiliary means (calculator, torch, reminders, etc.)									
	(8) Photography									
	(9) Multimedia (watch movies and pictures, audio books, e-books, etc.)									
	(10) Researches (persons, questions, etc.)									
	(11) Navigation / travel planning									
Q 0-2-2	<b>Would you accept intelligent background services and assistance systems? (1-9)</b>									
Answers	<table border="1"> <tbody> <tr> <td>No acceptance</td> <td>2</td> <td>3</td> <td>4</td> <td>Average acceptance</td> <td>6</td> <td>7</td> <td>8</td> <td>High acceptance</td> </tr> </tbody> </table>	No acceptance	2	3	4	Average acceptance	6	7	8	High acceptance
No acceptance	2	3	4	Average acceptance	6	7	8	High acceptance		

Table 68: Questionnaire - General Experience

Questionnaire 1: Media Rich Communication										Proband: ___		
<a href="http://survey.ucm.io/index.php/survey/index/sid/222351/newtest/Y/lang/de">http://survey.ucm.io/index.php/survey/index/sid/222351/newtest/Y/lang/de</a>												
Q 1-1		Without UCM										
Q 1-1-1	A	How easy and comfortable was it to take the call?								<u>Errors</u>		
Answers		Intuitive	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 1-1-2	A	How would you rate the experiences made during the call?								<u>Satisfaction</u>		
Answers		Exciting	1	2	3	4	Neutral	6	7	8	9	Boring
Q 1-1-3	B	How easy and comfortable was it to perform the call?								<u>Efficiency</u>		
Answers		Intuitive	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 1-1-4	B	How easy was it to transmit all information correctly?								<u>Efficiency</u>		
Answers		Easy	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 1-1-5	C	How difficult was it to start the "write message" dialogue?								<u>Learnability</u>		
Answers		Easy	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 1-1-6	C	How easy and comfortable was it to write and send the e-mail?								<u>Memorability</u>		
Answers		Intuitive	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 1-2		With UCM										
Q 1-2-1	D	How easy and comfortable was it to take the call?								<u>Errors</u>		
Answers		Intuitive	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 1-2-2	D	How would you rate the experiences made during the call?								<u>Satisfaction</u>		
Answers		Exciting	1	2	3	4	Neutral	6	7	8	9	Boring
Q 1-2-3	E	How easy and comfortable was it to perform the call?								<u>Efficiency</u>		
Answers		Intuitive	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 1-2-4	E	How easy was it to transmit all information correctly?								<u>Efficiency</u>		
Answers		Easy	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 1-2-5	F	How difficult was it to start the "write message" dialogue?								<u>Learnability</u>		
Answers		Easy	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 1-2-6	F	How easy and comfortable was it to write and send the e-mail?								<u>Memorability</u>		
Answers		Intuitive	1	2	3	4	Feasible	6	7	8	9	Difficult

Table 69: Questionnaire UCM-S1 – “Media Rich Communication”

Questionnaire 2: Mobility scenarios											Proband: _____	
<a href="http://survey.ucm.io/index.php/survey/index/sid/333548/newtest/Y/lang/de">http://survey.ucm.io/index.php/survey/index/sid/333548/newtest/Y/lang/de</a>												
<b>Q 2-1 Without UCM</b>												
Q 2-1-1	G	How efficient was it to execute the planning task?									<u>Efficiency</u>	
Answers		Easy	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 2-1-2	G	How easy was it to find the right bus line for the trip?									<u>Learnability</u>	
Answers		Very efficient	1	2	3	4	Moderate	6	7	8	9	Inefficient
Q 2-1-3	H	How safe and well-oriented did you feel during the trip?									<u>Satisfaction</u>	
Answers		Safe	1	2	3	4	Moderate	6	7	8	9	Unsafe
Q 2-1-4	H	How difficult was the decision to go left or right?									<u>Memorability</u>	
Answers		Easy	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 2-1-5	I	How difficult was it to check the timeline for the appointment?									<u>Learnability</u>	
Answers		Easy	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 2-1-6	I	How easy and comfortable was it to confirm your arrival?									<u>Errors</u>	
Answers		Intuitive	1	2	3	4	Feasible	6	7	8	9	Difficult
<b>Q 2-2 With UCM</b>												
Q 2-2-1	J	How efficient was it to execute the planning task?									<u>Efficiency</u>	
Answers		Easy	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 2-2-2	J	How easy was it to find the right bus line for the trip?									<u>Learnability</u>	
Answers		Very efficient	1	2	3	4	Moderate	6	7	8	9	Inefficient
Q 2-2-3	K	How safe and well-oriented did you feel during the trip?									<u>Satisfaction</u>	
Answers		Safe	1	2	3	4	Moderate	6	7	8	9	Unsafe
Q 2-2-4	K	How difficult was the decision to go left or right?									<u>Memorability</u>	
Answers		Easy	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 2-2-5	L	How difficult was it to check the timeline for the appointment?									<u>Learnability</u>	
Answers		Easy	1	2	3	4	Feasible	6	7	8	9	Difficult
Q 2-2-6	L	How easy and comfortable was it to confirm your arrival?									<u>Errors</u>	
Answers		Intuitive	1	2	3	4	Feasible	6	7	8	9	Difficult

Table 70: Questionnaire UCM-S2 – “Mobility”

**C-1. EXPERIMENT SETUP AND TEST ENVIRONMENT UCM-S1**

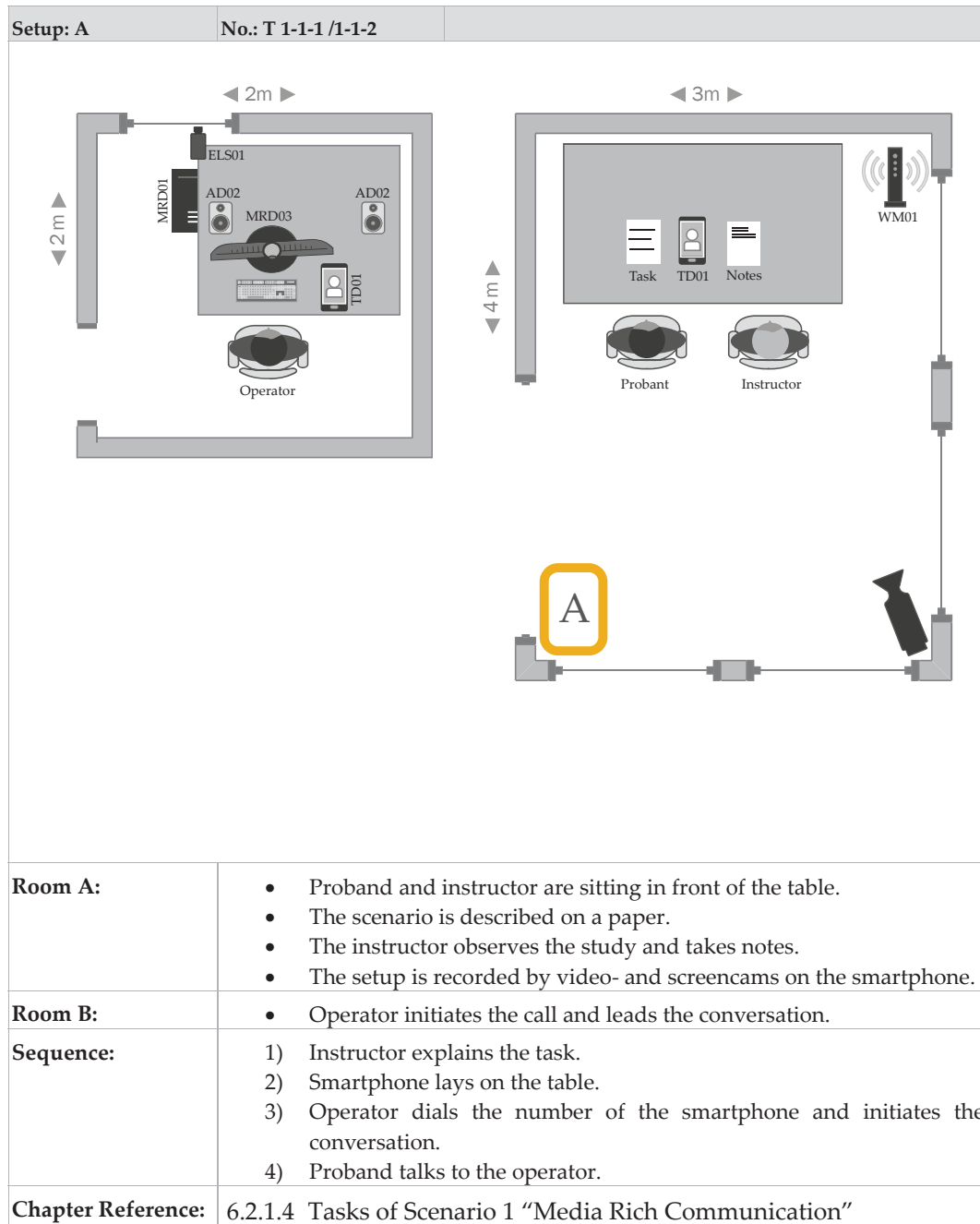


Figure 67: Setup A, T 1-1-1 / 1-1-2

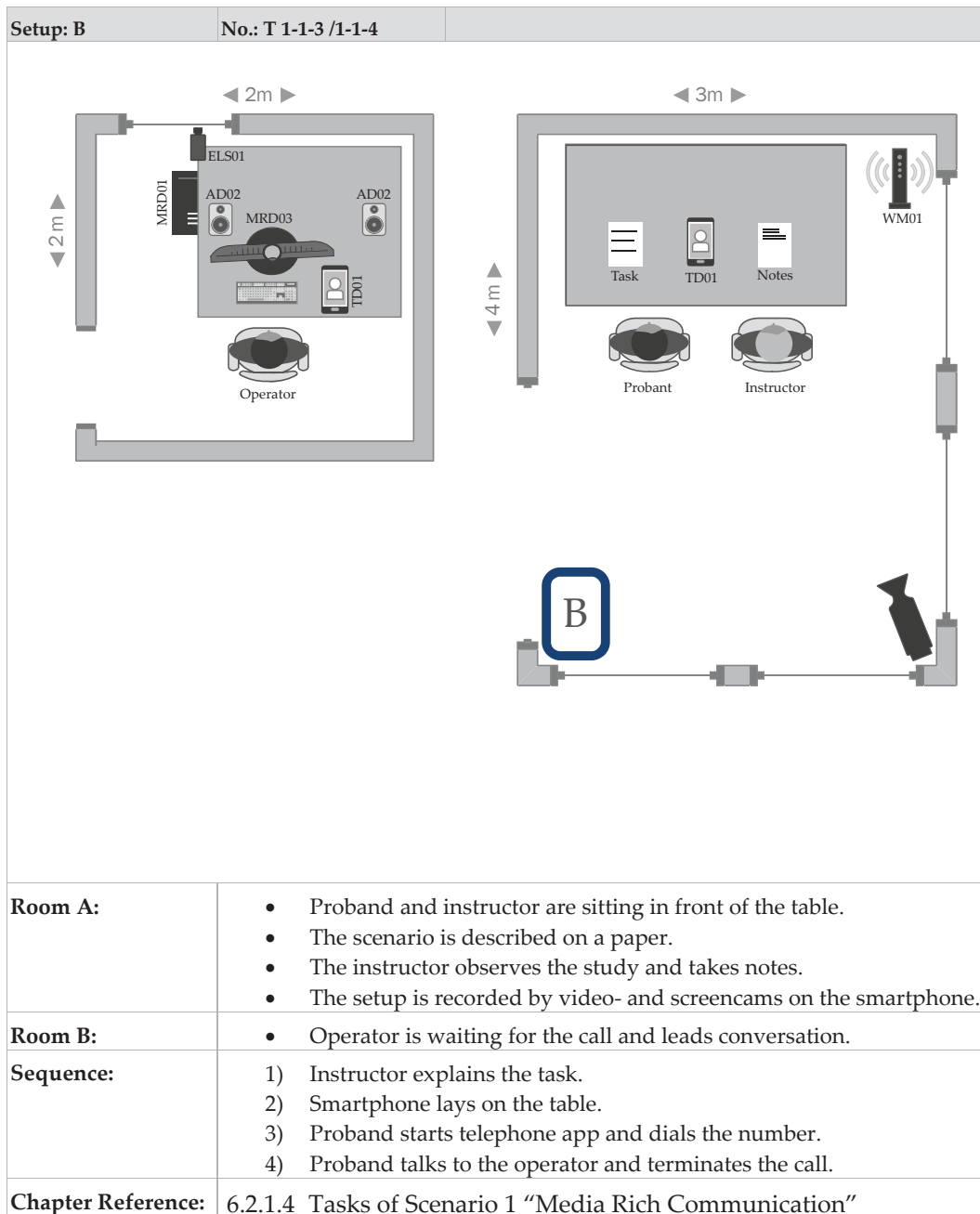


Figure 68: Setup B, T 1-1-3 / 1-1-4



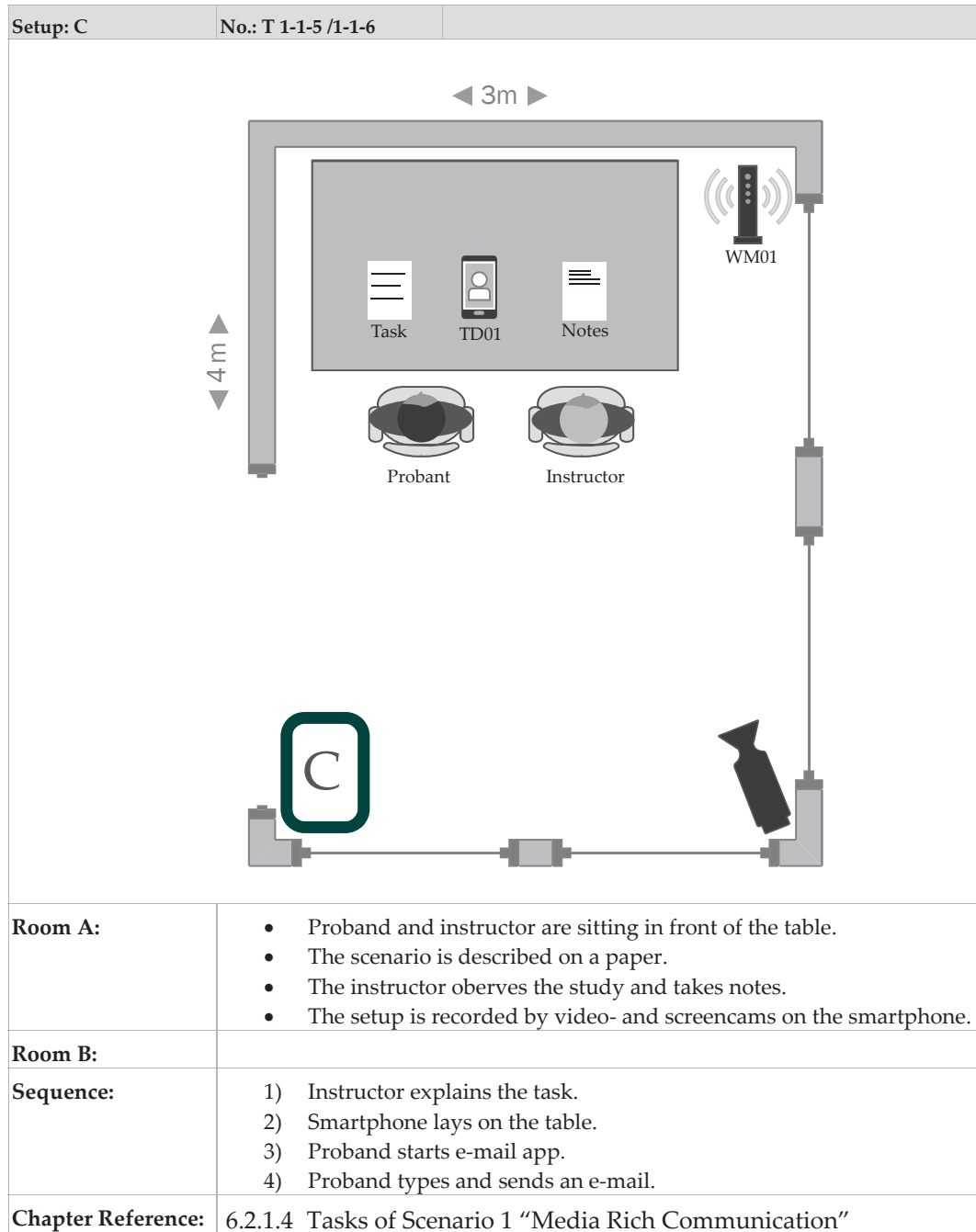


Figure 69: Setup C, T 1-1-5 / 1-1-6

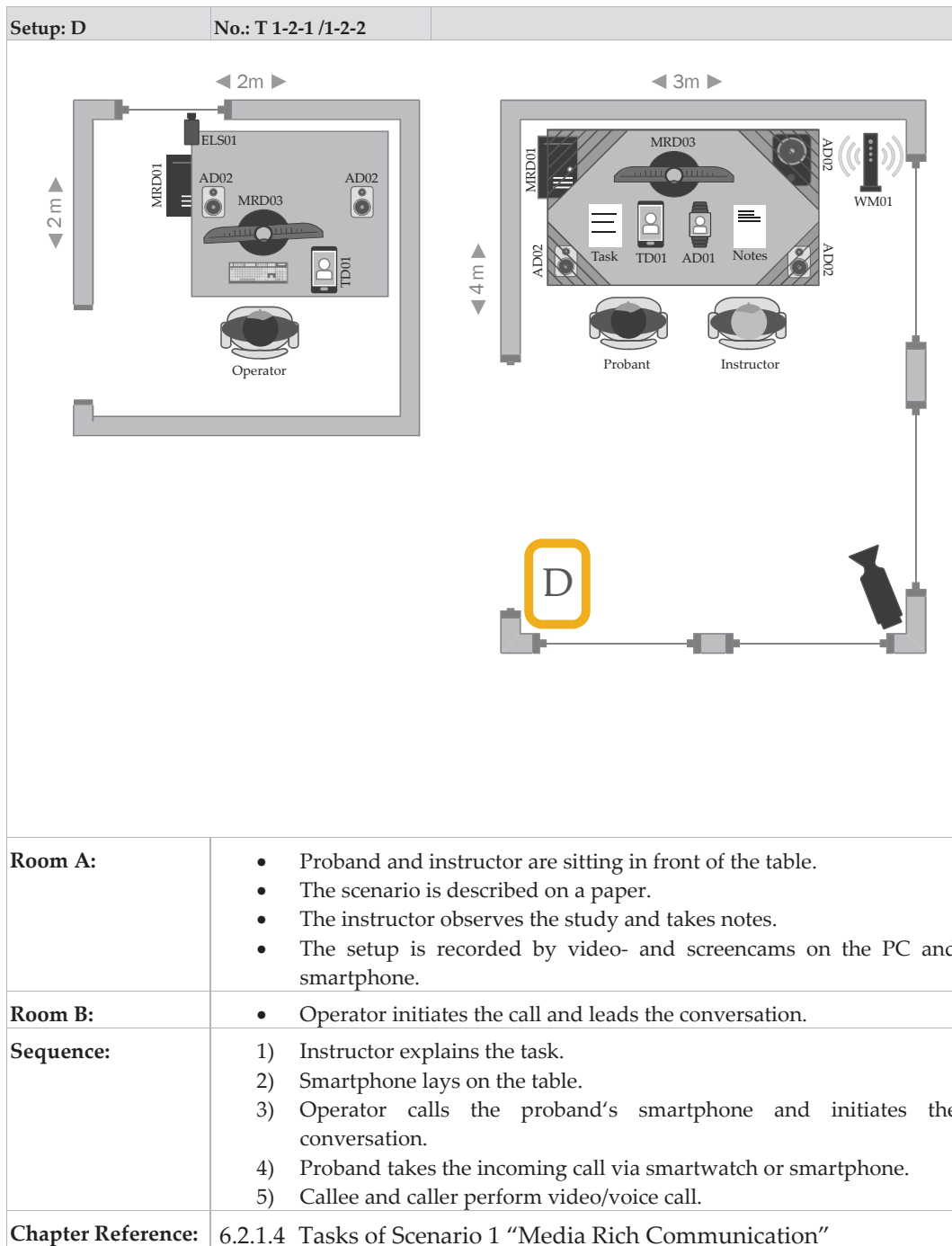


Figure 70: Setup D, T 1-2-1 / 1-2-2

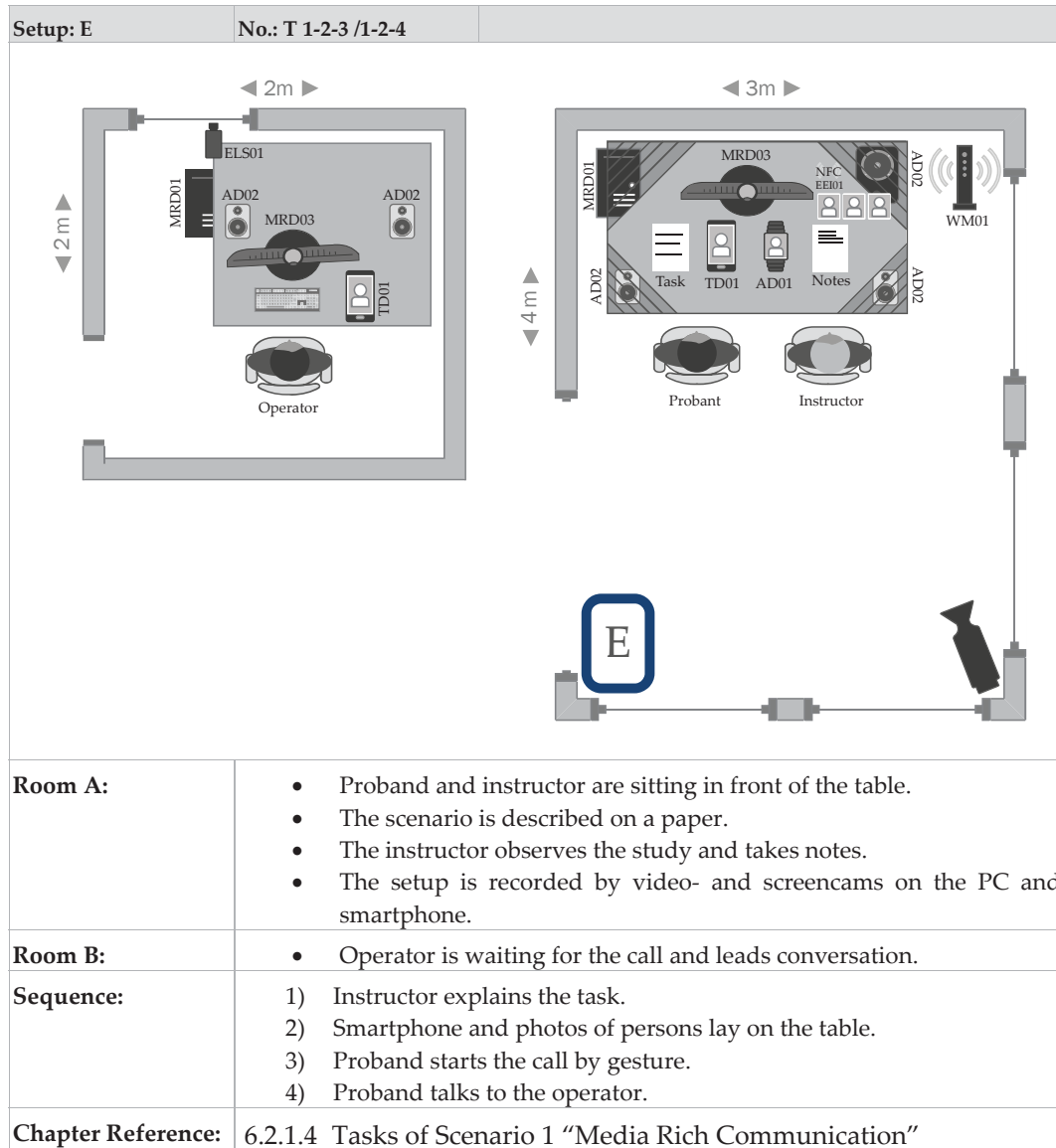


Figure 71: Setup E, T 1-2-3 / 1-2-4

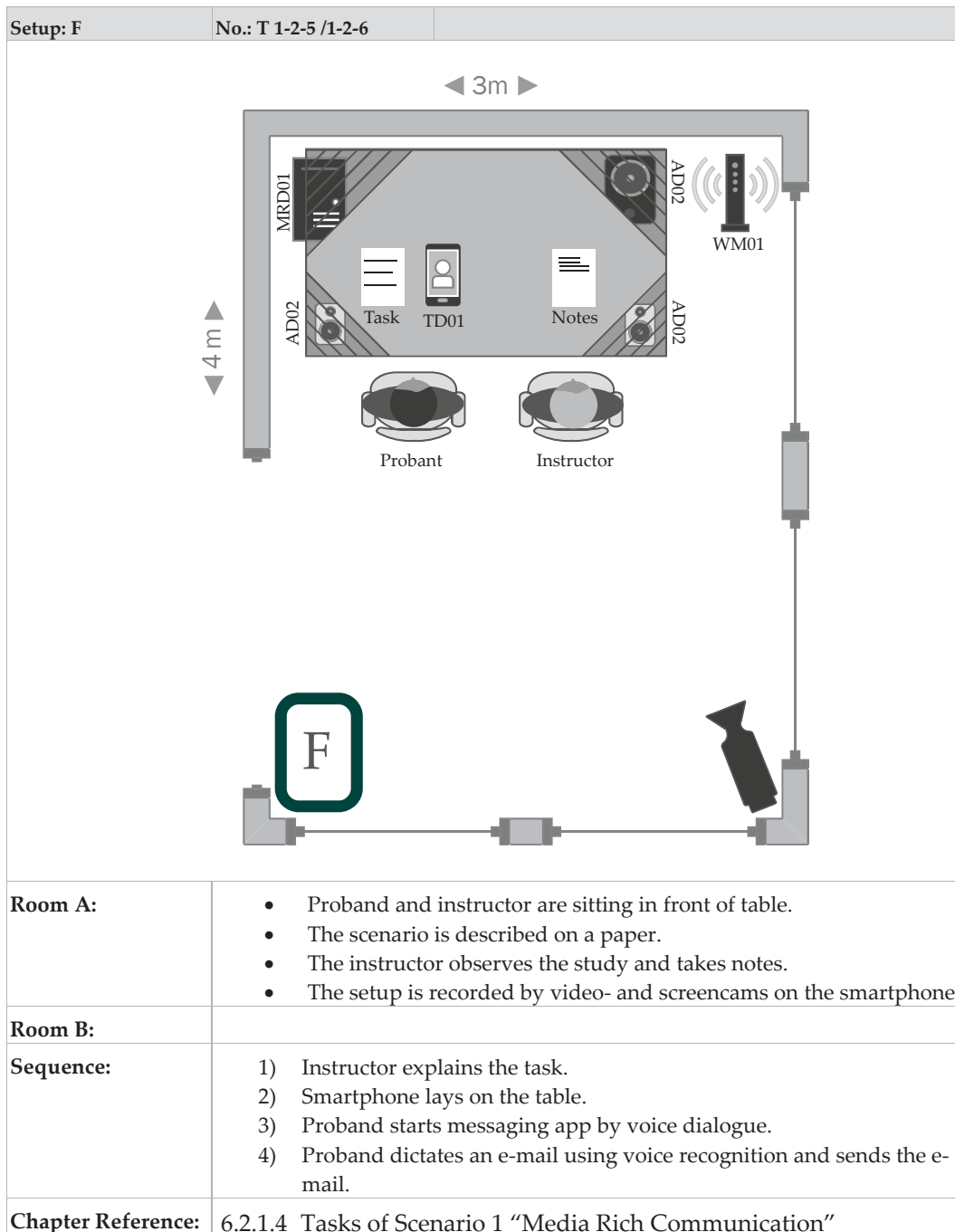
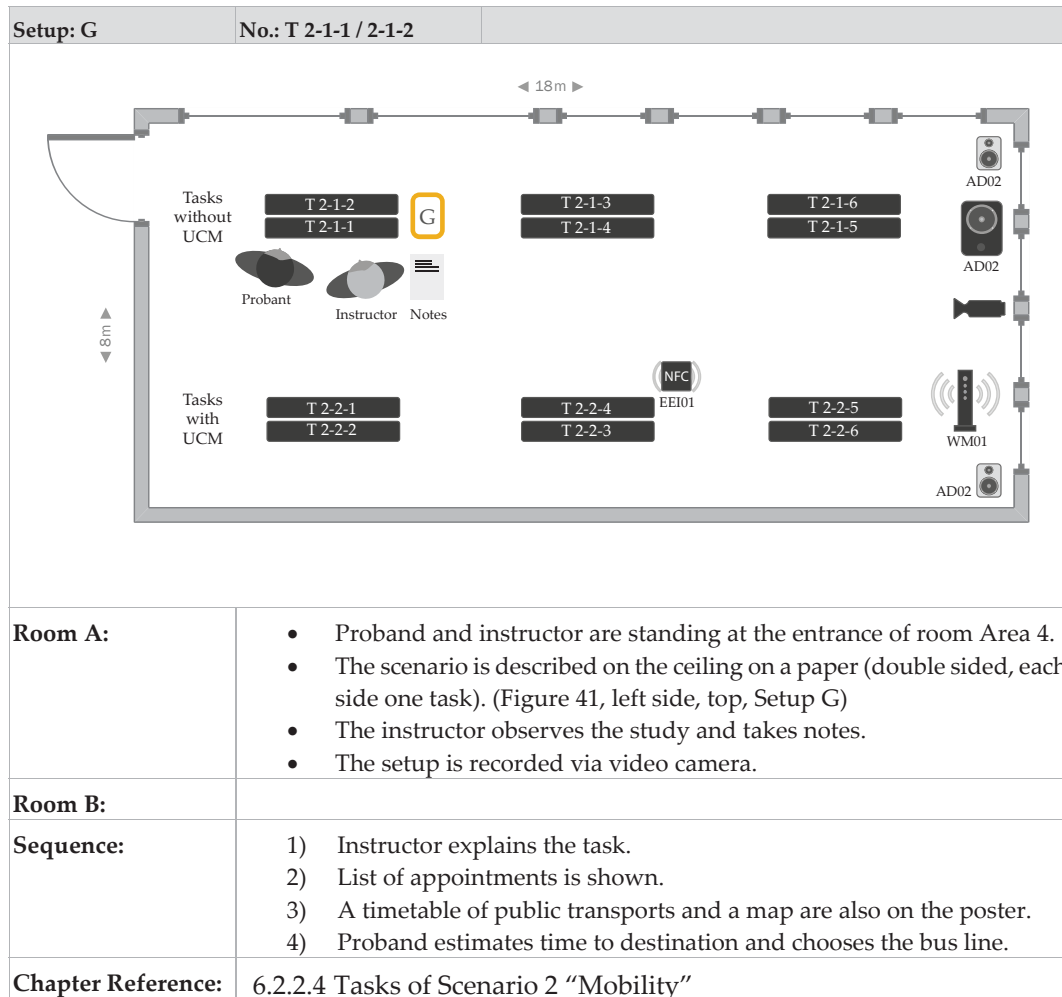


Figure 72: Setup F, T 1-2-5 / 1-2-6

**C-2. EXPERIMENT SETUP AND TEST ENVIRONMENT UCM-S2**



**Figure 73: Setup G, T 2-1-1 / 2-1-2**

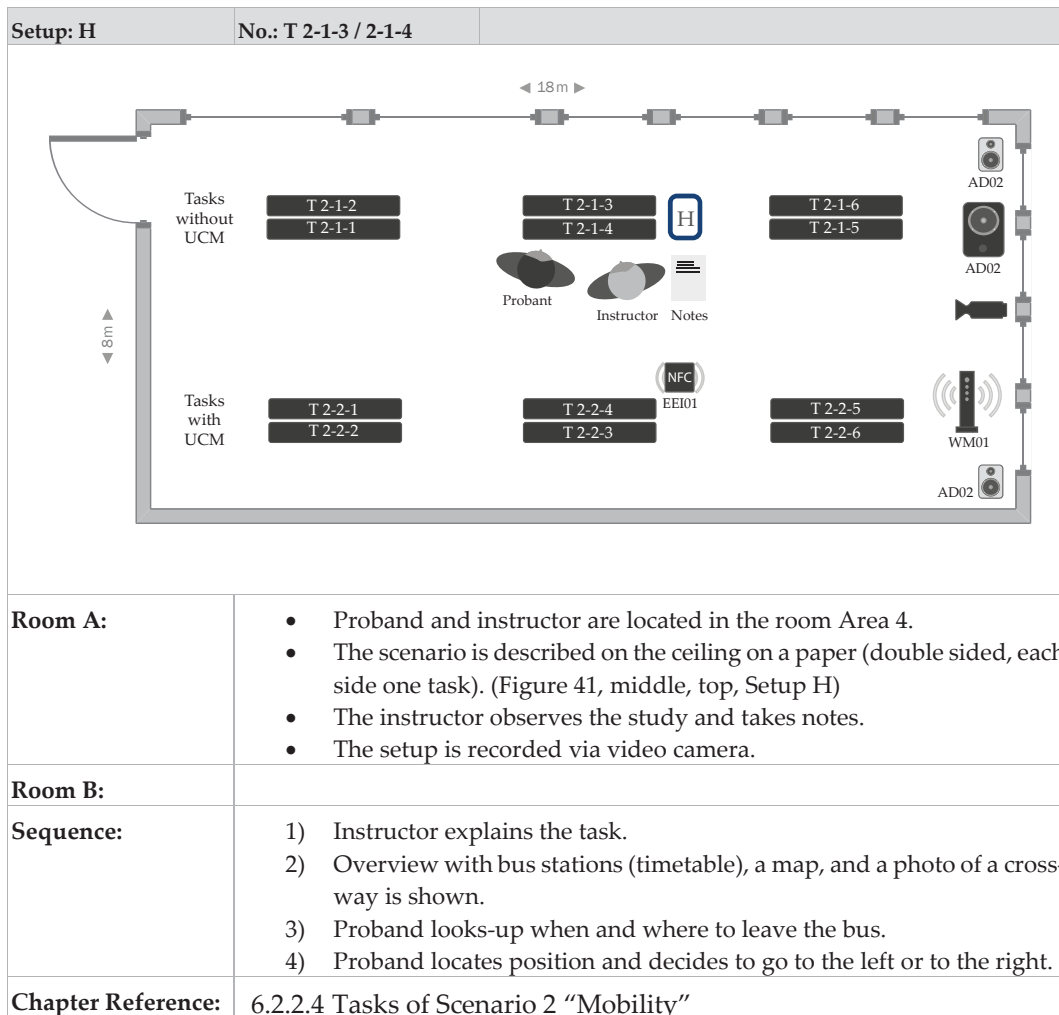


Figure 74: Setup H, T 2-1-3 / 2-1-4

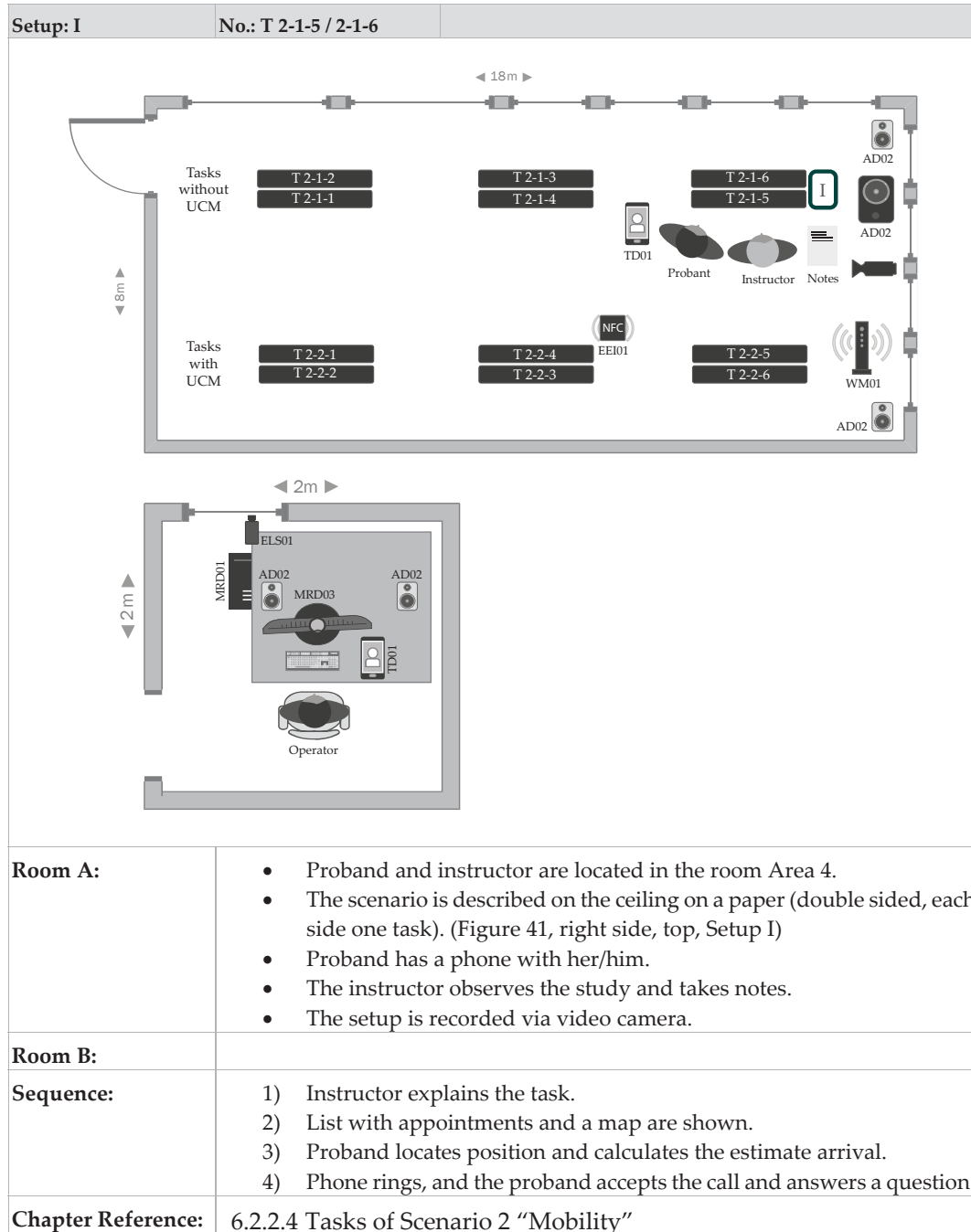


Figure 75: Setup I, T 2-1-5 / 2-1-6

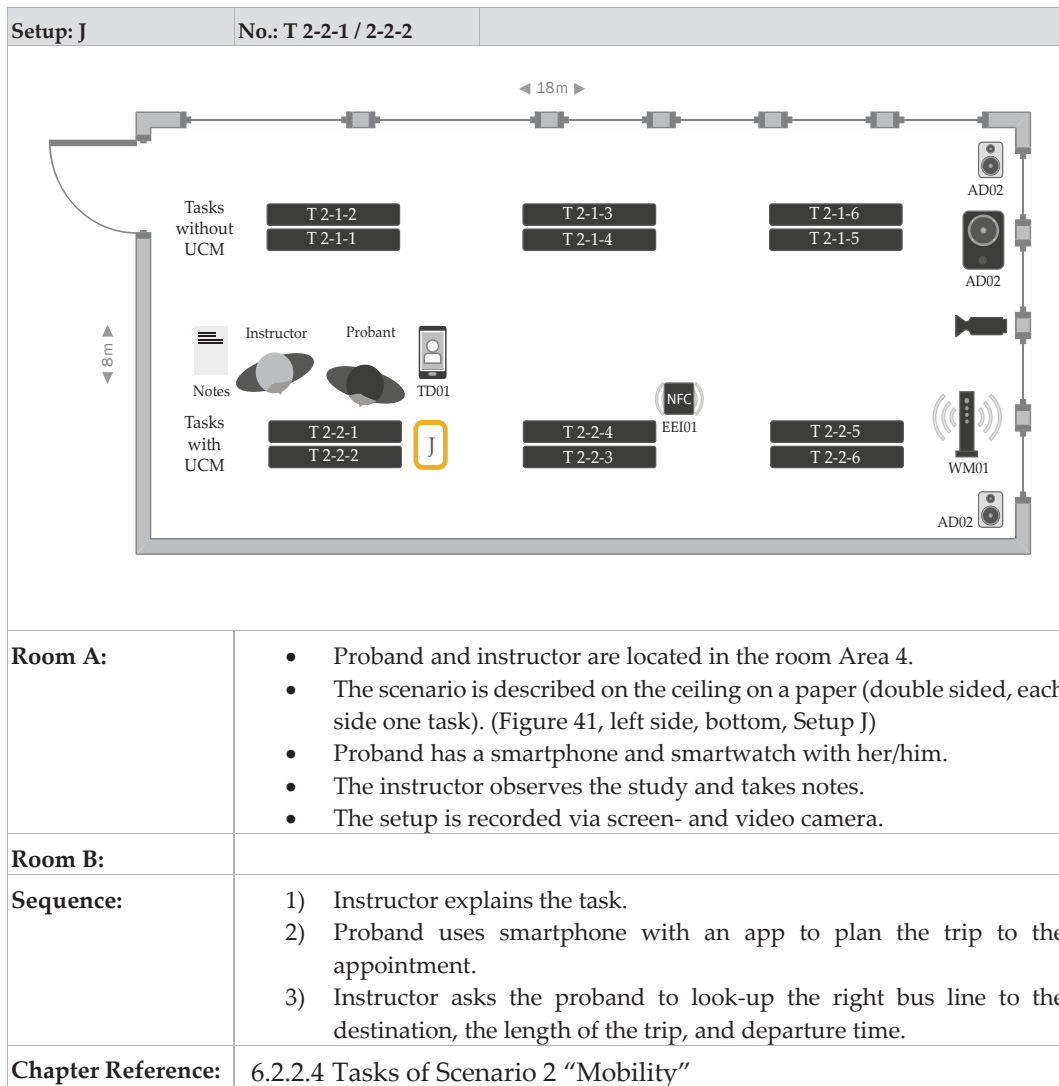


Figure 76: Setup J, T 2-2-1 / 2-2-2



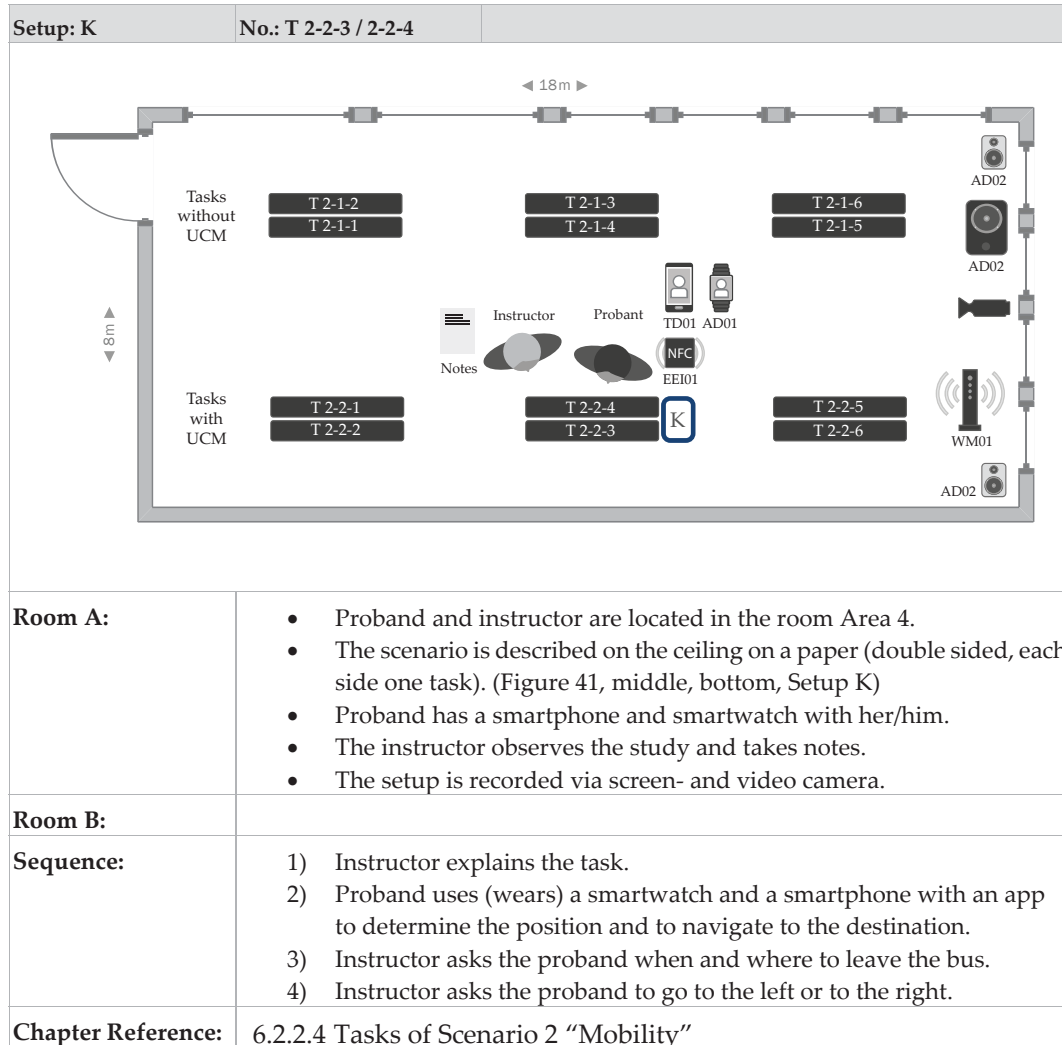


Figure 77: Setup K, T 2-2-3 / 2-2-4

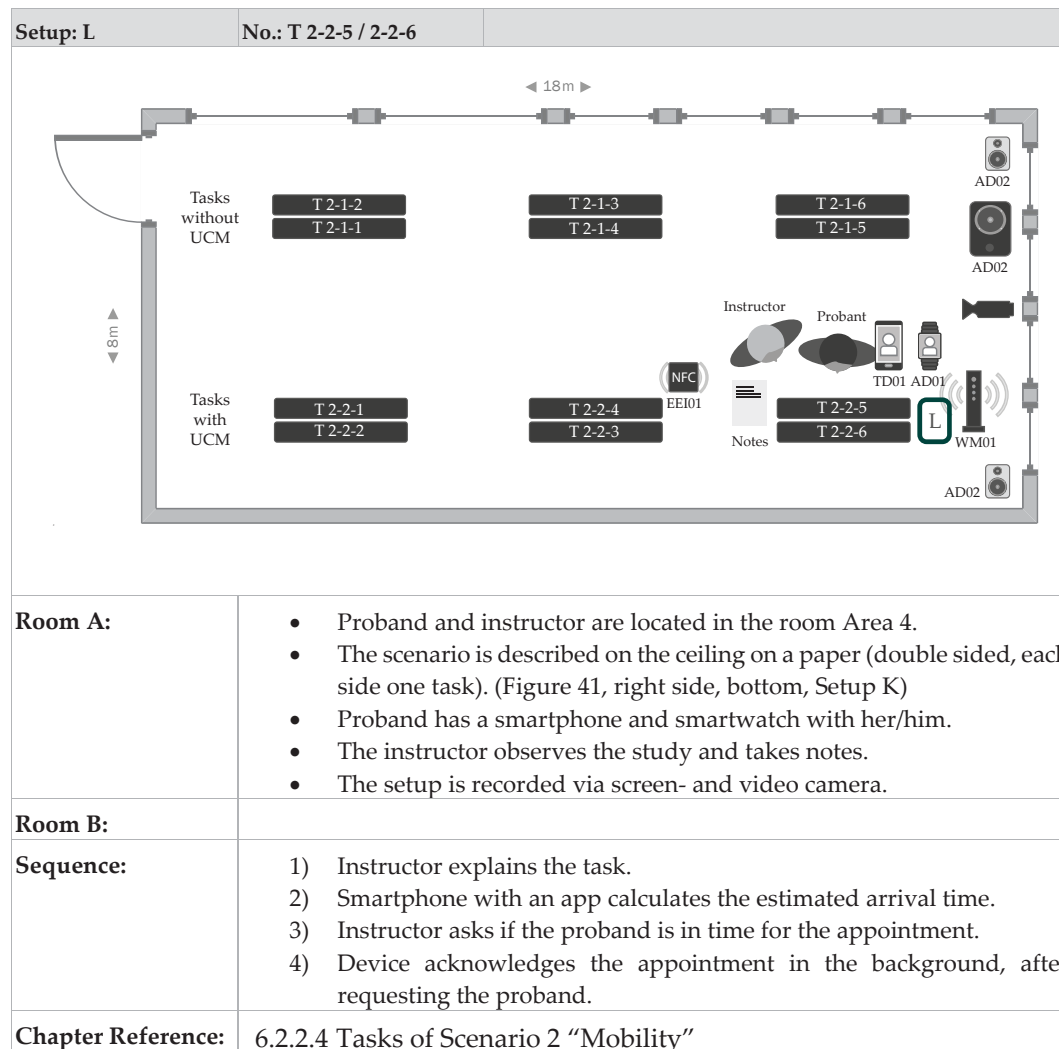


Figure 78: Setup L, T 2-2-5 / 2-2-6

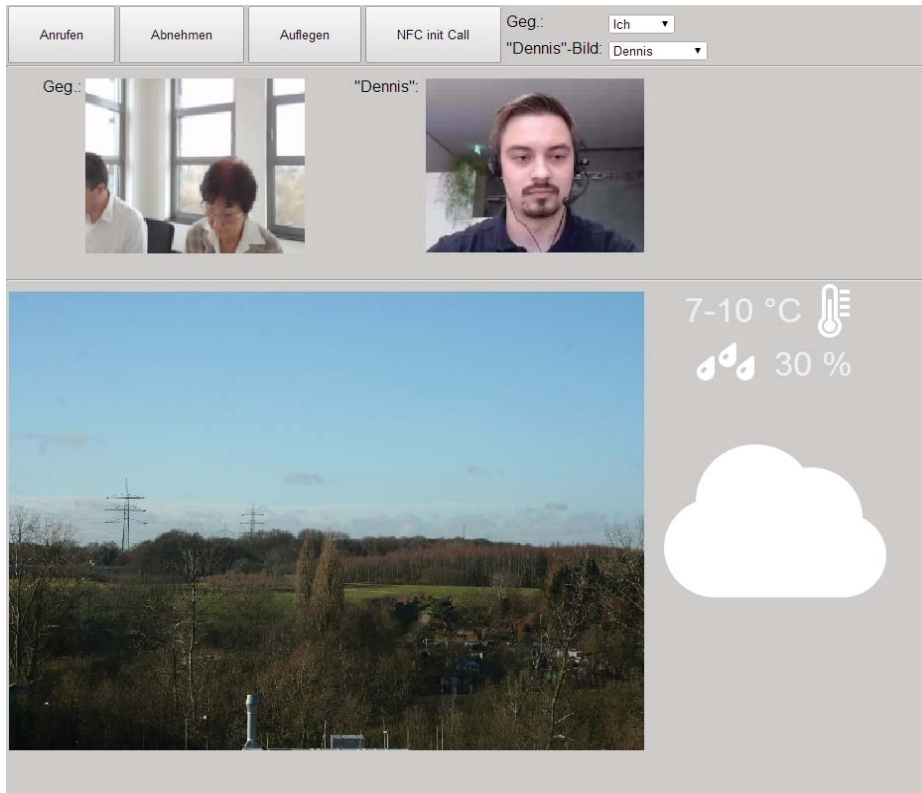
**D-1. UCM-S1 APPLICATION**

Figure 79: Operator Admin Panel for UCM-S1

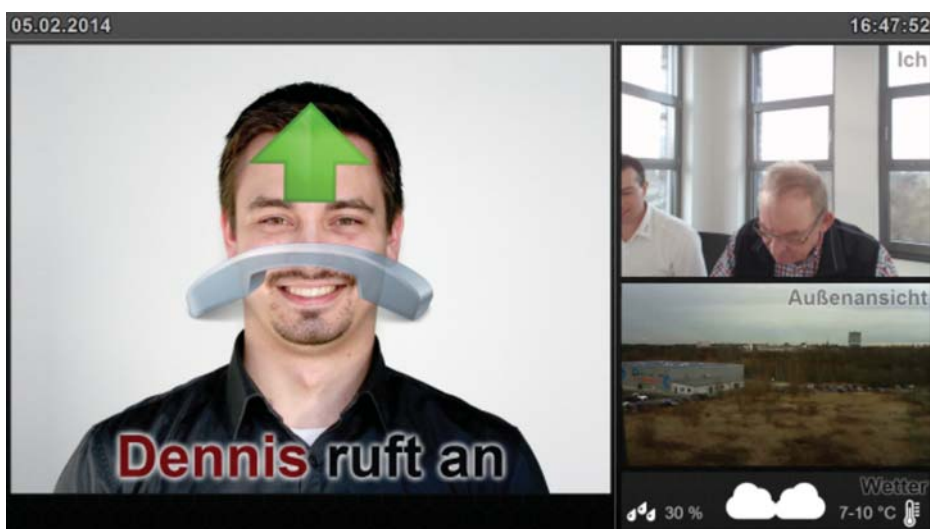


Figure 80: UCM-S1 Communication Screen of Media Rich Device



Figure 81: UCM-S1 Start Screen on Touch Device



Figure 82: UCM-S1 Caller Screen on Touch Device



Figure 83: UCM-S1 Caller Screen on Smartwatch



Figure 84: UCM-S1 Proband Call Screen on Touch Device

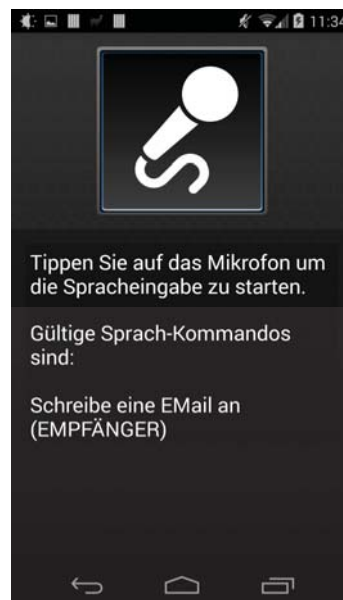


Figure 85: UCM-S1 Start Screen of Message App on Touch Device

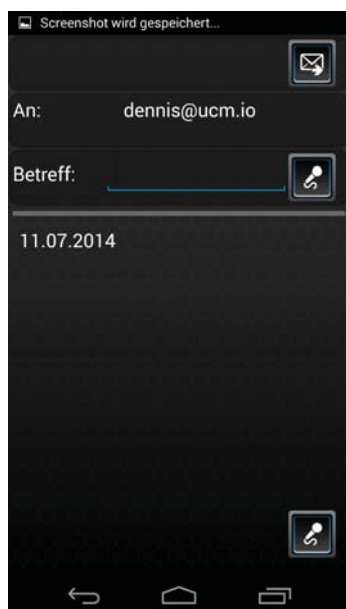


Figure 86: UCM-S1 Message App "Write Message Dialogue" on Touch Device

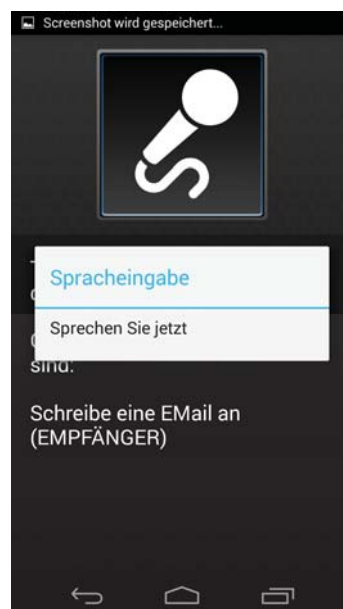


Figure 87: UCM-S1 Message App with STT Dialogue on Touch Device

## D-2. UCM-S2 APPLICATION

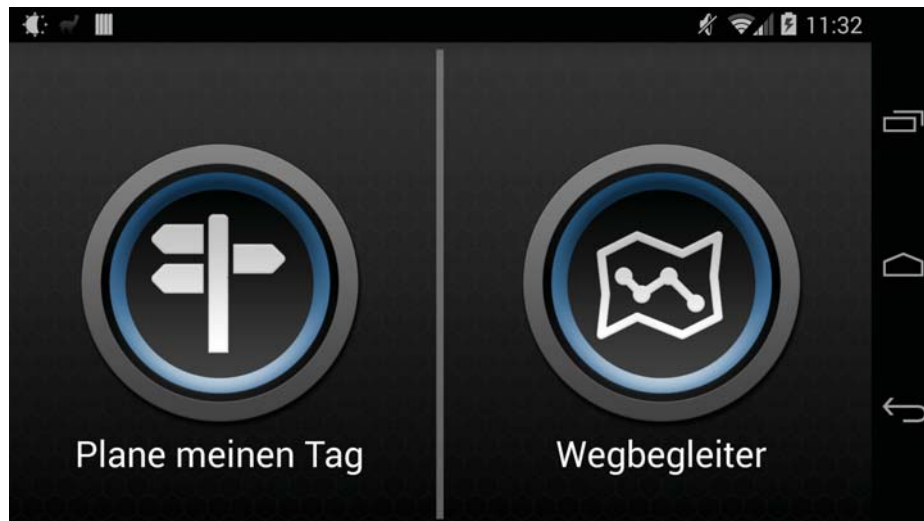


Figure 88: UCM-S2 Start Screen "Plan My Day" of Touch Device



Figure 89: UCM-S2 "Plan a Trip" Overview Screen of Touch Device

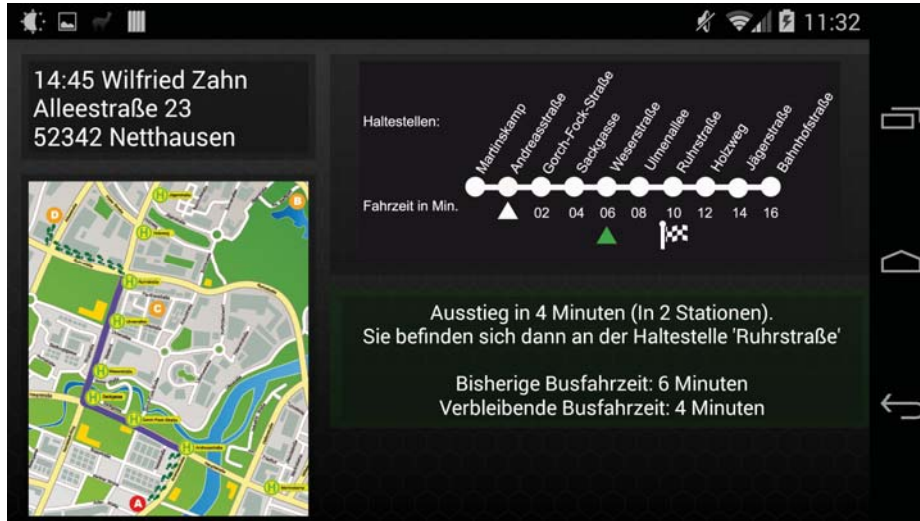


Figure 90: UCM-S2 "Riding the Bus" Screen of Touch Device



Figure 91: UCM-S2 "Augmented Navigation" Screen of Touch Device



Figure 92: UCM-S2 "Check Timeline" Screen of Smartwatch

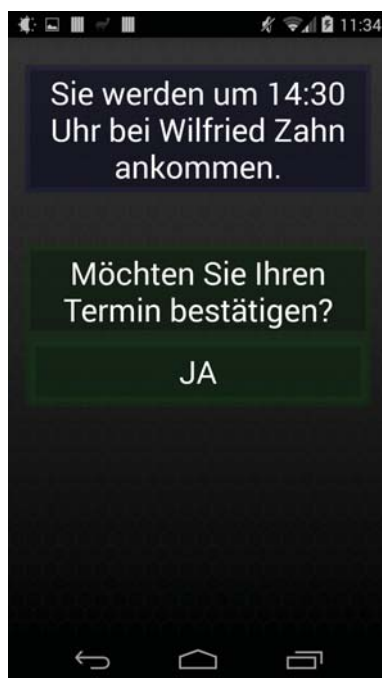


Figure 93: UCM-S2 "Acknowledge Appointment" Screen of Touch Device



Figure 94: UCM-S2 "Acknowledge Appointment" Screen of Smartwatch

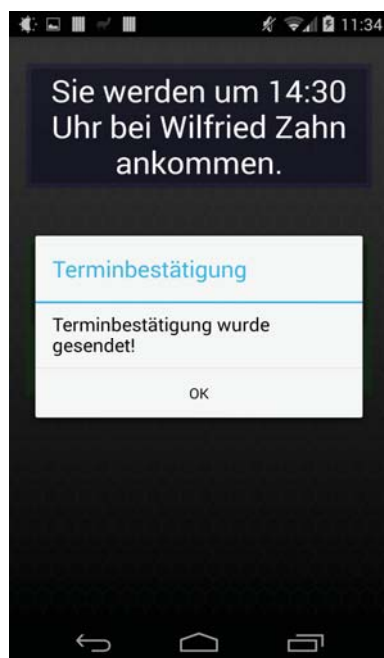


Figure 95: UCM-S2 "Acknowledgement Send" Screen of Touch Device



Figure 96: UCM-S2 "Acknowledgement Send" Screen of Smartwatch



## D-3. UCM-LEARNING APPLICATION

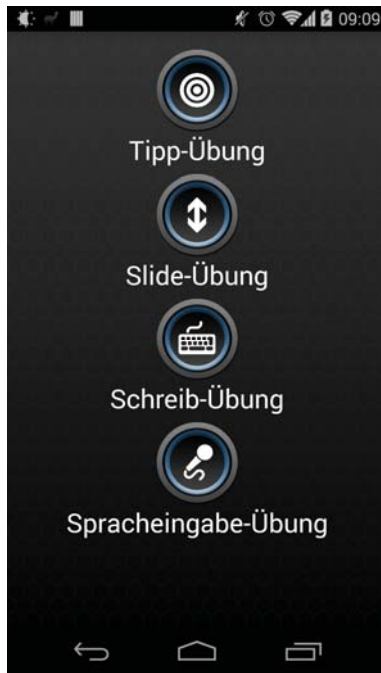


Figure 97: UCM-Learning App Exercise Overview

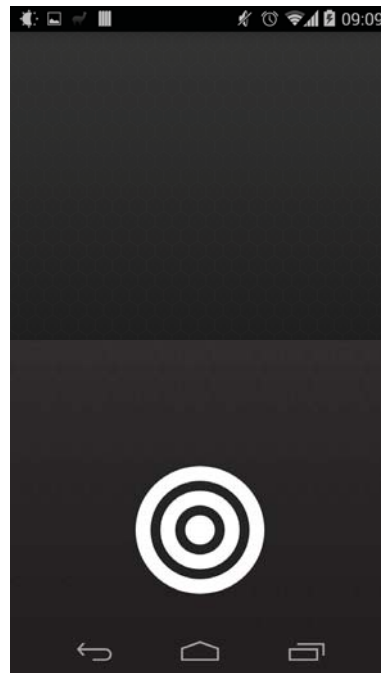


Figure 98: UCM-Learning App "Press the Button"

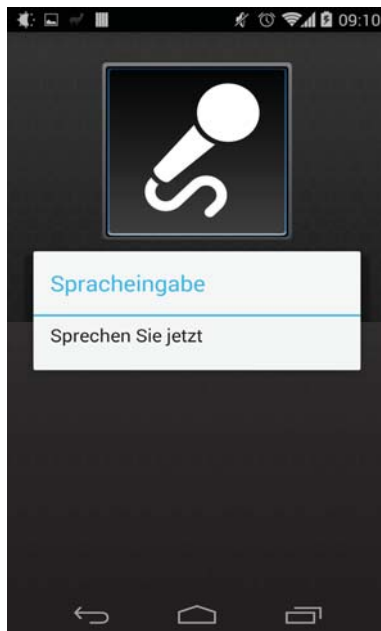


Figure 99: UCM Learning App "STT Input"

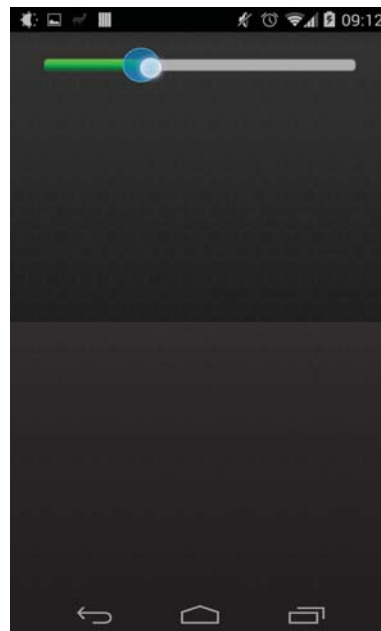


Figure 100: UCM Learning App "Sliding Button"

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**E-1. EXPERIMENTAL MEASUREMENTS OF SCENARIO 1**

Measurement values (in Seconds) of 30 probands (P1 to P30) of Scenario 1 “Media Rich Communication” without (T 1-1-1 to T 1-1-6) and with UCM (T 1-2-1 to T 1-2-6).

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
T 1-1-1	6	19	5	4	4	5	4	7	4	7	4	4	3	3	8
T 1-1-2	23	28	33	30	22	23	22	37	38	19	27	23	19	20	29
T 1-1-3	56	21	40	32	19	22	17	17	35	20	19	17	12	18	21
T 1-1-4	23	31	28	35	36	29	41	36	42	20	27	39	19	31	29
T 1-1-5	12	15	21	23	8	11	7	7	17	10	10	11	24	8	5
T 1-1-6	166	182	162	113	69	88	90	92	216	89	75	64	48	96	97
T 1-2-1	7	4	6	3	2	6	4	5	5	5	4	4	4	8	9
T 1-2-2	23	24	21	20	34	17	23	30	20	19	17	18	12	16	18
T 1-2-3	16	1	2	2	2	2	1	4	4	14	4	6	3	2	3
T 1-2-4	24	24	20	19	19	21	29	34	30	20	18	21	19	22	20
T 1-2-5	10	7	6	5	3	5	5	5	7	3	4	6	5	6	6
T 1-2-6	114	51	34	23	50	31	23	20	72	87	48	18	15	50	42
	P16	P17	P18	P19	P20	P21	P21	P23	P24	P25	P26	P27	P28	P29	P30
T 1-1-1	3	6	7	4	3	5	6	3	7	6	4	4	2	2	9
T 1-1-2	19	26	19	18	24	35	23	19	23	24	21	26	29	21	29
T 1-1-3	16	24	15	15	16	18	32	19	18	28	23	17	19	21	24
T 1-1-4	19	20	20	18	24	30	19	19	20	29	23	28	25	24	21
T 1-1-5	11	7	10	9	14	7	16	11	11	18	17	16	9	20	15
T 1-1-6	80	100	58	100	110	125	115	100	84	131	103	150	73	114	137
T 1-2-1	5	4	4	3	3	4	5	3	3	3	4	8	2	10	4
T 1-2-2	13	15	14	10	19	16	14	14	20	17	15	16	19	16	19
T 1-2-3	2	3	4	4	3	2	2	3	2	3	2	2	2	7	4
T 1-2-4	16	19	18	18	19	18	21	16	27	18	16	29	20	16	20
T 1-2-5	3	5	8	7	4	5	4	5	4	6	4	9	6	5	7
T 1-2-6	25	25	64	38	45	21	46	32	22	43	30	37	29	34	26

Table 71: Experimental Measurements of Scenario 1 without and with UCM

**E-2. EXPERIMENTAL MEASUREMENTS OF SCENARIO 2**

Measurement values (in Seconds) of 30 probands (P1 to P30) of Scenario 2 “Mobility” without (T 2-1-1 to T 2-1-6) and with UCM (T 2-2-1 to T 2-2-6).

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
T 2-1-1	114	49	89	153	77	82	86	69	138	71	63	80	89	75	94
T 2-1-2	91	99	106	65	27	28	70	39	69	25	36	40	28	26	82
T 2-1-3	32	41	39	5	27	4	14	6	61	22	21	11	28	15	30
T 2-1-4	12	34	21	14	2	8	17	24	6	85	2	12	7	12	15
T 2-1-5	65	70	41	32	10	44	33	27	21	15	38	27	63	8	76
T 2-1-6	40	32	30	30	40	24	27	19	33	26	29	31	18	18	34
T 2-2-1	62	23	46	29	21	25	11	11	19	29	21	21	25	5	9
T 2-2-2	37	19	32	13	57	5	10	28	52	19	17	16	21	18	16
T 2-2-3	19	29	34	27	15	20	14	31	28	34	14	13	20	31	24
T 2-2-4	12	17	19	13	14	9	11	9	8	9	10	10	9	14	8
T 2-2-5	10	15	15	11	8	8	8	8	13	10	16	8	10	14	14
T 2-2-6	4	3	10	12	4	3	5	2	8	4	3	3	3	5	5
	P16	P17	P18	P19	P20	P21	P21	P23	P24	P25	P26	P27	P28	P29	P30
T 2-1-1	45	79	31	29	94	94	46	70	126	90	86	106	93	57	121
T 2-1-2	47	44	26	31	86	85	20	34	51	90	48	95	44	39	95
T 2-1-3	10	29	21	14	8	10	5	11	6	17	6	11	20	15	38
T 2-1-4	17	13	5	15	2	5	3	9	7	8	8	8	10	4	6
T 2-1-5	19	41	10	14	11	52	24	51	38	27	16	11	28	21	58
T 2-1-6	24	31	21	16	18	33	22	21	39	25	20	55	27	29	44
T 2-2-1	7	10	12	9	25	40	22	9	11	18	12	51	9	20	19
T 2-2-2	16	32	5	5	5	69	29	16	22	44	24	16	13	48	24
T 2-2-3	16	18	14	15	17	48	14	21	14	21	18	42	22	17	54
T 2-2-4	13	11	13	7	13	9	8	10	7	7	8	7	7	6	9
T 2-2-5	9	12	18	6	6	8	10	7	8	7	1	5	6	6	10
T 2-2-6	3	3	2	1	2	4	3	1	2	6	2	3	1	1	3

Table 72: Experimental Measurements of Scenario 2 without and with UCM

### E-3. QUESTIONNAIRE VALUES OF PROBANDS ICT USAGE

Questionnaire values of the 30 probands (P1 to P15) about their ICT usage.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Q 0-0-1	70	69	67	70	66	60	58	73	73	73	62	59	62	63	56
Q 0-0-2	F	M	F	F	M	F	F	M	F	M	F	M	F	M	M
Q 0-0-3	P	P	P	P	W	P	W	P	W	P	W	W	P	P	W
Q 0-0-4	House wife	Engi neer	House wife	Mana ger	Archi tect	House wife	Teacher	Techni cian	House wife	Director IT	Depart ment chief	Archi tect	Teacher	Teacher	Techni cian
Q 0-1-1	2	2	3	2	2	2	2	2	1	2	2	2	2	2	2
	3	3	5	3	3	3	3	3		3	3	3	3	3	3
	5	5			4			4		4	4	4	4	4	4
Q 0-1-2	3	2	1	4	5	4	3	5	-	7	4	6	4	7	4
Q 0-1-3	7" Tab	7" Tab	7" Tab	-	7" Tab	-	-	Lap- top	-	S3 mini	iPh	S4	S3	S3	iPh
Q 0-1-4	4	5	5	5	6	5	5	6	-	6	6	6	5	6	5
Q 0-1-5	5	6	6	7	6	5	6	6	-	7	7	7	5	7	6
Q 0-1-6	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1
	4	4	4	2	3	2	3	2		2	4	2	3	2	2
	8	7	8	4	5	3	8	3		3	5	3	4	3	3
	9	8	10	10	8	9	10	4		4	8	4	5	4	7
	10	9		11	10	10	11	5		5	9	5	6	9	8
		10	11		11			8		7	10	7	7	10	9
							9		8	11	8	8	11	10	
							10		9		9	10		11	
							11		10		10	11			
									11		11				
Q 0-2-1	1	1	-	-	3	-	8	-	-	10	-	1	-	-	-
	9	8					9					2			
	11	10										3			
												5			
												9			
												10			
Q 0-2-3	9	1	9	9	9	9	4	5	9	6	9	9	9	6	8

Table 73: Questionnaire Values of Probands (P1-P15) ICT Usage

Questionnaire values of the 30 probands (P16 to P30) about their ICT usage.

	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30
Q 0-0-1	60	66	63	64	76	69	67	65	68	69	66	72	67	75	72
Q 0-0-2	F	F	M	M	M	F	F	F	M	M	F	M	M	M	M
Q 0-0-3	P	P	P	P	W	P	P	P	P	P	P	P	W	P	P
Q 0-0-4	Office Worker	Office Worker	Manager	Manager	CEO	CEO	Office Worker	Office Worker	Office Worker	Office Director	Project Manager	Housewife	Scientist	Director	Doctor
Q 0-1-1	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2
	3	3	3	3	3	4	3	3	3	3	3	3	3	3	3
Q 0-1-1			4	5	4	5		4	5				4	4	
				5	5		5								
Q 0-1-2	2	4	8	5	4	2	2	3	2	3	3	8	4	3	3
Q 0-1-3	PC	-	iPh 4	7" Tab	iPad	iPh	-	S1	7" Tab	-	PC	-	iPh	iPh	-
Q 0-1-4	4	4	5	6	5	5	1	5	5	5	4	4	6	5	5
Q 0-1-5	5	5	7	5	6	5	1	6	6	4	5	4	6	6	5
Q 0-1-6	1	1	1	1	1	1	-	1	1	1	1	1	1	1	1
	2	3	2	2	4	8		4	2	4	4	2	2	3	2
	8	4	3	3	8	9		6	4	6	8	8	6	4	4
	9	9	4	4	9			8	10	10	10	11	7	7	8
	10	10	5	8				9	11	11	11		8	8	9
	11	11	6	9				10					10	9	
Q 0-1-6			7	10			11						11	10	
			8	11										11	
			9												
			10												
Q 0-1-6			11												
Q 0-2-1	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-
Q 0-2-3	7	4	5	5	9	5	5	1	9	6	6	9	7	9	5

Table 74: Questionnaire Values of Probands (P16-P30) ICT Usage

### Partition of Probands

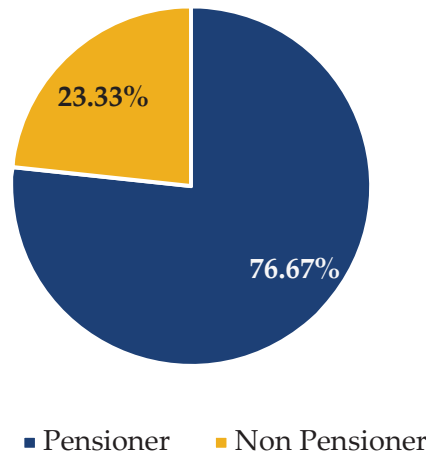


Figure 101: Partition of Probands (Pensioner / Non Pensioner)

### ICT Experience of Probands

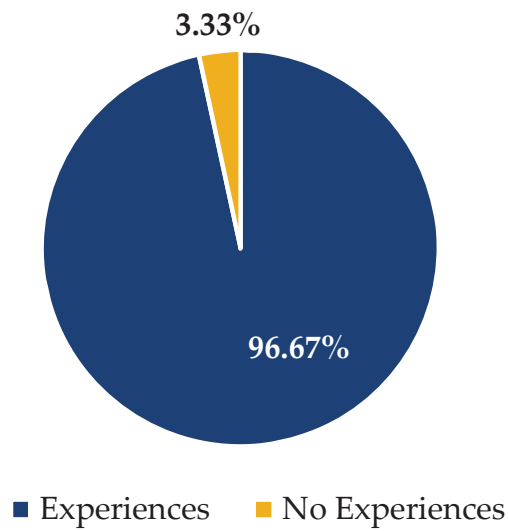


Figure 102: ICT Experience of Probands

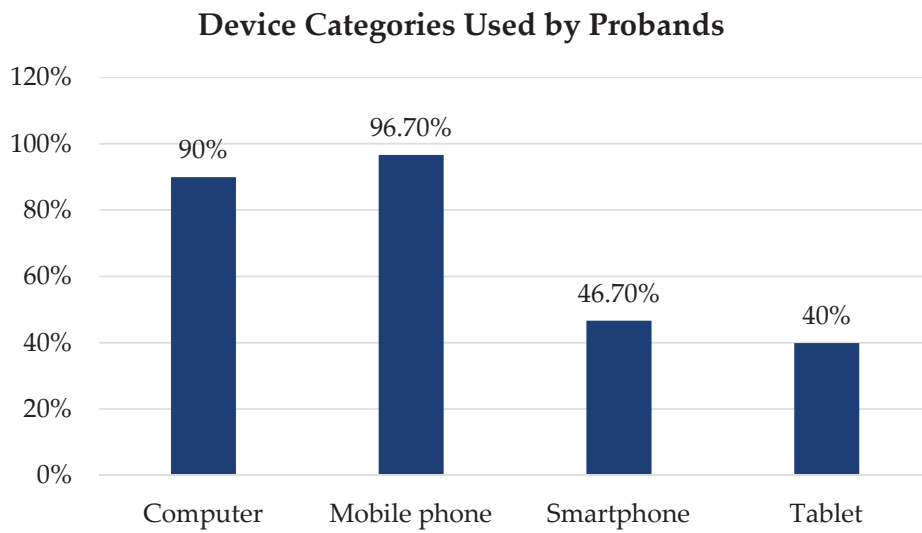


Figure 103: Device Categories Used by Probands

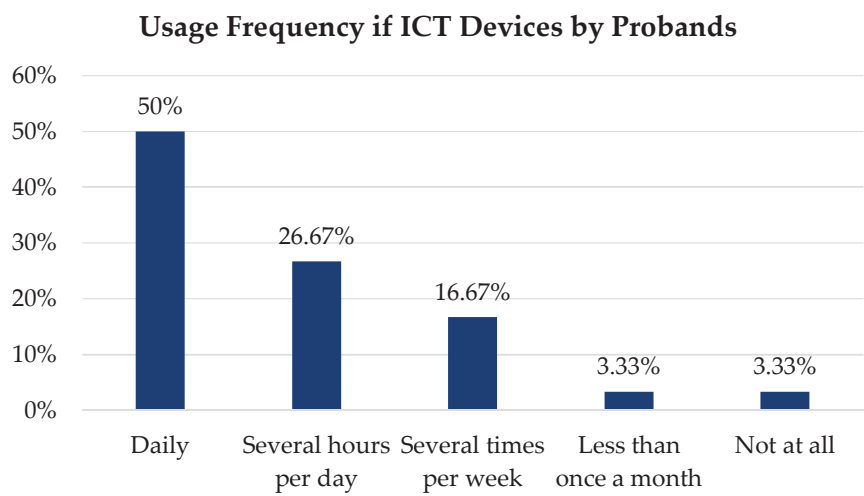


Figure 104: Usage Frequency of ICT Devices by Probands

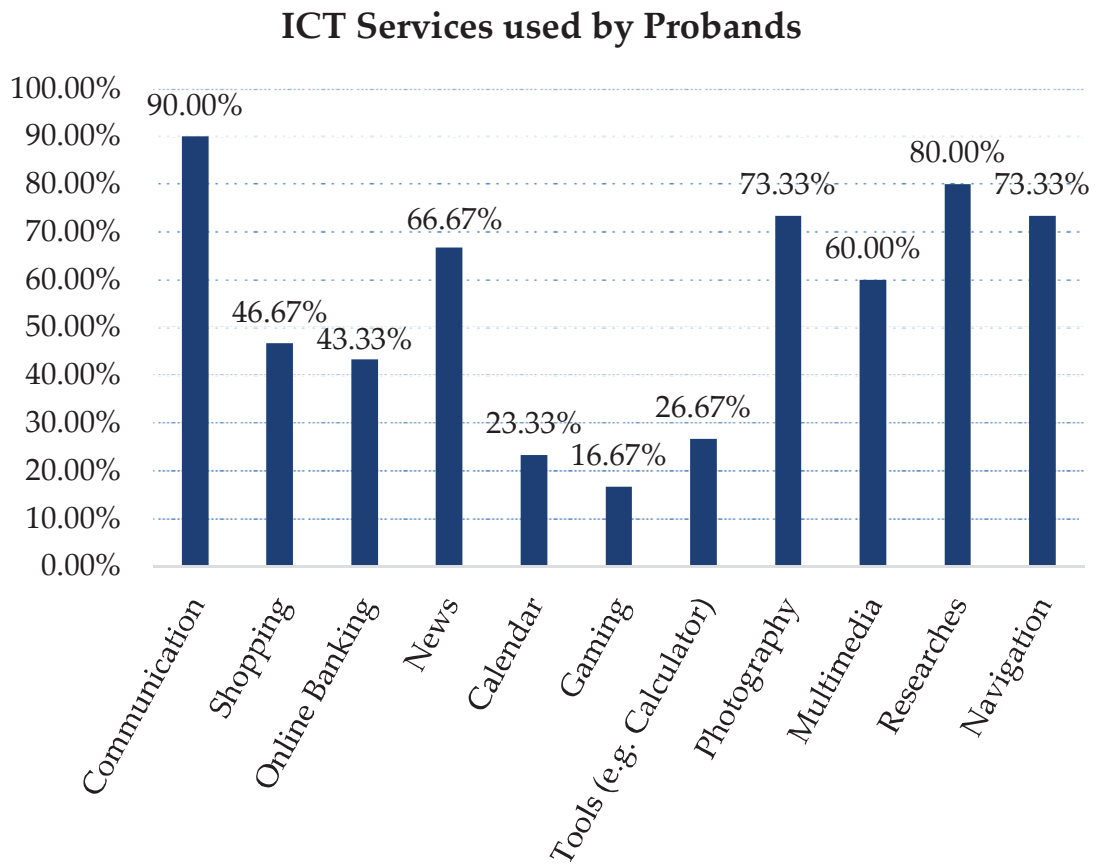


Figure 105: ICT Services Used by Probands



**E-4. QUESTIONNAIRE VALUES AND EVALUATION OF SCENARIO 1**

The table shows the questionnaire values of 30 probands (P1 to P30) of Scenario 1 “Media Rich Communication” without (T 1-1-1 to T 1-1-6) and with UCM (T 1-2-1 to T 1-2-6). The answers (in a range from one to nine) represent the attitude to the usability attributes of the task, where one is a positive and nine is a negative attitude.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Q 1-1-1	2	1	2	1	1	2	2	1	2	2	3	1	2	2	2
Q 1-1-2	7	5	5	3	5	5	5	2	3	5	7	5	3	5	5
Q 1-1-3	7	2	2	2	3	3	1	1	2	3	5	1	2	2	3
Q 1-1-4	2	2	1	3	2	5	1	1	2	2	5	1	2	1	3
Q 1-1-5	2	5	1	2	1	5	1	1	2	3	2	1	3	3	2
Q 1-1-6	8	5	2	4	2	5	2	1	2	4	5	1	3	3	5
Q 1-2-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Q 1-2-2	1	1	1	1	1	3	3	2	1	3	5	2	1	3	1
Q 1-2-3	1	1	1	1	1	1	2	1	1	3	2	1	1	1	1
Q 1-2-4	1	1	1	1	1	2	1	1	2	3	2	1	1	1	1
Q 1-2-5	1	1	1	1	1	5	2	1	1	2	1	2	2	4	1
Q 1-2-6	1	1	1	1	5	6	2	1	2	5	5	2	2	3	1
	P16	P17	P18	P19	P20	P21	P21	P23	P24	P25	P26	P27	P28	P29	P30
Q 1-1-1	1	2	1	2	2	2	4	1	1	4	1	2	1	2	4
Q 1-1-2	5	5	5	5	5	5	5	5	5	5	5	5	5	2	5
Q 1-1-3	3	2	1	2	2	2	3	1	3	3	2	1	1	3	5
Q 1-1-4	2	4	1	3	1	4	3	2	2	3	2	1	1	1	5
Q 1-1-5	3	4	1	3	1	1	5	1	1	3	2	1	1	2	5
Q 1-1-6	3	3	1	3	2	2	5	1	1	5	3	1	1	2	7
Q 1-2-1	1	2	1	1	1	1	2	1	1	4	1	1	1	1	1
Q 1-2-2	3	3	4	2	3	5	5	2	2	3	2	1	2	1	5
Q 1-2-3	1	2	3	1	1	1	1	1	1	3	1	1	1	1	1
Q 1-2-4	1	2	1	2	1	1	2	1	1	3	1	1	1	1	1
Q 1-2-5	1	4	4	1	1	1	5	1	1	4	2	1	1	1	2
Q 1-2-6	1	4	5	2	1	2	3	1	1	4	2	1	2	1	2

Table 75: Questionnaire Values of Scenario 1

Survey	Average Value	Attribute
Q 2-1-1	1.84	Errors
Q 2-1-2	4.75	Satisfaction
Q 2-1-3	2.38	Efficiency
Q 2-1-4	2.25	Efficiency
Q 2-1-5	2.22	Learnability
Q 2-1-6	3.00	Memorability
Q 2-2-1	1.16	Errors
Q 2-2-2	2.34	Satisfaction
Q 2-2-3	1.28	Efficiency
Q 2-2-4	1.31	Efficiency
Q 2-2-5	1.84	Learnability
Q 2-2-6	2.28	Memorability

Table 76: Average Values of Usability Attributes of Questionnaire of Scenario 1

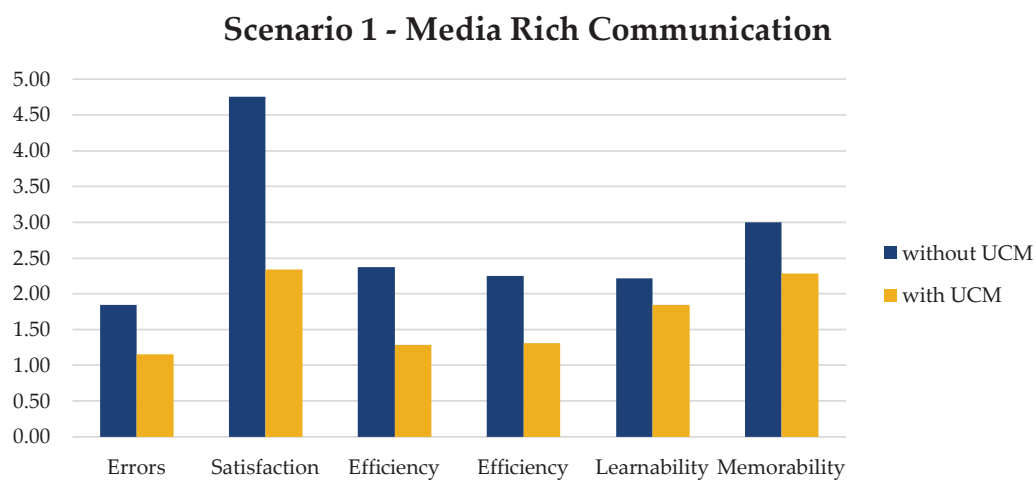


Figure 106: Questionnaire Evaluation of Scenario 1

**E-5. QUESTIONNAIRE VALUES AND EVALUATION OF SCENARIO 2**

The table shows the questionnaire values of 30 probands (P1 to P30) of Scenario 2 “Mobility” without (T 2-1-1 to T 2-1-6) and with UCM (T 2-2-1 to T 2-2-6). The answers (in a range from one to nine) represent the attitude to the usability attributes of the task, where one is a positive and nine is a negative attitude.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Q 2-1-1	5	8	4	5	3	5	6	5	5	1	5	4	2	1	6
Q 2-1-2	6	9	3	5	8	5	7	5	5	3	5	6	3	2	5
Q 2-1-3	3	3	5	3	6	2	5	6	5	3	6	3	3	2	7
Q 2-1-4	2	2	8	2	1	3	6	2	2	7	2	2	3	3	6
Q 2-1-5	5	3	7	3	8	5	7	5	2	3	2	5	4	3	6
Q 2-1-6	5	2	2	2	2	2	5	2	3	1	1	1	1	1	2
Q 2-2-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Q 2-2-2	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1
Q 2-2-3	1	1	1	1	1	1	1	1	1	2	1	1	1	2	1
Q 2-2-4	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1
Q 2-2-5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Q 2-2-6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	P16	P17	P18	P19	P20	P21	P21	P23	P24	P25	P26	P27	P28	P29	P30
Q 2-1-1	3	5	5	4	3	3	2	3	5	2	4	3	3	5	3
Q 2-1-2	5	5	6	5	5	4	4	2	5	2	4	2	3	5	5
Q 2-1-3	6	4	6	6	2	5	2	1	6	2	3	5	3	5	3
Q 2-1-4	5	2	7	6	1	3	2	1	4	2	2	1	1	1	1
Q 2-1-5	3	5	3	4	2	5	2	2	6	1	2	1	1	5	5
Q 2-1-6	1	3	1	3	1	2	1	1	1	1	2	1	1	1	2
Q 2-2-1	1	2	1	1	1	1	1	1	1	2	1	1	1	1	1
Q 2-2-2	1	2	1	1	1	1	1	1	1	1	1	1	1	2	1
Q 2-2-3	1	4	1	1	5	1	1	1	1	1	2	1	3	1	2
Q 2-2-4	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1
Q 2-2-5	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1
Q 2-2-6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 77: Questionnaire Values of Scenario 2

Survey	Average Value	Attribute
Q 2-1-1	3.91	Efficiency
Q 2-1-2	4.66	Learnability
Q 2-1-3	3.94	Satisfaction
Q 2-1-4	2.88	Memorability
Q 2-1-5	3.69	Learnability
Q 2-1-6	1.78	Errors
Q 2-2-1	1.06	Efficiency
Q 2-2-2	1.13	Learnability
Q 2-2-3	1.41	Satisfaction
Q 2-2-4	1.06	Memorability
Q 2-2-5	1.06	Learnability
Q 2-2-6	1.00	Errors

Table 78: Average Values of Usability Attributes of Questionnaire of Scenario 2

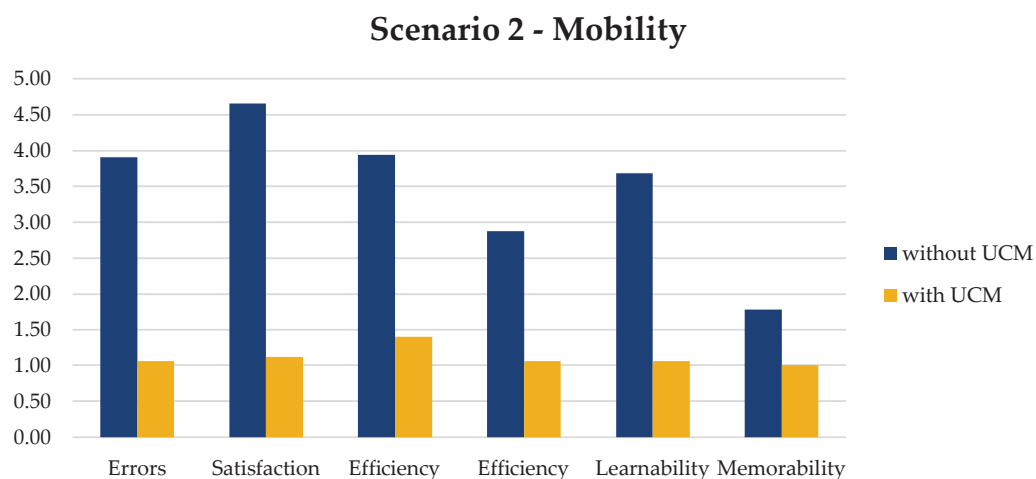


Figure 107: Questionnaire Evaluation of Scenario 2

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