ESPOO 2007 VTT RESEARCH NOTES 2376

Design Issues in All-IP Mobile Networks

VTT TIEDOTTEITA – RESEARCH NOTES 2376

Design Issues in All-IP Mobile Networks

Edited by

Pertti Raatikainen

ISBN 978-951-38-6928-1 (soft back ed.)
ISSN 1235-0605 (soft back ed.)

ISBN 978-951-38-6929-8 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN 1455-0865 (URL: http://www.vtt.fi/publications/index.jsp)

Copyright © VTT 2007

JULKAISIJA – UTGIVARE – PUBLISHER

VTT, Vuorimiehentie 3, PL 1000, 02044 VTT
puh. vaihde 020 722 111, faksi 020 722 4374

VTT, Bergsmansvägen 3, PB 1000, 02044 VTT
tel. växel 020 722 111, fax 020 722 4374

VTT Technical Research Centre of Finland, Vuorimiehentie 3, P.O.Box 1000, FI-02044 VTT, Finland
phone internat. +358 20 722 111, fax +358 20 722 4374

VTT, Vuorimiehentie 3, PL 1000, 02044 VTT
puh. vaihde 020 722 111, faksi 020 722 7028

VTT, Bergsmansvägen 3, PB 1000, 02044 VTT
tel. växel 020 722 111, fax 020 722 7028

VTT Technical Research Centre of Finland, Vuorimiehentie 3, P.O.Box 1000, FI-02044 VTT, Finland
phone internat. +358 20 722 111, fax +358 20 722 7028

Technical editing Leena Ukskoski

Edita Prima Oy, Helsinki 2007

Raatikainen, Pertti (ed.). Design Issues in All-IP Mobile Networks. Espoo 2007. VTT Tiedotteita – Research Notes 2376. 136 p.

Keywords mobile networks, wireless telecommunication, All-IP, networking technology, resource management, services, positioning, quality of service, network dependability, propagation models

Abstract

This report summarises the results of the "Design of All-IP mobile network" (DAIMON) project, whose objective was to develop new networking technology solutions for an All-IP mobile network. The presented results form a complete concept for a future All-IP mobile system. The concept addresses both, the technical problems and social implications of such a system. The technical part focuses mainly on the radio propagation issues, radio resource management, services and QoS, positioning and heterogeneity. All addressed problems have been analysed from the user's and network's perspective. Several new methods and solutions, related to the above mentioned research areas, have also been developed and utilised in the project and are presented in this report.

Preface

The work presented here was carried out in the “Design of All-IP mobile network” (DAIMON) project, which was part of the VTT Theme programme “Tulevaisuuden tiedonsiirtotekniikat”. The project reused results of earlier projects, e.g. CAUTION and CAUTION++ (EU IST projects). Some of the research activities were performed jointly with other parallel projects, i.e. T1MGIS, Mercone (TEKES project), Motive (EU project) and Magnet (EU project).

The project was led by Prof. Pertti Raatikainen and supervised by Markku Sipilä. Seppo Horsmanheimo, Jari Hämäläinen, Leena Norros, Ilkka Norros and Urho Pulkkinen were the other members of the steering group of the project. They coordinated activities of several research teams within VTT: System usability team, Network performance team and Wireless systems team.

This report has been prepared by Pertti Raatikainen, Wenche Backman, Jari Hautio, Annemarie Hjelt, Seppo Horsmanheimo, Paul Kemppi, Jorma Kilpi, Krzysztof Kordybach, Jari Laarni, Yanli Li, Eija Myötyri, Ilkka Norros, Leena Norros and Urho Pulkkinen.

Contents

List of acronyms

3D	Three-dimensional
3G	3rd generation (cellular telephony)
3GPP	3rd Generation Partnership Project
AAA	Authentication, Authorization and Accounting
ABC	Always Best Connected
ABI	Algorithms for Broadband Infrastructure (a project)
ACK	Acknowledgement (protocol message)
AIFS	Arbitrary IFS
AOA	Angle-of-Arrival
AP	Access Point
API	Application Programming Interface
AS	Appraisal of Service
ATM	Asynchronous Transfer Mode
B3G	Beyond 3G
BAN	Body-Area Network
BE	Best Effort (QoS class)
BER	Bit Error Rate
BGP	Border Gateway Protocol
BPSK	Binary Phase-Shift Keying
BS	Base Station
BSS	Basic Service Set
BT	British Telecom
BTS	Base Transceiver Station
CA	Collision Avoidance
CAUTION	Capacity and Network Management Platform for Increased Utilisation of Wireless Systems of Next Generation (a project)
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CINR	Carrier to Interference Ratio
CMW	Cassioli-Molish-Win (model)
COST	European co-operation in the field of scientific and technical research
CPE	Customer-Premises Equipment
CPU	Central Processing Unit (processor)

CSMA	Carrier Sense Multiple Access
CTS	Clear-to-Send (protocol message)
CW	Contention Window
DCM	Database Correlation Method (positioning)
DHCP	Dynamic Host Configuration Protocol
DL	Downlink
DNS	Domain Name Server
DoS	Denial of Service
DPCCH	Dedicated Physical Control Channel (UMTS)
DPDCH	Dedicated Physical Data Channel (UMTS)
DS-CDMA	Direct Sequence CDMA
DSL	Digital Subscriber Line
DTV	Digital TV
DTX	Discontinuous Transmission
ECC	Electronic Communications Committee
EDCA	Enhanced Distributed Channel Access
ErtPS	Extended Real-Time Packet Service (QoS class)
ESS	Extended Service Set
ETSI	European Telecommunications Standards Institute
EU	European Union
EVD	Extreme Value Distribution
FBSS	Fast Base Station Switching
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FDTD	Finite Difference Time-Domain
FER	Frame Error Rate
FM	Frequency Modulation
FTP	File Transfer Protocol
FWA	Fixed Wireless Access
GBSBEM	Geometrically Based Single-Bounce Elliptical Model
GIS	Geographical Information System
GNSS	Global Navigation Satellite Service
GPRS	General Packet Radio Service
GPS	Global Positioning System

GSG	GPS Signal Generator (SSF's tool)
GSM	Global System for Mobile Communications / Groupe Spécial Mobile
HCCA	HCF Controlled Channel Access
HCF	Hybrid Coordination Function
HDR	High Data Rate
HHO	Hard Handover
HP	Hewlett-Packard
HSDPA	High Speed Downlink Packet Access
IBSS	Independent BSS
ICT	Information and Communications Technology
ID	Identifier
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IFS	Interframe Spacing
IMT	International Mobile Telecommunications
IP	Internet Protocol
IPLU	Dependability Evaluation Methods for IP Networks (a project)
IR	Infra-Red
ISM	Industrial, Scientific and Medical (radio band)
IST	Information Society Technologies
IT	Information Technology
ITU	International Telecommunication Union
L2VPN	Layer 2 VPN
L3VPN	Layer 3 VPN
LAN	Local Area Network
LDR	Low Data Rate
LOS	Line of Sight
LRD	Long Range Dependence
LTE	Long-Term Evolution
MAC	Medium Access Control
MBMS	Multimedia Broadcast/Multicast Services
MDHO	Macro Diversity Handover
MEA	Mesh Enabled Architecture
MIMO	Multiple Input / Multiple Output

MLP	Mobile Location Protocol
MOS	Mean Opinion Score
MPEG	Moving Picture Experts Group
MS	Mobile Station
NGN	Next Generation Network
NLOS	Non-Line of Sight
NRT	No Real Time
nrtPS	Non-Real-Time Polling/Packet Service (QoS class)
OAM	Operations, Administration and Maintemance
OMA	Open Mobile Alliance
OPQoS	Overall Perceived QoS
OSG	OpenSceneGraph
PAN	Personal Area Network
PC	Personal Computer
PCF	Point Coordination Function
PDA	Personal Digital Asistant
PDH	Plesiochronous Digital Hierarchy
PER	Packet Error Rate
PHY	Physical (protocol layer)
PL	Path Loss
POP	Point of Presence
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
QPSK	Quadrature Phase-Shift Keying
RAN	Radio Access Network
RET	Radiative Energy Transfer
RF	Radio Frequency
RFCMOS	Radio Frequency Complementary Metal Oxide Semiconductor
RFI/C	Request for Information and Comments
RFID	Radio Frequency Identification
RFP	Request for Proposals
RLS	Recursive Least Square
RMT	Resource Management Technique

RNC	Radio Network Controller
ROI	Return on Investment
RRC	Radio Resource Control
RRLP	Radio Resource LCS (Location Services) Protocol
RRM	Radio Resource Management
RSS	Received Signal Strength
RSSI	RSS Indicator
RTLS	Real-Time Location System
rtPS	Real-Time Polling/Packet Service (QoS class)
RTS	Request-to-Send (protocol message)
RTT	Round-Trip Time
SAC	Smart Access Control
SCM	Spatial Channel Models
SCME	SCM Extension
SDH	Synchronous Digital Hierarchy
SEEmesh	Simple, Efficient and Extensible Mesh (a business group)
SHO	Soft Handover
SINR	Signal to Interference plus Noise Ratio
SIR	Signal to Interference
SISO	Single Input / Single Output
SMS	Short Message Service
SNR	Signal to Noise Ratio
SOAP	Simple Object Access Protocol
SS	Subscriber Station
SSF	Space System Finland
STP	Spanning Tree Protocol
SUI	Stanford University Interim
SUPL	Secure User Plane Location
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TDOA	Time Difference of Arrival
TOA	Time of Arrival
TPM	Task-oriented Performance Measures

TRX	Transceiver
TTLS	Tunnelled Transport Layer Security
TV	Television
TX	Transmission
TXOP	Transmission Opportunity
UDP	User Datagram Protocol
UGS	Unsolicited Grant Service (QoS class)
UL	Uplink
UMA	Unlicensed Mobile Access
UMTS	Universal Mobile Telecommunication System
UTD	Uniform Theory of Diffraction
UTRA	UMTS Terrestrial Radio Access
UWB	Ultra-Wide Band
VLAN	Virtual LAN
VoIP	Voice over IP
VPN	Virtual Private Network
WGS84	World Geodetic System 1984
WISP	Wireless Internet Service Provider
WLAN	Wireless LAN (Wi-Fi)
WPA	Wi-Fi Protected Access
WPAN	Wireless PAN
WPS	Wi-Fi Positioning System
WSSUS	Wide-Sense Stationary Uncorrelated Scattering

1. Introduction

In the development of the modern telecommunications networks it is possible to distinguish several trends:

Going wireless
The trend of providing more and more wireless telecommunications solutions is especially visible, because going wireless is supported by the telecommunications service providers as well as by the end-users. For users, wireless means mobility plus easier and more flexible access. Also, aesthetic point of view can be mentioned here (no inconvenient cables). For operators and providers, wireless means cheaper access, especially in the "last mile".

Service independency
In the traditional approach, telecommunications services were strictly bound to the networks that deliver them. For example, telephone networks were used exclusively for voice services. Later some services were added to these systems (e.g. fax to the telephone networks), but in principle the hardware system and service were inseparable. The development of IP-based services, however, led to a situation where the same service is offered over different networks and technologies – as long as IP can be provided. These services become therefore independent from the underlying access technologies. On the other hand, almost all new access technologies are designed to be "All-IP", i.e. to provide end-to-end IP connectivity.

Heterogeneity
In many situations different telecommunication systems coexist thus forming a heterogeneous telecommunications environment. This, however, does not exhaust the problem of heterogeneity. The term applies also to the coexistence of different operators and service providers. Finally, different users' needs can also be defined as heterogeneous. Due to these aspects, addressing variety of systems, environments, services, technologies and needs has already now become a big problem for the telecommunications technology and it is very likely to continue gaining importance.

These trends were the motivation for a research project called "Design of All-IP mobile network" (DAIMON). The main objective of the project was to address the above mentioned trends and to form a consistent concept of an All-IP telecommunications network with wireless access. The project took into account both the user's and the network's perspectives. In particular, the following areas have been addressed:

- existing implementations and concepts of All-IP wireless networks
- resource allocation and management in wireless systems, both existing and planned

- traffic management and modelling, with special focus paid to the IP-based services
- modelling for radio wave propagation
- positioning in wireless systems, especially for indoor environment
- network architectures and configurations, including mobile solutions
- dependability studies
- human-technology interaction.

The results have initially been published as short versions in the Project Final Report [1]. This paper provides a complete description of the designed concept.

2. User Perspective

In the case of human-technology interaction, a bit more substantial methodological discussion is motivated. User-oriented design has already for some time been an accepted goal for the design of human-computer interaction and user interfaces for everyday appliances. Another user-centred approach is the so-called human factors perspective, which plays an important role in the design of human-system interfaces in high-reliability environments. Developing a user-centred perspective to the design of large infrastructures such as IP networks could make use of the experience gained in both above mentioned user-centred design traditions. Actual attempts to realise this possibility in the design of IP infrastructures are currently very few. In the DAIMON project we made such an attempt. We saw that it would be beneficial already in the conceptual phase of the design of All-IP infrastructures to try to foresee what the usage of the network would require for the technology and its implementation. Hence, an appropriate approach also in the All-IP network development should give advice how to define requirements in the development of the network for different contexts and services, not to try to define what features the solutions should specifically have.

Outlining the user perspective was seen to be mainly a theory and concept building task. The goal was, in collaboration with the experts of network and telecommunication technology, to conceptualise the intrinsic features of All-IP networks. Our attempt was to outline a new approach to comprehending user experience and acceptance. We accomplished literature studies in the areas of usability and user experience of mobile ICT and further studies in media theory. We also took advantage of the possibility to integrate the project's measurement-based studies on the round-trip time variability into the study. The findings in the literature and own measurements were to be synthesised into a model of user acceptance and into further hypotheses concerning the formation of user acceptance.

2.1 Social implications of wireless technology

Castells et al. have proposed in [2] that new forms of space and time emerge due to wireless technology. According to them, wireless communication both 'homogenizes' space and creates a new practice of time. The space of social interaction has to be defined differently when people that are located in different places communicate with each other and use their present place to build a network of communication with other places. In this context service quality is appreciated in terms of support for the building of communication networks. Services should, for example, provide support for rendezvousing, "the informal, geographical co-ordination of small groups of people" ([2], p. 233).

Also new forms of time are emerging. There is a de-sequencing of social action based on time compression and by random ordering of the moments of the sequence and a blurring of time due to de-sequencing of activities that is allowed by space of persistent connectivity ([2], [3], [4]). Mobile communication makes possible to fill time with social and other practices, i.e., it makes possible to insert communication and use of information services in those moments when other activities cannot be conducted. Therefore, service quality should also be appreciated on the basis of supporting this type of use of mobile technology.

All in all, wireless network services are perceived and evaluated in terms of their ability to support the development of communication networks and the co-ordination of everyday life. Since people always perceive and evaluate mobile services in the context of everyday life activities, service quality and acceptability should also always be assessed in the context of everyday livings and in mobile contexts of use.

2.2 Quality of Service

Quality of service (QoS) is a set of judgments of how good the service is. It has been defined as “the collective effect of service performance which determine the degree of satisfaction of a user of the service” [5], and “the degree of conformance of the service delivered to a user by a provider in accordance with an agreement between them” [5]. In [6] the definition of quality of service is based on three criteria, 1) *speed* indicates aspects of temporal efficiency of a function, defined on measurements that are made on particular time intervals, 2) *accuracy* indicates the degree of correctness, based on ratio or rate of incorrect realizations of a function (losses), and 3) *reliability* indicates the degree of certainty with which a function is realized, which is related to dependability of the system.

Typically, a distinction has been made between subjective and objective QoS in which perceived and assessed QoS are included in subjective QoS [7]. According to Hardy ([7], p. 5) objective or intrinsic quality of service is related to technical design of the communication network and terminations and provisioning of network accesses, terminations and switch-to-switch links. Perceived quality of service results when the service is actually used, and it determines whether people will be satisfied with the service.

2.2.1 Objective quality of service

For streaming applications, audio and video, a user can always hear or see the bad quality. There exist natural variables like, for example, delay or delay variation and well known bounds for these variables such that if these bounds are not exceeded then a user does not recognize any problems with the streaming application

The knowledge and understanding of the factors that currently affect to experienced service is a natural cornerstone when trying to say something about the QoS of future users. Still today, TCP is the dominating transport protocol and this situation is likely to continue in the near future. For a feedback based protocol, like TCP, *the round-trip time (RTT)* affects to the data transfer rate that the TCP offers to the application layer(s). TCP is also used for streaming applications since its simplified version, called User Datagram Protocol (UDP), has no flow control (feedback) features and it is not intelligible to re-program any flow control features at the application layer.

2.2.1.1 RTT variability

For a feedback based protocol, like TCP, the *RTT variability* is one of the main factors which affect to the available bandwidth offered for the application layer protocol. Thus it is also a thing that the end user experiences about the service. Roughly expressed if RTT stays well below 1 second during a data transfer (flow) then a user may experience a continuous though perhaps slow transfer rate but if RTT gets sometimes, even only once, values over 1 second then a user typically notices a break in the data transfer. A thorough measurement based study of the RTT variability has been finalized within the DAIMON project [8]. The data used in the analysis was obtained from the Finnish mobile operator Elisa in an earlier, TEKES funded project PAN-NET. The results of [8] can be summarized as follows.

In current mobile networks, the RTT variability is mostly due to a deterministic reason, namely the slow access rate and buffering of packets before the slow radio access link. The load by other users of the same radio interface and the distance to the base station may be reasons but not very dominating or typical ones. Actually, the other main reason for RTT variability is the user itself. Namely, with broadband access an experienced user may be accustomed to use several applications simultaneously but the same behaviour does not fit well to the combination of slow access speed and relatively low (possibly even battery limited) CPU capacity. With such a combination simultaneous data transfers of different applications disturb each other significantly. Especially simultaneous up- and downloading caused severe problems for TCP. The methodology in [8] was based on applying signal processing methods, Fourier and wavelet analysis to the measured RTTs of TCP flows.

2.2.1.2 The effect of the bandwidth that the application really gets

Dependence between downloaded file size and access rate has been studied a few years ago in Würzburg, Germany, and also in VTT in the cases where reliable knowledge of true access rates were directly available. See [9] and [10] for more details. These older results on wired (dial-up) networks confirmed the quite obvious hypothesis that the higher the access rate is, the higher the probability of downloading larger and larger files is. This is a probabilistic, not deterministic statement and it must be emphasized that very large downloadings occur also with very slow access rates. This latter is just more seldom but still a regular phenomenon and is statistically reflected as heavy-tailed character of the file size distribution.

In wireless connections the best access rate and the true data transfer rate that the application really gets may differ quite significantly. More dedicated studies of the dependence between a web content (file) size and the (mean) rate that the TCP protocol offers for downloading of the web content have been initiated in the DAIMON project ([11], [12]). One preliminary motivation for this research issue was to understand how much the real transfer rate that the application gets affects to the user behaviour. The preliminary results of [11] were based on the approach of expressing the bivariate distribution of a TCP flow size and the (mean) obtained rate in terms of a so called copula. The work started in [11] is still in progress, aiming now more to the analysis of the particular effects of TCP and, actually, excluding the user behaviour. In [12] a different, purely statistical approach to the same problem has been taken, which includes the user behaviour. The work of both [11] and [12] continues in the TEKES funded project ABI.

2.2.2 Subjective or perceived quality of service

Perceived quality of service is defined as a subjective quality of the service perceived by the user. It includes dimensions such as loading latency, sound and image quality and perceived reliability. There is always a trade-off between complexity (how many network parameters are taken into account) and usefulness (capturing accurately the interaction between a mobile network and perceived QoS [13]). Overall Perceived Quality of Service (OPQoS) can be thought as a weighted sum of individual quality factors.

Perceived QoS is typically assessed by such measures as Mean Opinion Score (MOS) and Task Oriented Performance Measures (TPM). When using MOS, users express their judgments according to a particular scale; TPM present users different levels of stimuli and the outcomes are measured objectively. Table 1 presents some measures of perceived QoS classified according to whether they are subjective or objective and qualitative or quantitative. We aim at developing a dialogic method for investigating people's attitudes and experiences of information technology. The method is based on such techniques as focus group -methodology, repertory grid analysis and dialogic intervention methodology.

Table 1. Possible measures of perceived/experienced QoS and appraisal of service.

	SUBJECTIVE	OBJECTIVE
QUANTITATIVE	Post-test rating scales Continuous assessment techniques Psychophysical methods - e.g., MOS	Post-test rating scales Continuous assessment techniques Psychophysical methods - e.g., MOS
QUALITATIVE	Continuous verbal reporting Ethnographic methods Focus groups Etc.	Course of action analysis

2.3 Extended model of Quality of Service

A basic problem with all previous- models of perceived quality of service is that they do not consider to a sufficient degree the role of context and usage situation. Perceived quality of service is critically dependent on by which way the service functions in a particular context. We have to 'contextualize' QoS models and systematically analyze how people use mobile technologies in different usage situations. For example, we have to analyze, which kind of tasks people have and ways they accomplish these tasks without/with mobile devices. User acceptance and quality of service have also typically addressed from the perspective of individual users. However, since the use of wireless technology is typically a collective enterprise between groups of people, we should pay more attention to the needs of communities of users. To that end, we need a systemic analyses and studies of how people and communities live in experience of mobile technologies in different contexts.

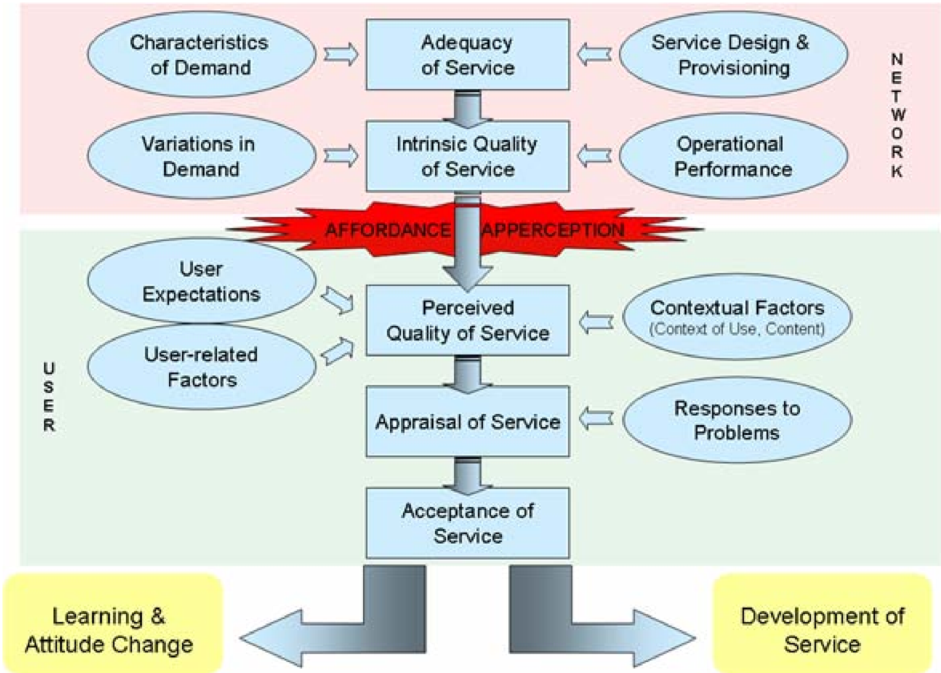

Figure 1. An extended model of quality of service (exQoS).
The model is modified from [7].

According to the model, appraisal of service (AS) and acceptance of service result when the user makes an evaluation on whether the quality of service is good enough to rely on. Appraisal of Service is shaped by users' experiences while interacting with the service. It concerns the question of what is the meaning of the service to the user. Appraisal is influenced by user experiences in a particular context and in a particular activity. Several authors have presented lists of features that are characteristic to mobile contexts (e.g., [4], [14], [15]). Mobile devices are used both in work contexts and during leisure activities. Major characteristics of mobile contexts are that there are typically frequent interruptions, temporal tensions, and frequent side courses and sidesteppings. People also typically have to manage multiple tasks simultaneously.

Typically, there is no linear relationship between intrinsic (objective) and perceived (subjective) qualities. Neither can users distinguish between network and application/terminal problems. For example, Koivisto and Urbaczewski found that users could not separate network performance into multiple factors like connection establishment time, bandwidth and release time but they were considered as a single factor [16]. Additionally, the relationship was shown to be application specific. It is highly probable that services for new kind of smart, pervasive environments will cause new problems for the measurement of perceived QoS.

In order to comprehend better the connection between the engineering quality features of the network and the experience people have when they use the services built on the network we decided to draw on the idea of the psychologist James Gibson [17]. According to him the human actor's perception of the environment is not a subjective representation of the physical parameters that are used in a scientific characterisation of the environment. Instead people perceive the environment in the form of holistic attributes that Gibson called affordances [17]. These are latent action possibilities in the environment, independent of the individual's ability to identify these possibilities.

The idea is to identify what are the generic attributes of the mobile all IP-network that provide new types of possibilities for the user. In the interdisciplinary discussions and work with the DAIMON projected we have arrived at three generic attributes of mobile network technologies, which we assume to have implications on service quality and acceptance. These are connectivity, contextual awareness and adaptability:

Connectivity ("being connected") means that the user is Always Best Connected (ABC-concept) to the service, that is, the user has an access to the mobile network through the best possible wireless interface. Thus users are always connected to services in the best possible way, and the network offers flexible usage of services anytime and anywhere (mobility).

Location awareness ("being located") means that a mobile device can be sensitive to its current location and should function accordingly. Location awareness is one form of contextual awareness, the application's ability to react in a sophisticated way to situational information. Basic forms of contextual awareness are location awareness, environmental awareness, mobility awareness, and user awareness.

Adaptability ("being served") and especially self-adaptability, refers to "to any variants tending to modify the end-to-end communication, preventing the user from feeling changes" ([18], p. 2051).

Connectivity affords a possibility to being connected, that is, experience or belief of being connected to other people, locations, services etc. anytime and anywhere. Location awareness provides a possibility to being located, that is, an experience/belief of being located by other people/services where ever the user is physically located at any given time. Pro-activeness and adaptability, in turn, provides prerequisites for being served, which includes the experience or belief of being smoothly and continuously served and supported.

Concerning the appraisal of service, and finally the acceptance of service, the critical questions are: 1) how generic affordances (to be connected/located/served) influence appraisals; 2) what is the role of perceived quality in appraisals; and 3) how users' experiences shape their appraisals.

In Figure 2 some aspects of user experience that may be relevant to user acceptance are shown. An interesting question is which type of effects the generic attributes of smart/mobile computing environments may have on these attributes. Considering connectivity and mobility, inter-technology roaming and limitations of portable devices may cause transient fluctuations in QoS, and this, in turn, would cause reduced feeling of control/trust and feelings of irritation in users. Contextual awareness by making proactive/predictive services possible may obscure limitations in intrinsic quality so that limitations in QoS remain unnoticed. On the other hand, services may be privacy-intruding and reduce feeling of control/trust. Connection speed is also critical: services must be delivered just on time, otherwise they may elicit feelings of irritation.

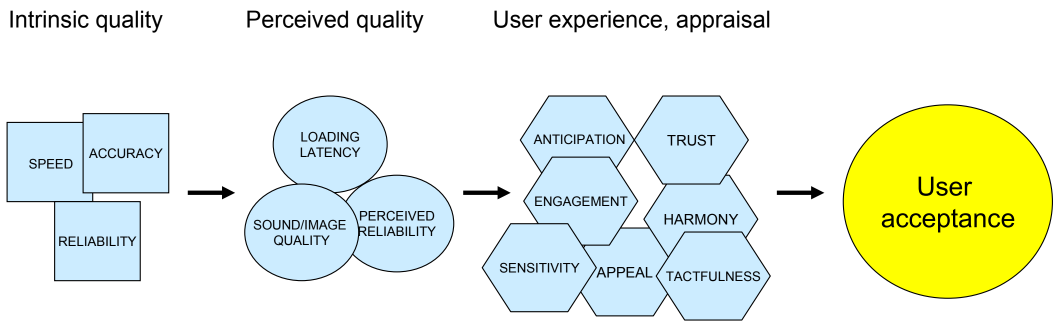

Figure 2. Examples of possible dimensions of user experience that may be related to intrinsic/perceived QoS.

2.4 Apperception of IP connectivity – creating network literacy

With reference to the "Extended Model Quality of Service" (exQoS; Figure 1) we raised questions concerning features that would have an influence on the user appraisal of service. Among other things we asked how the generic affordances of mobile technologies, connectivity, contextual awareness and adaptability, would influence appraisals. In this section we shall return to this question.

We shall discuss All-IP mobile network as a resource for different wireless technologies for diverse everyday usage. From this resource perspective the affordance of *connectivity* is the central generic attribute that we have to consider. The two other affordances, i.e. location awareness and adaptability, relate closer to services that are build upon IP network. Hence, they make use of connectivity or add further features to it.

The network environment affords the feature of connectivity that can provide possibilities for the users to act and develop their activities. According to Gibsonian theory, it further holds that in order for the possibilities to exist, the users need to be in the position to apprehend i.e. grasp these features. We consider this ability to “read” the environment as *network literacy*.

In this section we shall elaborate the connectivity affordance of the IP network, and then propose some basic features of what could be considered as network literacy and how to acquire it. The section will end with some notes for the future work in the area.

2.4.1 Mobile Network as a tool and medium

Taking a user perspective denotes analysing the use of technology in different life activities in which peoples’ practices and cultures are formed. Technology is one part of these practices and culture. It is possible to approach technology at least from two different perspectives, i.e. technology as a tool for human activity and technology as a medium that enables communication and shared consciousness. These frames denote different theoretical traditions of social science research. Both are relevant for considering the role of ICT technology in general and, as we see, IP network in particular.

When considering IP network as a *tool* we take a system-oriented point of view to human activity. According to the cultural-historical theory of activity ([19], [20]) human conduct could be considered as a system of mediations between the subject, object and the human community. Tools – in this case the network – have three basic functions. These are the instrumental, psychological and probably communicative function. The instrumental function is the most evident one relating to a tool’s role to shape the environment in a targeted way. The second function, the psychological function is less evident but quite important. It refers to the fact that by using and developing tools, including concepts, human beings create an external factor that influences their own mental structure and bodily behaviour. In order to a hammer to be a tool there must be the instrument but also the ability to use the instrument [21]. However, the hammer is a full-fledged tool due to being developed as such in a community, members of which all know how to use the tool, what it means to use the tool, and what is good usage of the tool etc. The tools crystallise practices of usage and mediate them to further people. In this sense tools clearly have a third, the communicative and a sense making function.

The communicative function of tools and the interaction of the functions is even emphasised when the tools become reliant on the ICT technology that basis on electricity and digital technology. ICT enables efficient and intelligent control and monitoring of systems, mediates information effectively and provides a universal way of interacting with the environment that is shared by nearly everybody in every domain of the society. Due to this ICT has acquired a consciousness shaping role [22]. Hence, it becomes evident that technology could and should today be also dealt with as a *medium*. Hereby we enter to the domain of media theory.

In media theory it is less usual to consider the role of technology in mass communication, and to see that all technologies would have the communicative and consciousness shaping function typically attributed to mass media ([23], [24]). One of the media theoreticians who deliberately dealt with a broad concept of media technology and the role of media in shaping human perception, activity, consciousness and culture was Marshall McLuhan (1911–1980). McLuhan focused on the connection between technology and human perception. He was particularly known of the idea of technology as an extension of man, and electrical media that of the nervous system. He identified the background role of media in shaping the way people comprehend their environment. This idea was expressed clearly in his slogan "Medium is the message" or "Medium is the massage", both indicating that media shape humans beyond the content that is mediated.

McLuhan was criticized by colleagues of technological determinism and was almost forgotten after the 1970´s [23]. Today McLuhan has experienced a renaissance when IP network has verified and made real his vision of the electrical network that is implemented everywhere and used in numerous services using multimodal interfaces. While aware of the critique to some aspects of McLuhan's thinking we appreciate the insightfulness of his ideas. We are open to make use of these ideas when we attempt to conceive the role of IP in the activities of people. It is not possible to explain in details McLuhan's abundant ideas in this connection. We restrict ourselves to demonstrate his main idea of how to identify the performance shaping nature of new technologies. We restrict ourselves to demonstrate his main idea with the help of Figure 3. It depicts the process of transformations from the original medium of *speech* to the second major medium of human conduct, the *phonemic alphabet*, to the presently on-going transformation to the use of *electrical or digital* medium. What we attempt to clarify with this simplified picture is that in the early history people where predominantly tuned to speech communication, which could be characterised to form an acoustic space that was multi-sensory and multidimensional ([25], p. 18). Not by the use of signs as such, but by the invention to connect singular meaningless sounds, phonemes, with signs i.e. alphabets, people created a completely new medium to interact with the world ([25], pp. 13–14). Typical to this medium is a separation between senses: eyes where made to read speech as linear text without the human actually hearing the speech. As it is known from history, people first read text loud and only later silent reading became usual. The visual sense became dominant and a linear non-spherical representation of the world became a standard. The print technology ripened and fortified the alphabet medium and the role of writing.

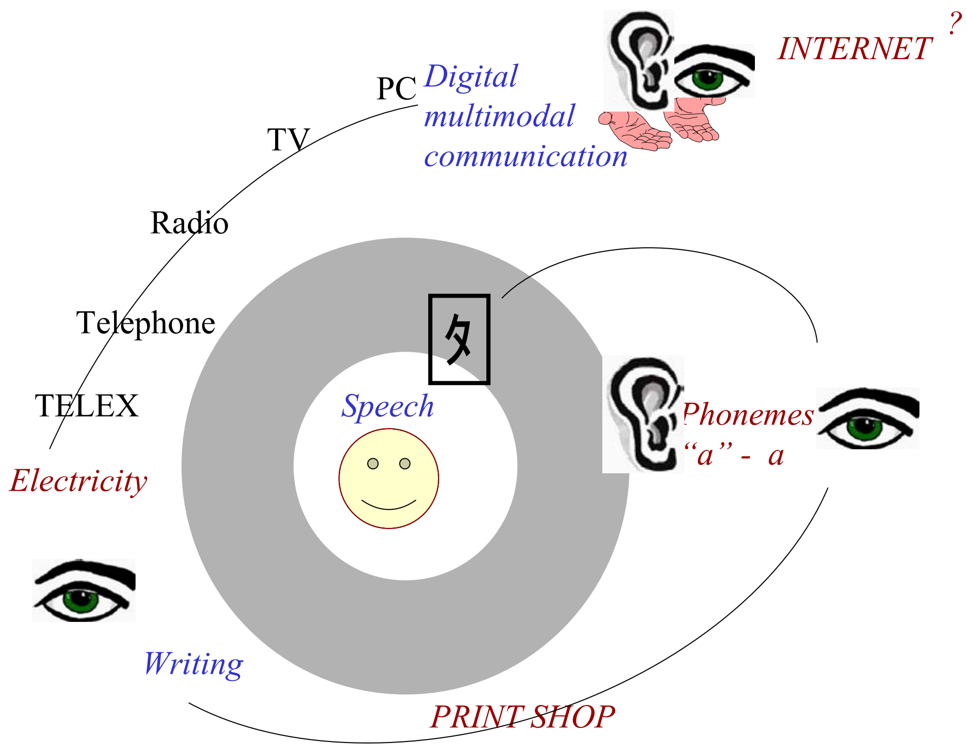

Figure 3. Transformations of dominance of media: from speech, to writing, and to digital multimodal communication based on the ideas of Marshall McLuhan.

2.4.2 Connectivity is the central affordance of IP medium

Electricity was the medium extensively considered by McLuhan. This medium developed first in the form of telex, then telephone, radio and television. Television was the last electric tool McLuhan himself experienced. In this medium he already saw the basic intrinsic feature of electrical media to connect with the human nervous system and to re-establish the synaesthesia or integration of senses that disappeared with the invention of phoneme based alphabets, linear writing and dominance of the visual modality. McLuhan and McLuhan see the electric media to resemble the tactile sense. They see this sense to have an integrative role in perception. The idea that McLuhan was advocating was that, due to the physical features of producing the TV image and the resulting low-definition image, watching TV is closer to tactile than linear visual sensing. This would be even strengthened by the use of colours that facilitate a tactile way of interacting with the object.

What has the computer technology and its connection to the IP added to this picture? First of all, an increasing part of the objects that people deal with are transforming to immaterial digital entities that can be called files. This concept was first used in restricted sense by computer professionals but today people are accustomed to think music performances and films as files. This is just an example of the forthcoming change in the ontology of the human world and environment. Connecting the Internet to PC, or to other user appliances, and the availability of multimodal forms of representation appear to provide a way of ripening the possibilities of electricity, in analogy to extension of the role of alphabet medium via the print house technology. It should be emphasised, however, that the transformations of ways of perceiving the environment and that of practices is a very slow process. It has been shown e.g. that the transition from a predominant speech-mediated communication to alphabet-mediated written communication took hundreds of years [26].

The medium nature of IP network is supported by the fact that IP is a generic and independent technology that supports innumerable services. IP network is distinct from any earlier communication networks which typically are structured according to the service they provide. In other words, in the case of Internet the medium is composed of the universal network. It provides the performance-shaping background for practices, even though typically people are not aware of this background effect. It has been indicated "Without the artists' intervention man merely adapts to his technologies and become their servo-mechanisms." ([25], p. 98). A further typical feature of a genuine medium is that it swallows former media and makes them as its content. This precondition is very clear in IP network that is capable of making use of text, telephone, TV, movies and MP3. Hence it is evident that IP network has a *medium character*. At the same time it provides basis for services that make sense to different contextually defined activities that the IP network may support. In this sense IP also has the *tool character*.

The most important affordance of Internet is it global *connectivity.* Due to connectivity Internet becomes an extension of the human nervous system. If we can assume connectivity being such a generic intrinsic feature we should try to foresee what kind of processes would take place in the implementation of IP network into the daily lives of people, and what kind of abilities people should develop in order to grasp and make use of the affordance of connectivity as fully as possible. We propose the application of the method McLuhan labelled the Laws of media [25]. The laws of media is a conceptual way of testing and falsifying "observations about the structure and nature of things man makes and does" ([25], p. 3). The method does not rely on a theory of technology but provides a heuristic but systematic device to understand the nature of media. This device is a tetrad that raises four questions that can be put on any technology or medium. The questions are indicated in the tetrad in Table 2.

By using the tetrad to IP medium a following first approximation of the processes of IP implementation were revealed. These are depicted in the following Table 2. Each point could be concretised by analysing how they are portrayed in peoples' daily practices and in problems that people appear to face in handling their work, leisure or other situations.

Table 2. Sketching the transformations of practices in the age of IP networks using the tetraed method of Laws of Media [25].

ENHANCEMENT: *What does the medium enhance or intensify?* Extension of the human nervous system to a global nervous system; being connected to everywhere Significance of tactile relationships, resonance	REVERSAL: *What does the medium produce or become when pressed to an extreme?* Paralysis due to loosing focus and presence
RETRIEVAL: *What does the medium retrieve that was previously obsolete?* Presence in local village Integration of senses	OBSOLENCE: *What does the medium render obsolete or displace?* Specificity, differences and hierarchy of media Dominance of the visual space

2.4.3 IP connectivity and dependability of service

So far we have analysed the generic feature of connectivity and what kind of performance shaping potential this affordance provides for human usage. In this section we shall change the perspective and conceptualise the relationship of connectivity with the dependability of IP medium. In other words we would like to raise the question of how people experience the threat of loosing connectivity.

An intrinsic part of a user's relation to networking and the network-mediated services and functions is the dependability of the IP medium, i.e., the questions about its availability, reliability, controllability, vulnerability and security. Can the user rely on this new infrastructure as much as on the traditional technologies and the old ways of acting? High level of dependability should be a natural requirement for a global information infrastructure, but, so far, this has not been the trademark of the Internet. Rather, although the dominant experience is the impressive success of the Internet, its users are accustomed to many kinds of negative surprises.

The traditional telephone network is a highly reliable and stable "machine". It has existed more than hundred years, and it has been rooted in people's consciousness as well as in legislation. There are generally accepted principles, laws and regulations on aspects like confidentiality, and emergency telephony. Now, when the IP medium is approaching the status of the dominant information transmission infrastructure, it is important to recognize the fact that new networks and network-based services emerge and are developed largely in a bottom-up fashion. Cheaper and more effective solutions are rapidly replacing older ones, and this development is faster than the development of regulations that would adequately secure the availability of the new medium in any non-typical circumstances. Part of these questions are already receiving considerable attention, like information security and infrastructure protection, whereas an adequate conceptualization of the dependability of the IP network from an everyday user's point of view and the development of a related measurement and regulation apparatus have hardly entered serious discussion.

The availability of the network layer service in the access network, that is, the successful transmission of IP packets between the user's device and an IP core network, is a prerequisite for all networked applications, and its unexpected failures are often very frustrating for the user. Moreover, the nature and reason of the failure remain usually completely obscure. Although the network can mediate direct criminal threats to the user's safety and property, making the concern about information security more than justified, the DAIMON project wanted to pay attention to less dramatic but still highly significant aspects of dependability. Hours wasted because of lack of everyday dependability of the network medium are paid dearly both in dissatisfaction and economically.

The user's experiences on the dependability of the network focus on *network availability*. Experience of availability is closely related to the experienced Quality of Service. Indeed, if the QoS falls below a certain level, the service cannot be considered available, and the notion of network availability could be extended to the quantified notion "availability for transmission at rate *r*". However, a user of the IP medium should learn to distinguish between unavailability of a particular service and the unavailability of IP connectivity. If only the first is the case, a user may, if he can, try with another application, or with another access network afforded through the multi-access terminal device. Flexibility and innovativeness in the usage of new communication affordances compensate part of the existing lack of dependability and should be taken into account when assessing network dependability as a whole. The significance of the dependability question is differentiated according to age groups, interests, education etc. This may be one reason why it has been to some extent neglected: we live still in a pioneering era of the IP medium, pioneers are not intimidated by temporary difficulties and, on the other hand, the legacy systems are still widely in use and available when IP connectivity fails.

The above discussion concerning how users would consider the dependability of the IP connectivity reveals an issue that we see very significant for users' apprehension of IP affordances in general. It appeared that in order to realistically identify how to react to the fluctuations of the quality of service due to fluctuations in the IP availability, the users should distinguish between the network and the service application. From earlier discussion in the chapter we know however, that user experience is typically focused on the application and users are not able to identify which part of the whole IP medium is relevant to the experience. On the basis of this discussion a following generic hypothesis can be formulated concerning the comprehension of IP affordances:

- *In order to make use of the major affordance of IP, i.e. connectivity, it is necessary that the user, who basically is interested in making use of Internet-mediated end-services, has to distinguish between the internet (and its access technologies) and the higher level end-services.*

- *Making this distinction between the network affordances and the service functionalities is a sign of network literacy. In contrast to many popular visions, we maintain that the network will not and should not disappear from the users' awareness.*

- *Network literacy is the user's ability to apprehend or "read" the affordances of the IP-network in the environment, and to interpret the quality of network service in a realistic way. This would facilitate appropriate and meaningful usage of available end-services.*

A distinction between the Internet medium and the services is assumed to promote a realistic perception of the quality of service (QoS) and the ability to utilise the diversity of the network to improve the QoS. Because awareness of the net/service distinction also promotes awareness of the state and functioning of the network, it would prevent from false blaming of the net or miss-diagnosing of loss of the net.

Empirical studies would be needed to find out what kind of awareness the users should develop of the IP affordances (IP as generic medium) while they focus on the different functionalities of the service that are related to their work, learning or any everyday activities (IP as a tool).

2.4.4 Network literacy

We introduce the term "Network literacy" to indicate the user's ability to apprehend the connectivity affordance of the IP network in the environment. Grasping the affordances facilitates appropriate and meaningful use of services. By naming this ability as "literacy" we refer to a particular type of relationship in which the interaction between human and environment is mediated predominantly via signs that distantly denote the actual real world. Technology is in this connection experienced as part of the environment, because people perceive the signs that denote the environment, not (predominantly) the actual world. It is foreseen that, in the future, intelligent technologies are embedded in the environment. IP network is assumed to create continuity to perceptions of the environment, to enable communicating perceptions, and to facilitate collaborative activities in the environment. This would result in an even more concrete merging of technology with the environment. Technologically augmented reality creates new affordances and, hence, new practices for grasping these must be created.

The concept of "network literacy" is not very widely used so far. It appears that it is typically used as an extension of the "computer literacy", which has been defined and used already since 1970´s. It has developed into a particular subject in computer pedagogic aiming at teaching people to use computers. Hoffman and Blake give an instructive overview of how the concept and content of computer literacy has developed [27]. One definition of network literacy that we could find for it in the literature indicates that "Network literacy describes the capacity to use electronic networks to access and create resources, and to use electronic media to communicate with others" [28]. This definition was adopted by the author from the British Department for Education and Employment. No further determinants are mentioned by the author that would relate to the particular nature of IP medium.

Computer literacy/fluency has usually been defined as particular skills that are acquired in formal education at schools and universities. Recently, changes have appeared in the acquisition of computer literacy that might necessitate reconsidering the whole conception of computer literacy. Hoffman and Blake crystallise these changes into three points [27]: The first point is that children and students in today's schools and universities are quite skilful in computer and web usage already when they enter the computer classes. Secondly, learning takes place spontaneously and the content of skills is specified according to the students' and users' own demands. The authors raise the question whether informal learning would in general be more effective in acquiring computer literacy in today's situation. They also state that "students learn about the technology if they can relate it to their lives" ([27], p. 222).

Rückriem provides results of studies on learning computer literacy at university level that cohere with the above authors' views. He shows that the acquisition of skills was much more effective when students first had constructed a societal context and personally meaningful perspective for the usage [26]. Rückriem does, however, not contrast formal and informal learning but makes the point that an activity and communication system is needed to adopt a medium into wide societal usage. Literacy in its traditional sense was adopted in the school system. If the schools are not functioning in this mission appropriately, what would be the activity and communication system within which the uses of computers and IP network will be adopted and culturally mediated?

A third point that Hoffman and Blake made was that even though people are well equipped with using the computer and Internet they do not have knowledge of the technological or other scientific foundations of the media they use.

On the basis of above reasoning and in connection to the hypothesis proposed in the previous section we would like to formulate a second hypothesis:

Depending on the level of network literacy different societal perspectives to the implementation of IP-medium will be opened:

A) The consumer perspective: Merging the network with end-services leads to adoption of the role of a service consumer, i.e. forming an audience.

B) The authorship perspective: Identifying the Network as a generic medium leads to active usage and authorship, i.e. forming a public.

We propose that creating network literacy and facilitating the authorship perspective to IP would assume at least the following five preconditions. Some important issues under each point are also listed. These should be considered as questions for further research.

1) forming a personal sense and perspective for the usage of the network

2) developing new practices and competencies to grasp or apprehend the IP connectivity. The capability of apprehending the intrinsic features of IP would promote:

- coping with complexity and uncertainties: IP-media provides a new catalogue function, finding innumerable perspectives to the environment and the world

- coping with simultaneity and instantaneousity [29]: reference to past and future, personal lifespan

- coping with global presence: embodiment, and locality is needed for creativity and identity, ability to act ([30], [33])

- coping with interactions; responsibilities, habits, norms, values

3) creating trust in the medium

- medium is external part of the human – there might be lack of trust in oneself when using own creations

- understanding the constraints for the use of the medium

4) creating awareness of the different forms of governance of the network

- different scenarios have been sketched ([30], [31], [32]): users as consumers or users as authors

5) enabling involvement in a communication system

- meaningful usage of the medium develops in activity systems [26], what are these?

As can be inferred from the above our conception of network literacy describes an ability to use a new type of medium for interacting with the environment. Network literacy is not a mere extension of the literacy conception which is based on written alphabetic text. It could even be proposed that instead of speaking of literacy we could use the notion of *teleactiveness* in order to emphasise that "reading" the environment is grasping, i.e. perceiving and acting upon the distant environment in a multimodal way.

3. Network Perspective

3.1 Existing wide area wireless access networks

WLAN is one of very few All-IP systems that have gained wider popularity. Because of that popularity, WLAN experiences can be studied to find possible problems and challenges that a broader implementation of an All-IP system may face. WLAN or IEEE 802.11 has been utilized in many very different ways since its first standardization in 1997. The restraints brought by the original standard have been stretched and even overcome by new standards or proprietary solutions over the years. The focus of the research was on municipal and other large scale WLAN deployments that use All-IP, attempting to define “best practices” and “lessons learned” in respect to adapted technical solutions.

The study was made as a literature review, with an emphasis put on the network structure chosen for wide area WLAN implementations and other technical details. The material was mostly found on the Internet; through news articles, case studies, white papers, and product description. Also results from interviews with network planners and users concerning Finnish domestic implementations were taken into account. Existing domestic cases and networks from overseas were studied. Solutions provided by different equipment vendors give a picture of the evolution of network structures.

3.1.1 From hotspots to city-wide networks

Some restaurants, hotels, airports provide free WLAN, assuring that it is a way to lure customers and that it will provide ROI. A relatively small capital investment in WLAN base stations (compared e.g. to advertisements) will pay itself back in a very competitive business. A business traveller stated he rather stays overnight in Oulu than in Rovaniemi because the hotel provides WLAN. Usually, though, it is the smaller parties that benefit from offering free WLAN, whereas the larger ones are more known and the increase in customers won’t be that clear.

Starbucks in the U.S. has offered WLAN in partnership with T-mobile USA. This paid WLAN helps attract customers after peak morning hours. They tend to stay longer and be “high income customers”. In Finland the fast food restaurant Hesburger offers free Internet to all member-card owners and this probably is one reason for international McDonalds not to offer WLAN in Finland. There are Internet cafés, on the other hand, which are selling Internet access as prime product and drinks and food as secondary products.

In February 2006 it was written in "Computerworld" that according to JiWire Inc., which has kept a directory of hot spots since 2003, there were more than 100,000 public hot spots worldwide. Those locations include hotels and restaurants, as well as an estimated 30 systems run by U.S. cities. Only about 8,000 hot spots globally offer free access, although the trend is moving in that direction.

These presented hotspots are mostly built indoors in private places. Public places and especially outdoor areas have been during the last years covered by municipal networks. Some have even been city-wide.

Municipal broadband are generally either wholesale or retail. In the retail case the municipality owns and operates broadband facilities, and also distributes the services, such as: Internet access, video, and telephony. This approach exists in markets where no private broadband service provider wishes to participate. The wholesale case is when the municipality funds and builds the broadband facility, but leases it to the private sector service providers. Service providers can enter market without huge investments and lines do not have to be leased from local incumbent providers as much.

The primary reason to build municipal wireless networks for the public has in the U.S.A. been to overcome the digital divide by providing affordable or free Internet access. Other motivations have been attracting companies and tourists and establishing an image for the community as well as providing a network for city services.

The MuniWireless list of US wireless cities and counties from June 2006 lists 59 larger networks, 32 city hotzones and 35 city- or countywide networks purely for public safety employment [34]. The success of citywide WLAN has not been quite as large in Europe because of the larger penetration of cellular networks. The majority of built networks have been metro-scale in the US and campus-scale in Europe, mainly since the mobile cellular coverage is more complete in Europe. Most cellular network operators argy that municipal networks, being unprofitable, cannot survive, whereas some groupings do not even try to make a profit.

One of the first actors in hotzone and larger WLAN networks in Finland were local energy companies, who were visioning a profitable business. They signed roaming agreements with each others and also with international roaming aggregators and wanted to expand [35].

3.1.1.1 Mäntsälä, Finland

Out of the original seven networks driven by energy companies in Finland, three closed and one evolved into the Mastonet network in Lahti. One of the successful ones is the

MSOYnet network in Mäntsälä, which has been working since 2001 and covers ca. 400 km^2. It sells access to private households, smaller enterprises and the community. The network uses 150 Airspan FlexNET units at 2.4 GHz (802.11b/g) and for backhaul in longer NLOS situations links at licensed 3.5 GHz and in shorter LOS situations links at unlicensed 5 GHz. The network features security, QoS and full mobility.

3.1.1.2 Lahti, Finland

The Mastonet network in Lahti, Finland is operated by the city itself since August 2005. Anyone can access the network without authentication for free and Internet and the city e-services should be available everywhere and anytime. The network includes ca. 150 IEEE 802.11b/g access points (Orinoco and Proxim) and they are placed within a 5 km radius from the city centre. Now the city says they are changing coverage strategy from total outside coverage to a more hotspot-type coverage and both financial and development resources are needed. According to the user statistics there have been between 80 and 150 users per day, with a 550 user peak during the Lahti Ski Games. Mastonet has had a media value to the city of Lahti.

3.1.1.3 panOULU in Oulu, Finland

In Oulu, Finland both public and private local organizations joined their "visitor" WLAN networks and created panOULU in October 2003. Accessing the network is free and since June 2005 it does not require any authentication and is therefore open for everyone. The network is expanded by the member organisations and also by the local phone companies, who offer companies besides the regular corporate subscription also a free panOULU access point.

In June 2006 there were approximately 380 access points in the network. The panOULU network consists of IEEE 802.11b access points and in some indoor cases also 802.11a. The positions of the access points can be found on a map and the state, type, and statistics can also be found on the panOULU webpage [36]. Both the network as well as several research projects that have utilized the panOULU network has brought much publicity [37].

The three year project (2005–2007) TAITO Oulu 400 will expand the panOULU network with 400 access points. The city of Oulu has reserved 800 000 € per year for this project. The sum covers besides expanding the WLAN network also building a community portal and computers and educations for the inhabitants. [38]

3.1.1.4 SparkNet/OpenSpark in Turku, Finland

Beginning in 2003 in Turku, Finland, the SparkNet and OpenSpark network are expanding to other Finnish cities and also open for international cooperation [39]. Neighbouring communities to Turku (Raisio, Naantali, Kaarina, Lieto, Parainen and Merimasku) and have joined SparkNet. SparkNet access points can be found both in the premises of the city and other members indoors and also in some outdoor public places.

Both public and private organizations can join SparkNet, there are different network solutions for different size companies and municipalities. Using SparkNet outside the own domain is free only for public parties, as well as for individuals who have joined the OpenSpark part of the network. All users are authenticated centrally.

The network is managed, planned, maintained by a local IT company. Site surveys are not, however, made since they are found to expensive and not having a large impact. Three frequency channels are used. The business model is cooperative, and private parties join by bringing their own access points to the network. It is also possible to buy access. A somewhat similar principle is used by FON [40].

The network consists of separate, different size WLAN hotspots, mostly built by connecting already existing access points. Most access points are based on the IEEE 802.11g standard and the core network is wired, except for in the Turku archipelago where WiMAX has been used. Using WLAN access points as bridges has been tested, but found unreliable. Both directive and omnidirectional WLAN-antennas are used in SparkNet and usually they are vertically polarized. Cells have been sectorized using directive antennas, but so far there has not been a need to limit the effect of the access points in order to control the coverage area. Mobility is not supported in SparkNet. It is more a portable than a mobile network. QoS is not yet supported in SparkNet [39].

3.1.1.5 Great Britain and metro-WLAN

BT-Openzone already has WLAN in over 7800 locations, in typical hotspots such as cafés, airports and shopping centers. In May 2006 BT-Openzone announced their plan to cover 12 British cities with widespread WLAN coverage [41], among these were Birmingham, Edinburgh, Leeds, Liverpool, Cardiff and Westminster. The partners in these city-wide networks are Intel and local authorities. The plan is to fit the WLAN antennas to “street furniture” (traffic lights, light poles, and e.g. building corners). The first six planned networks should be in use by early 2007.

Promoting services, as is the trend especially in Europe: That could be anything from where to park to what's on at the local cinema, as well as improved public services, like health monitoring, traffic monitoring and public safety.

The Cloud is another British WLAN hotspot operator, which is also setting up wireless zones in nine cities including three London boroughs, Edinburgh, Leeds, Manchester and Birmingham, Nottingham, Oxford, and Cambridge [42]. In late 2006 they announced to expand city-wide WLAN coverage to cities across European starting with Amsterdam. The Cloud has chosen to use the solution by Tropos to create the mesh. It has also used Firetide mesh products earlier.

3.1.1.6 Leiden, the Netherlands

Wireles Leiden is a network, which was planned to cover 25 km^2 outdoors. No hills or forests existed in the area and the total number of people was approximately 160 000. For indoors an extra client antenna with LOS to the nearest node was needed. IEEE 802.11b standard was chosen and should have yielded up to 15 km links outdoors with LOS. A mesh was made, as each node was connected through at least two other wireless connections. The cells themselves were interconnected by point-to point wireless connections. This formed the backbone of the network. Their view was that out of the 13 available channels at 2.4 GHz 3 channels were completely separate. At the cost of a small increase of noise but no decrease in available bandwidth they still chose to use 4 channels. Network planning was done with hexagonal cells (typical for cellular network) with radio propagation software based on the Hata–Okumura model. A sight survey was also performed using open source software. Both sectored and omnidirectional antennas were used. Besides radio frequency planning also the IP space was planned.

During the start-up phase some problems were encountered. On the physical level, the network had to be reconfigured, by e.g. redirecting the antennas. The network drivers used for the wireless boards also had errors.

On the IP level there were problems configuring all point-to-point links and applications correctly. Routing protocols were used. The latency of the network might cause problems for some real-time applications. In the future the backbone links would probably be upgraded to 802.11g or 802.11a, which is appropriate if the traffic grows. They also planned to make it a mesh network. [43].

3.1.1.7 Chaska, U.S.A

One of the pioneers in city-wide WLAN in the US is the small city Chaska in Minnesota. The Chaska.net network, owned and operated by the city itself, opened in June 2004 and offered cheap Internet access. The city is about 36 km2 and about 95% of the city's households are covered with 365 Tropos mesh transceivers placed in light poles. The four month trial period with 1000 households was more than the network could handle. The new network still had bugs, the signal strength could be weak, and the speed wasn't good. It took about one and a half year for the city to learn how to operate it. The town had to invest more in the network by adding gateways and only two years after building the network it invested in a new generation of Tropos radios [44].

3.1.1.8 Earthlink/Google in San Francisco, CA, U.S.A

In September 2005 the mayor in San Francisco, U.S.A announced that they wished to build a WLAN network covering the city's 125 km^2 as a first step in promoting digital inclusion [45]. The RFI/C (request for information and comments) got responses in the form of 26 industry proposals and 300 public comments. Six proposals were received in response to the more detailed RFP (request for proposals). In the end three different solutions where competing. The proposed networks will be compared next, especially the technical solutions with respect to coverage, different user groups, open access, transmission rates, network infrastructure and security.

In San Francisco Earthlink together with Google won the RFP (Request for Proposal) and are building a city wide WLAN network. Besides offering paid access, Google will offer ad-supported free access, which will include accepting user positioning. The network will use Tropos MetroMesh product at a density of 12 per km^2 with high gain directional antennas in light poles. Every third mesh node includes Motorola Canopy backhaul capacity and point-to point microwave links will be used between 14 master towers, which will be connected by fibre to the internet. The network will support WPA (Wi-Fi Protected Access), 802.1x, and TTLS (Tunnelled Transport Layer Security) (user must authenticate using username, domain, and password). The plan is to use antenna diversity at CPE, i.e. separate antennas for transmitting and receiving. There was an interesting comment about creating coverage above second floor in the network plan: "it is difficult in practice to achieve 90 to 100 % indoor coverage ... cellular systems are a good example, and users have already become accustomed to moving around to find a good signal".

Another interesting proposal was made by MetroFi using 10–12 SkyPilot mesh network nodes per km^2, with both 802.11b/g at 2.4GHz and 4.9 GHz licensed band for public safety, and built in 802.11a for backhaul mesh and 18 GHz microwave for connecting back to a single central point of presence (POP). MetroFi planned to provide 100% WiMAX coverage via additional overlay gateways. The indoor coverage would be created by the residents' own "repeaters". MetroFi would support nomadic broadband service via 802.11b/g at 1 Mbps downstream, 256 kbps upstream, session-level connectivity for in-motion subscribers at speeds of 48.3 km/h (30 MPH). Users could be logically segmented into different "domains", and different profiles can be defined and managed. Traffic was to be prioritized using 802.1p and the network also supports bandwidth shaping and QoS (quality of service).

3.1.1.9 Roaming models

WLAN networks are common in homes and offices to enable more mobility. Cafés and hotels try to attract customers by offering Internet access through WLAN to them. The WISP is in many cases not the café or hotel itself but a commercial hotspot provider, such as TeliaSonera, DNA Finland or Maxinetti in Finland, the Cloud or BT Openzone in the U.K., and T-Mobile or Wayport in the U.S.A. Those WISPs, who also act as cellular network providers, see WLAN as a niche, and as custom is among cellular operators they sign bilateral roaming agreements with each others. Roaming agreements enable customers of one provider to access another provider's network, and thus increase the availability.

Operators whose core business lies in WLAN hotspots more often rely on hotspot aggregators (clearinghouses) instead of dealing with each partner separately, such as Boingo, iPass, Trusive, or WeRoam, for roaming agreements.

Roaming agreements have also been made at a grassroots level, in the form of OpenSpark [39] and FON [40]. These are decentralized and international community hotspot models in which owners of broadband connections open them to each other. In FON all private AP owners can become FON hotspot managers by downloading a Linux code to the router, which then includes the AP in the network. FON network users without an AP in the network get charged, otherwise the network is free. OpenSpark members can use the commercial SparkNet network as well.

3.1.2 Wide area network structure

Even though large WLAN networks are managed by municipalities especially in the USA, they rely on different concepts developed by companies specialized in the area. Large area networks are commonly based on mesh networking solutions. WLAN does not through its standards support seamless mobility, although some proprietary solutions for this have been implemented.

In small scale cases access points are connected directly to the wired network. On larger scale this kind of network becomes expensive (range of one AP isn't large) and wiring is also required all over. Also, if on AP fails, there should be an alternative way to connect. The result is that most municipal networks use mesh networking. Backhaul nodes can be used in mesh networks to gather data that is sent to a router with a wired connection. Some networks use WiMAX for backhaul. There are different WLAN mesh solution; one radio, dual-radio, and even multi-radio node infrastructures.

3.1.2.1 WLAN topology in the IEEE 802.11 standards

The WLAN topology can be either ad-hoc, where wireless stations communicate directly with one another, or infrastructure networks, where the communication goes through access points (AP). Both methods are described in the original IEEE 802.11 standard and presented in Figure 4. Infrastructure topologies include three different cases.

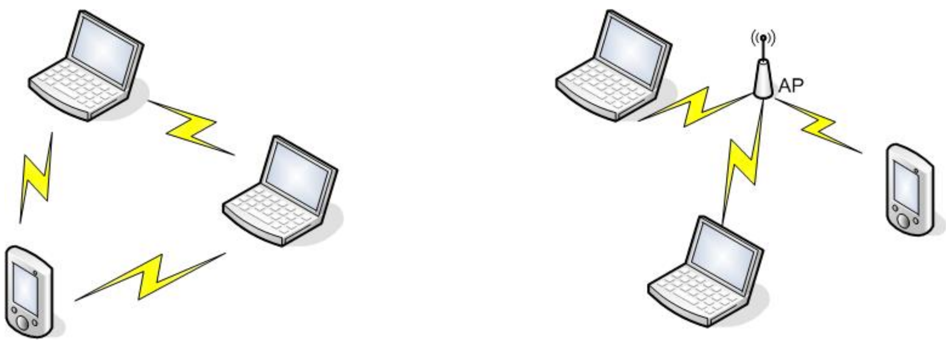

Figure 4. An ad-hoc network (left) and a BSS network (right).

Ad-hoc or peer-to-peer WLAN can also be called IBSS (Independent Basic Service Set). These are usually temporary networks that are demounted after use. The BSS (Basic Service Set) includes an AP (Access Point), which is connected to a wired network and a number of wireless stations.

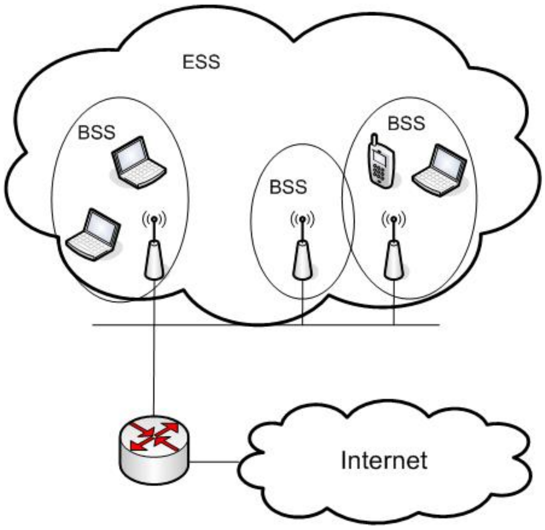

Figure 5. An ESS network.

Combining several BSS results in an ESS (Extended Service Set; Figure 5). Fibre for backhaul is safe since it will last practically forever and is fast, but since wired backhaul can be very expensive for establishing wide area WLAN coverage, different wireless solutions have emerged. WLAN with directional antennas as well as point-to-point and point-to-multipoint microwave links and WiMAX have been used. The most common approach for wide area networks is a mesh-network topology. Airspan, though, says that their experiences in Europe show that cellular, sector based network deployment is technically better than a mesh networking approach [46].

3.1.2.2 WLAN mesh

In a mesh network access points can communicate with each other without being routed through a central switch point (Figure 6). It works well in urban areas, as the relatively cheap access points can be placed densely on buildings and on lamp posts. Network costs depend on the geography and demography, number of users and usage peaks. The IEEE 802.11 standard does not include a non-infrastructure mesh topology. The 802.11s standardization group is working on WLAN mesh, and in March 2006 two mesh proposals, SEE mesh and Wi-Mesh Alliance, were merged into one. As long as there is no finalized standard all vendors have their own solutions for e.g. self-configuration of nodes, traffic signal hopping and routing and they are not interoperable with each other. Vendors have applied both bridged and routed mesh networking where the backhaul either consists of a shared network or a series of point-to-point links.

WLAN coverage with mesh depends on the amount of transceivers, where they are placed and how many are directly connected to the core network.

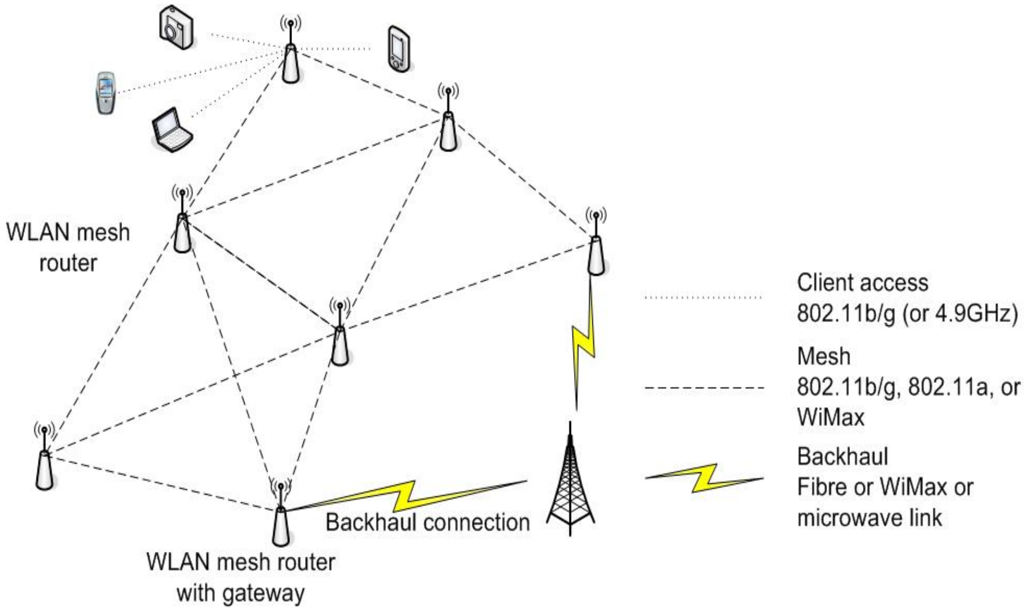

Figure 6. Basic WLAN mesh network structure.

There exists also WLAN mesh systems focused on sensor and telemetry applications. One system especially designed for public safety applications, but also supporting 802.11a/b/g besides the 4.9 GHz spectrum (in the US 4.9 GHz is reserved for public safety: surveillance, ambulance, police force, fire fighter usage) does not rely on the fixed access points but on the mobiles themselves that by the help of software can act as nodes in an ad-hoc mesh network. [47]

3.1.2.3 Hybrid WiMAX / WLAN mesh architecture

Most WLAN mesh equipments in outdoor citywide networks have nowadays multiple radios, such as WLAN, WiMAX and 4.9 GHz. WLAN itself supports only three non-overlapping channels at 2.4 GHz and 12 (in Europe) and 24 (in the US) non-interfering channels at 5 GHz. WiMAX is included in Motorola, BelAir, Strix Systems, Skypilot and Cisco solutions. Tropos Networks mesh only has one radio to keep costs down. Some vendors support QoS and security, especially since VoIP is becoming a demand in municipal WLAN networks. WiMAX is still much more expensive than WLAN, but since they work on longer distances they can be more suitable for rural wide-area coverage for backhaul. Pre-IEEE 802.11n solutions have also appeared on the municipal WLAN market. Satellite connection combined with GSM and 3G networks has also been used as backhaul for WLAN client access for example in trains and airplanes.

3.1.2.4 City-wide solutions

Next eight company specific WLAN mesh solutions are presented briefly. Also a couple of other methods used in citywide municipal networks are given.

BelAir Networks offers single-, dual- and multi-radio wireless mesh products for municipal wireless networks. They are scalable and have QoS tagging and classification capabilities and thus support services such as VoIP and broadcast video. Metro-scale Wi-Fi / wireless “mesh” Canopy – WiMAX feature compatibility, municipality market w/ hundreds of base stations BelAir Networks Inc.

BelAir “metro mesh” solution offers a multi-radio mesh system with one 802.11b/g radio for client access and up to three proprietary 5 GHz radios for backhaul. The antennas do not need to be manually directed since the direction of the signal paths can be switched.

Cisco RRM [48] (radio resource management) embedded software is used for consistently fine-tuning WLAN parameters including real-time RF management. Cisco usually only uses three channels (1, 6, and 11) to minimize the co-channel interference between different 802.11b/g standard equipment. The transmit power should be controlled in order to create the coverage in the wished area and e.g. not outside the office building. Also, the wireless environment changes very much during different office hours and for optimal performance the network can react to these statistical changes. Cisco offers since 11/05 also a mesh product. This is a dual radio system with one 802.11b/g radio on the client access side and one 802.11a radio for the backhaul. Cisco promotes mesh standards using the Lightweight Access Protocol.

Cisco lightweight AP’s can scan all channels in order to find rogue access points, rogue clients, ad-hoc clients and interfering access points. Typically all APs do this scan at different times and by default 0.2 of its time and send the information to the Cisco Wireless LAN Controller for analysis.

Firetide is a mesh network infrastructure maker, which can be combined with any AP. Since August 2006 also own APs. Firetide IT provides a single radio mesh version, the same 802.11b/g radio for both client access as well as backhaul. The mesh is built as small local clusters, with up to 30 nodes, of nodes which are connected to other customers. Firetide has partnered with EDX Wireless, a software developer of radio networks planning tools, in order to help municipalities plan and deploy wireless mesh networks and they have network management software of their own.

Nortel's [49] wireless mesh solution consists of three parts: the wireless APs, the wireless gateways and Nortel's own "Optivity Network Management System" for monitoring and managing the network operations, including fault managing. Nortel Networks has teamed with Aptilo Networks and Pronto Networks for municipal networks. They are, for example, building a wide network in Taipei, Taiwan with 3300 Nortel mesh access points.

Motorola acquired start-up pioneer MeshNetworks in the end of 2004 and their WLAN mesh product and the resulting Motomesh product was announced in March 2005. It consists of three devices: an intelligent four radio access point (two each on the 4.9 GHz and the 2.4 GHz frequency bands), wireless routers, and the optional MEA (Mesh Enabled Architecture) radios. On each frequency one radio uses WLAN and the other one the MEA protocol.

SkyPilot Networks has traditionally offered point-to-multipoint fixed wireless gear, but now also a metro-scale WLAN/wireless mesh platform. The SkyExtender DualBand is a dual-band radio mesh architecture based on a marriage of the company's synchronous mesh protocol and advanced antenna array technology. The SkyExtender DualBand currently employs Wi-Fi backhaul in the unlicensed 5.8 GHz band and the 4.9 GHz band for public-safety communications, with dedicated access via 2.4 GHz WLAN. In September 2005, the company announced that it had chosen Fujitsu Microelectronics America's WiMAX system-on-a-chip to power a WiMAX mesh solution SkyPilot has under development for a planned launch in the year 2006. The WLAN metro mesh architecture now used will evolve to WiMAX. WiMAX will become the mesh backhaul, and WLAN will provide the access to clients. With SkyPilot's traffic management traffic can be prioritized ensuring that latency-sensitive traffic is given end-to-end prioritization throughout the network. Traffic can be prioritized with the help of a wide variety of options, e.g. IP protocol type, IEEE 802.1q VLAN ID, IEEE 802.1p user priority, IP source or destination address, source or destination MAC address, or protocol type.

Strix Systems currently offers a dual-band radio mesh, announced in early October it will also use WiMAX in its dual-radio approach (As with SkyPilot's system, 2.4 GHz is used for access while 5.8 GHz is used for backhaul). Furthermore, Strix uses a frequency division duplexing scheme for mesh, with dedicated radios for transmitting and receiving. This helps to keep latency at the minimal levels and allows it to minimize network points of presence (to the transport network) down to one for every 60 WLAN nodes. Strix claims they are capable of getting WiMAX-like performance using optimized 802.11g technology. But there are benefits to WiMAX, when the network gets crowded, in that it can be deployed over licensed spectrum. One of the earliest US city-wide WLAN networks in Tempe, Arizona, uses 400 Strix access points to cover a area larger than 100 km^2.

Tropos Networks offers a metro scale mesh networking, MetroMesh, with a single radio: IEEE 802.11b/g for both client access and backhaul mesh.

3.1.2.5 Other solutions for city-wide WLAN networks

Wavion's solution for municipal city-wide networks is to use MIMO technology to directly connect the nodes to the backhaul. The access points have six antennas and the spectrum is reused through beam forming. The used new spatially adaptive beam forming is promised to double the range and penetrate buildings and foliage. Wavion plans to integrate their system into other companies' metro-scale systems.

Alvarion, a worldwide leader in wireless broadband, offers a WiMAX solution also for city-wide municipal networks market with hundreds of base stations. They also provide own management software.

3.1.3 Conclusions

Municipal WLAN include both success and failure stories. Municipalities have learned to build or buy networks according to current standards and rely on more than one vendor. Networks require regular upgrades, and this is easier when the network is well planned. Understanding the background, actual obstacles in large scale WLAN implementations and ways to overcome can help designing robust and adaptable All-IP networks.

3.2 DAIMON Architecture

3.2.1 State of the art

The present day telecommunications networks are a combination of circuit switching and packet switching networks. However, the circuit switching is gradually giving way to packet switching (Chapter 1). During the transitional period both techniques live side by side. Examples of this symbiosis are present in 2.5G (GSM/GPRS) and 3G (UMTS) networks, both supporting circuit and packet switching (see Figure 7).

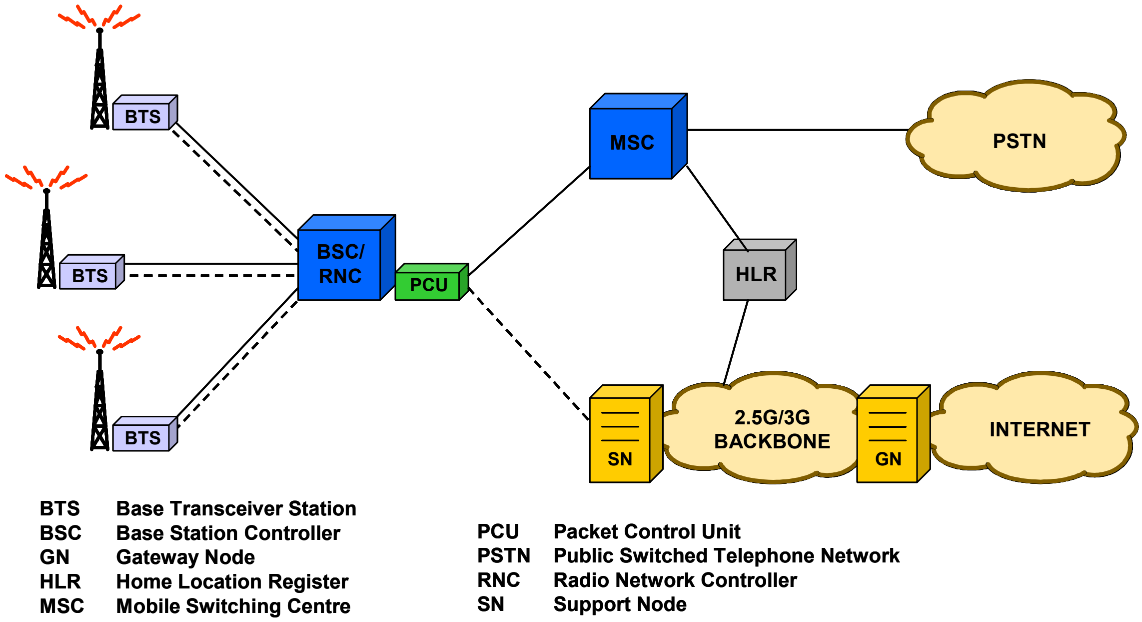

Figure 7. Simplified 2.5G/3G network architecture.

As the evolution proceeds, circuit switched networks shrink to isolated islands, which are connected together via packet based networks by emulating the circuit switched connections. Connection control mechanisms of the circuit and packet switched parts of the network are separated. Some operators have already started to carry PDH circuits (e.g. E1 or T1) over their packet switched backbone network.

The circuits can also be terminated at the edge of the packet network. The carried data is converted to the form supported by the packet network and the converted information is carried through the packet network over a packet switched connection. Connection control mechanisms have to work together, implying additional complexity. Interworking of the conventional telephony service and VoIP service is a good example of this sort of a solution.

In both of the above cases, the packet switching network acts as the core network, but in the latter case the packet core integrates the different access networks (circuit and packet switching ones) to a common IP based service network/infrastructure. This scenario is illustrated in Figure 8.

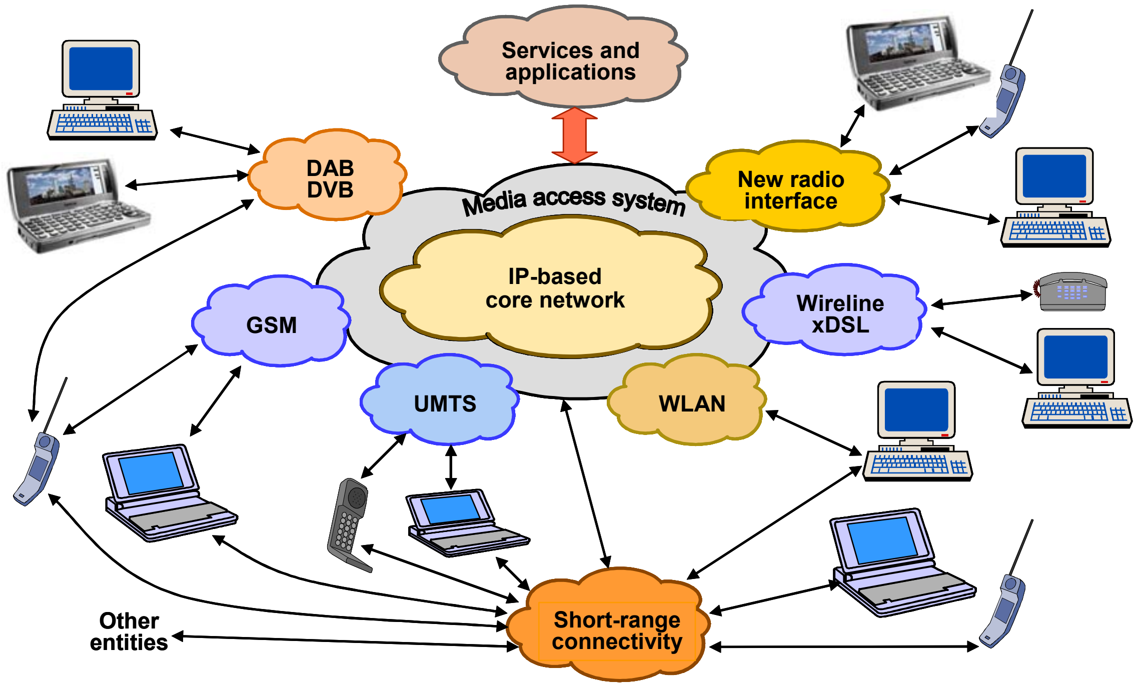

Figure 8. All-IP core network as an integrator.

3.2.2 Networking future

ITU-T NGN and 3GPP standardisation groups work for the future network concept that is supposed to be based on packet switching. Due to the legacy burden, the future packet network should support also the old established circuit switched networks. The proposed concepts are very complicate and are getting even more complicate as the IP based networks should support the quality and reliability of the circuit switched networks. IP networks do not inherently support circuit switching quality and adding those features implies that new protocols need to be defined. As a result the systems under standardisation process are getting so complicated that even the old telephone network with its backups is starting to look an easy solution.

ITU-T's NGN and 3GPP's concepts were considered as the starting point for the study of the All-IP network architecture. The target was to foresee the future development up to the point when the circuit switching has no foothold in the basic network architecture. The developed ideas were compared with ideas found in international publications.

3.2.3 All-IP architecture

The All-IP architecture, considered as the DAIMON architecture, assumes that all network connections, starting from a user device and ending up to some server or another user device, are based on packet switching technology. Taking the mobile network as an example, the major changes in the network architecture are that the circuit switching part and related network elements disappear, different (wireless) access networks are controlled by common network entities and new types of user, access, connection, service and etc. control units (servers) appear into the network (see Figure 9).

Based on the anticipated architecture, we developed scenarios about the functionality present in the future networks. The functionality must reside in some network elements (servers) and one part of the work was to estimate the type of network elements that are needed and where in the network they should reside. As the network develops into an All-IP network, its architectural structure gets less complicated. However, the need to have a carrier grade All-IP network means that additional complexity has to be added to sew up shortages of IP.

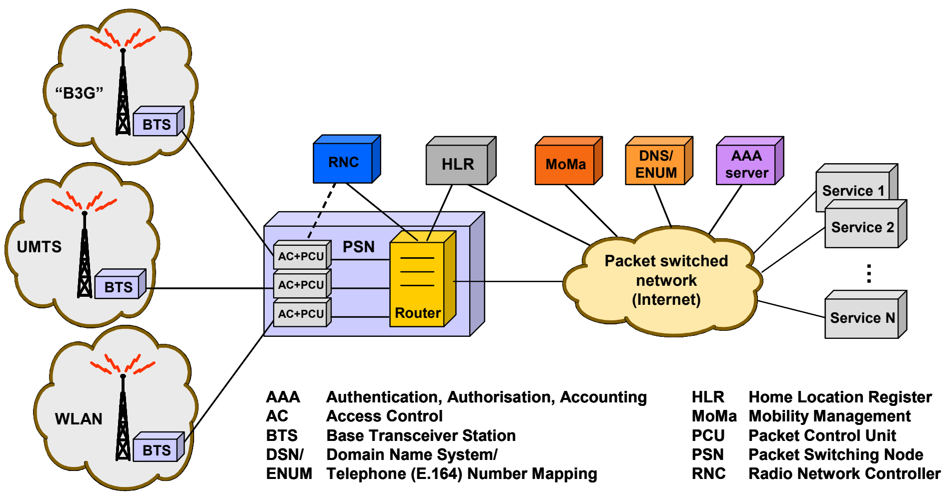

Figure 9. All-IP mobile network architecture.

IP networks are more vulnerable than the conventional telecom networks. In conventional networks, a lot of attention has been paid to reliability of connections and security of communication. For example, key network elements and functions are duplicated and control functions are isolated from the outside world. IP based networks are open in nature meaning that control functions, even the crucial ones, can be accessed from any corner of the network. Additional security mechanisms are needed to protect the network from malicious use.

The triumphal march of the IP technology is also based on lower cost, which is obtained by less secured network elements and connections as well as by less strict technical specifications. For example, duplication of key network nodes and functions is not as common as in the legacy networks. Since the IP networks are becoming the corner stones of the future society, it is highly justifiable to study also the dependability issues of the All-IP networks to pin-point the most vulnerable parts of the network.

3.3 Mobile Backhaul

In wireless networks, the base stations that communicate with the wireless terminals connect to the wire line core network via base station controllers (a.k.a. radio network controllers). Connections, either wire line or microwave, between the base stations and base station controllers form the wireless/mobile backhaul network.

3.3.1 Backhaul challenge

In existing mobile networks, the backhaul network usually builds on PDH, ATM/PDH, SDH, ATM/SDH and Frame relay/SDH techniques. These techniques offer reliable transfer of user data and control information between the core network and the base stations. These transport concepts are also scalable, i.e. large tree shaped network branches can be built without addressing problems.

As the IP technology advances and the telecommunications market gets more liberal, it has become possible to hire low-cost transport capacity from (local) network operators. As for the mobile networks, the problem is that these operators often sell pure IP or Ethernet transport, which means that the bit pipes coming from the base stations should be converted to IP/Ethernet form or carried over IP or Ethernet in dedicated tunnels.

IP and Ethernet lack many features considered essential for reliable backhaul transport. For example, protection of transport paths against failures and restoration of lost connections (features already well proven in the SDH technique) are missing or imperfectly defined. Scalability is another factor not being in an adequate level in the Ethernet concept. So even though IP and Ethernet are cost-effective solutions, they do not suit for mobile backhaul as such due to the mentioned shortcomings.

3.3.2 IP/Ethernet based backhaul

The starting point for the mobile backhaul study was the work done in IETF, IEEE and ITU-T working groups. The DAIMON project concentrated on studying technical details of layer 2 (Ethernet) and layer 3 (IP) VPN solutions, related signalling alternatives and their applicability to the mobile backhaul. The outcome of the backhaul study is summarised in Figure 10. A two-tiered network model was assumed where the BTSs and RNCs attach to a “VPN Backbone” network through “Access Networks” (not to be confused with RAN as a whole.

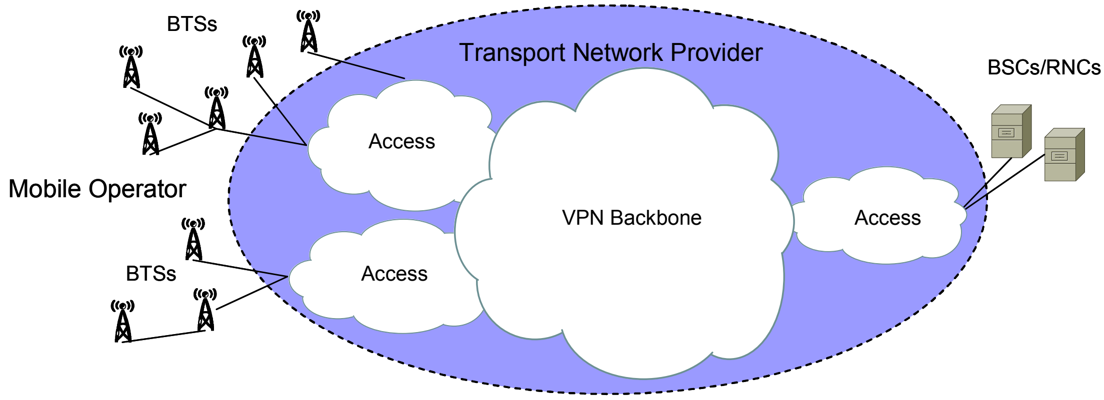

Figure 10. A backhaul network model.

The VPN Backbone provides transport services to multiple separate sets of customer networks each of which can be part of multiple VPNs, although Figure 10 shows only a single RAN. For example, the access networks can interconnect enterprise networks at dispersed geographical locations or they can provide residential/corporate access for connecting to the Internet. A specific feature in the BTS backhaul scenario is that traffic flows only between BTSs and RNCs and never between separate BTSs.

The VPN backbone and the access networks are managed by a VPN service provider that offers transport service to a mobile operator. The mobile operator manages the BTS and RNC sites. Optionally, the mobile operator can lease network access service from an access network operator, which may or may not be the same as the VPN backbone provider.

The type of a VPN service depends on the desired peering relationship between the access network (or end hosts) and the VPN backbone. By definition,

- An L2VPN switches Ethernet frames and uses Spanning Tree Protocol (STP) as the native network formation and resilience mechanism in the access network. The VPN Backbone could be conceived as a huge bridge or hub.

- In an L3VPN, routers in an the access network (or in the BTS/RNC sites) peer with routers at the edge of the VPN backbone. The interconnected customer networks learn routes to each other through routing information carried by routing protocols. The VPN backbone could be conceived as a huge router.

3.4 Network Dependability

3.4.1 An extended conceptual framework

The notion of *dependability* is usually defined as a collective term with a number of different aspects such as availability, maintainability and reliability. It is, however, not sufficient to assess the dependability of the All-IP network using only methods developed for other large infrastructure systems like power plants and the electric network. Among others, Doyle et al. have pointed rightly out in [50] that the dynamics of the Internet cannot be understood without an adequate theoretical understanding of its multi-layer communication protocol structure. Thanks to them, an IP network is a remarkably self-controlled system. Therefore, we added to the picture of dependability three more aspects with system theoretic flavour:

- the robustness of design of the basic algorithms and protocols, meaning stability with respect to arbitrary inputs

- as a counterpart to the former, one should pay attention to vulnerabilities of design that often are, in fact, neglected aspects of the generally robust design

- finally, despite the self-controlling character of part of IP technology, we want to include certain amount of controllability to the aspects of network dependability.

This idea is further developed in the baseline paper of the IPLU project [51].

3.4.2 Remarks on DNS and BGP

The Domain Name System (DNS) and the Border Gateway Protocol (BGP) belong to those elements of the current IP architecture that have a doubtful role from a dependability point of view.

DNS is not a part of the IP itself but necessary for practical usage of the Internet. It is a huge hierarchical distributed database of domain and host names and their associated IP addresses. Name servers belong to the most popular targets of denial-of-service (DoS) attacks. On the other hand, the vulnerability of DNS has been well recognized, and the threat has so far not fully realised despite of numerous malicious attempts and, also, some cases of unintended DNS overloading by bad software implementations. The main countermeasure has been mirroring of root name servers to a large number of hosts around the world. Another aspect, improving the security of DNS, has not advanced as well.

BGP is the protocol responsible for most inter-domain routing in the Internet. Its design is generally considered unsatisfactory for its central role in the architecture. Besides stability problems like route oscillations, it is dangerously sensitive to erroneous information from peer routers. It has also been pointed out that Internet service providers' trend to replace the use of centralized exchange points by bilateral transit agreements poses a risk to the robustness duo to the resulting cyclic topologies.

3.4.3 Dependability aspects of the DAIMON architecture

Let us now focus on the DAIMON architecture, leaving the general problems of the Internet architecture aside. Then, the fundamental requirement of the architecture is the provisioning of IP connectivity between the mobile users and the Internet. Further requirements are provisioning of IP connectivity with specified QoS, mobility support with seamless handovers both horizontally and vertically, and the availability of location information for services that need it. Considering the DAIMON architecture from the classical structural reliability point of view, two consequences can be drawn:

First, the provision of several independent radio accesses yields a remarkable increase of the overall dependability of IP connectivity. However, since the default access is typically that with highest transmission rate and quality, the QoS level can seldom be maintained if the default access is lost.

Second, the integrated design where several wireless access networks share the instances of system components like DHCP, DNS and AAA servers poses high dependability requirements for these components. To avoid single points of failure, it is not sufficient to invest in higher quality hardware and software, but it is important also to build more redundancy in the whole system, making the economic gain of the integration somewhat lower than one might think at the first glance.

3.5 Traffic

One of the main theoretical problems is the lack of generic traffic models in the cases where the level of traffic aggregation is low. Such models would be valuable tools in planning and dimensioning ubiquitous future networks. A traffic model should be able to take into account several properties of true traffic, such as *burstiness*, *long range dependence* (LRD), *heavy tails*, *bursty behavior determined by high bandwidth users* and *dependence determined by users without high transmission rates*. The motivation of both of the studies Kilpi et.al (2005) [11] and Markovich and Kilpi (2006) [12], started within the DAIMON project, were on such traffic models. The aim of the submitted study Markovich and Kilpi (2007) [52] was to obtain some statistical conditions from an access network and it's flow traffic that would have to be taken into account for any attempt to model the flow-level traffic of that network. Such conditions include the estimation of the proportion of flows, which pass through the relatively lowest or the highest access rate links and estimating whether the rate that a flow gets could be assumed to be independent of the flow size. This latter property would simplify the modeling step significantly but, indeed, in the access networks it is hardly justified.

Assume that we have observed a bivariate time series of n TCP-flow *sizes* (S) and the data transfer times of these sizes which are called *durations* (D). Thus the data would look like $(S_1, D_1), \ldots, (S_n, D_n)$. The bivariate *Extreme Value Distribution* (EVD) G is an *asymptotic* distribution of pairs (S^*,D^*) where $S^*=max\ (S_1, \ldots, S_n)$ and $D^*=max\ (D_1, \ldots, D_n)$ when n tends to infinity.

At the first glance it may feel strange to combine S^* and D^* since they need not correspond to the same TCP-flow. However, if all of the n TCP-flows would be, for example, file downloadings through *separate* access links but with the *same* access rate then, with very high probability, S^* and D^* would actually correspond to the same flow, that is, (S^*, D^*) would actually be one of the observed data pairs. This is due to the heavy tailed nature of the distribution of the flow sizes which means that S^* is typically very much larger than any of the other observed $S_1, \ldots, S_n, S_i \neq S^*$. Thus, the corresponding duration is very likely to be D^*, the maximum of all n durations. Cases where D^* does not correspond to the true duration of S^* can be due to congestion at the access link, congestion at the access/backbone network, congestion at the Internet or, for example, due to an application/service which keeps the TCP-connection open much longer than actually needed to download the observed file size.

However, typically the access rates are not the same for different users. In that case flows with different access link rates must be monitored separately and, within each access link class, we are back in the above mentioned simplified scenario. The estimation of G is then done from pairs (S^*, D^*) obtained over monitoring different access rate classes.

The interpretation of G, that it is an approximate distribution of true data points (S^*, D^*) with given access rate, remains the same. That is, both S^* and D^* are relatively large compared to other flows with the same access rate that arrive approximately at the same time. These flows form a small subset of all flows but this subset is important since it is reasonable to assume that it is *the most active users* who typically generate the relatively largest flows.

Let us define $R^*=S^*/D^*$. Now, if we assume that (S^*, D^*) is distributed according to EVD G and denote by G_2 the marginal of G that corresponds to D^*, we can write

$$F_{R^*}(z) = P\{S^* / D^* \le z\} = \int_0^\infty P\{S^* \le zy \mid D^* = y\} dG_2(y)$$

and

$$P\{S^* \le x, R^* \le z\} = \int_0^\infty P\{S^* \le \min\{x, zy\} \mid D^* = y\} dG_2(y)$$

Once we can estimate the *dependence structure* and *marginals* of G, these integrals of conditional probabilities can also be estimated. Hence, this approach provides a way to study F_{R^*} and may give some insight of how strong the dependence between S^* and R^* is. Small quantiles of F_{R^*} contain information about the proportion of relatively large flows that are bottle-necked by the low access rate, hence it provides information about active users who still have not migrated to faster access technology. Large quantiles of F_{R^*} tell about the proportion of very large flows through the fastest access links, hence it is related to the burstiness of traffic. A value like the expectation of R^*, $\boldsymbol{E}R^*$, can be assumed to be very close to a weighted average of the access link rates that the most active users have.

The above ideas actually work also in the case of congestion at the various parts of the network. Then the important thing is to estimate *the significance of congestion* at the access links or at the access/backbone network. This has also been a topic of research within the DAIMON project. In a preliminary research made for the study Kilpi and Lassila (2006) [11] *wavelet analysis* were applied to aggregate TCP traffic in order to infer signs of possible congestion in the network. This analysis was based on the assumption that the most common (or dominating) values of RTT of the aggregate traffic causes some rough periodicity that is visible in some time scales. While wavelets were found useful for the analysis of an aggregate of TCP flows, ordinary *periodogram* (*Fourier analysis*) was found useful for the analysis of an individual TCP flow. The use of these signal processing methods was promising and further research on this topic is planned to continue within the ABI project. Markovich and Kilpi (2007) [52] contains also a couple of statistical methods to test whether the aggregated network traffic at the access/backbone is significantly congested.

3.6 Radio Resource Management in All-IP Networks

The migration toward All-IP systems has an evolutionary character. It is therefore necessary to understand the systems that are the base for the development. One of such systems is UMTS. Enhancing the existing UMTS is the most straightforward way toward All-IP solutions, because this system is already heavily based on the IP networks: basically, most of its core network utilises this protocol. Another reason for special interest in UMTS is the fact that it is the first cellular system whose access technology is in general independent from offered services. This is possible, because the UMTS features very flexible resource model that can be adapted to very different QoS requirements. If this fact is combined with the current trend that more and more services are based on the Internet (and therefore on the IP protocol), it is clear the UMTS must be carefully analysed when resource management in All-IP systems is considered.

The first step in the UMTS study was to collect general information about the resource management in this system. This has been done and a project report has been issued. Then, simulations were used to analyse the most applicable techniques. They focused on the radio interface and the IP-based services. The latter is obvious: the Internet-based applications gain more and more popularity in wireless networks and the UMTS is no exception here. Regarding the radio interface, all published research (e.g. Laiho's "Radio Network Planning and Optimisation for UMTS", 2002) indicates that this is the bottleneck for the system capacity. Since there was not live network that could be used in the project, the study was based on simulations. For this purpose a system level UMTS simulator developed in Caution EU project was enhanced. The modifications were quite significant and enabled more accurate system capacity monitoring (both, effective and wasted through outage), added new resource management technique (DL scheduling based on number of DTX-active connections for NRT services) and generally improved simulator's stability. The actual simulations were focused on the impact of heavy IP-based application on the outage in the downlink and coexistence of data and voice services. The results have been presented at the 13th International Conference on Telecommunications (ICT 2006).

The radio bandwidth is limited and it is therefore likely that a possible bottleneck will occur here. In order to utilise the resources effectively radio resource management methods have to be applied also in wireless All-IP networks, such as WLAN (Wireless Local Area Network) and WiMAX (Worldwide Interoperability for Microwave Access). The more crowded a network becomes the more important it is to utilise the existing resources effectively and as a result, resource management is more often addressed in WLAN networks than in WiMAX networks.

Within the DAIMON project proposed resource management techniques were reviewed as they have been presented in journals and conference proceedings. Emphasis was put on IEEE journals and conference proceedings. Articles from the past three years were given the highest priority. Neither a simulator nor a trial network was available and consequently, the research had to be based on a literature review. Still, given the long background in resource management in UMTS networks at VTT, it was possible to identify problems and trends in resource management also in All-IP networks.

3.6.1 UMTS

3.6.1.1 Resource management in UMTS

The resource management theory was presented for UMTS in a project report issued in 2005 [53]. Here, part of that report is recalled.

In UMTS (FDD) radio access network is based on CDMA technology. Users can coexist in the same area and simultaneously communicate with the base station (or even several of them in case of so called "soft handover"). There are therefore two main resources that have to be managed: uplink interference and downlink transmission power. Both of them are shared by users of the system, but they are independent from each other.

As it is seen from Figure 11 both of the resources increase non-linearly and therefore even if they are not anyhow physically limited (as the interference is not), at certain point increasing load is not possible (it would require infinite amount of the resource). These curves define roughly capacity of an UMTS cell (in practice this is the maximum theoretical limit, because the actual limit is lower due to limited transmission powers in the base station and the terminals). However the way they are shared and granted should be controlled by the resource management.

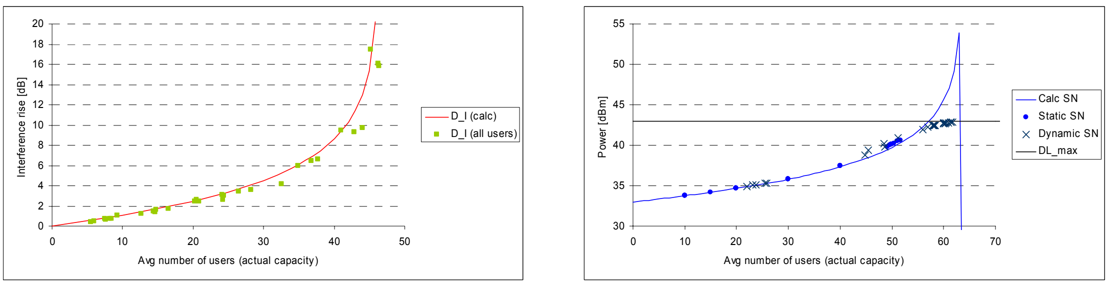

Figure 11. Comparison of the theoretical model and simulation results for the UL interference rise (left) and the total DL TX power (right).

In addition to the UL interference and DL transmission power, there are some other resources, which are related to the implementation of the system. They are explained briefly below, but none of them seems to be a limiting factor in UMTS; the main focus of the resource management should be put on the interference and the transmission power.

Codes: Transmissions in UMTS, as in any CDMA system, are recognised by certain code. Therefore, since there is limited number of codes, there can be a limited number of transmissions. Depending on the channel type and direction, there are from several hundreds to several millions codes available.

Frequencies: Even though in a CDMA system cells can reuse its neighbour frequency, this resource should be also considered. In some conditions an operator may want or have to allocate multiple frequencies. In that case the number of available bands becomes a resource that has to be managed (the limit usually is defined by an authority that issued a licence for the operator).

In the following part a brief summary of the resource management trends in the UMTS is presented.

Power control

It is relatively difficult to apply any resource management technique (RMT) in relation to the power control. This is because the procedure has been very precisely defined and standardised leaving no space for further research: according to ETSI standards the power control is based on measured signal to interference (SIR) ratio and comparing it to the target SIR. If the measured SIR is lower a command to raise the power (by a fixed step) is sent, otherwise power decreasing is ordered. However, some issues are still available: for example the problem of power balancing between two (or more) cells involved in soft handover procedure. Also amendments to the actual standard are proposed, for example replacing the binary transmit power commands (and fixed power control step) with actual SIR/SIR_{target} difference.

Handover

Contrary to the power control, the handover algorithm is not standardised (only its procedure are: link addition, dropping and replacement: they enable both hard and soft handovers). Therefore there are quite many various possibilities for implementation. Most commonly used algorithm is based on measurements of certain quality parameters (often the received power of the pilot channel) and performing the handover when the value of the parameter exceeds a given threshold. Additional functionality can be added, for instance decision delays to avoid ping-pong effect. The threshold can be either fixed or relative to the best cell in the active set, as proposed by ETSI. Currently research focuses on the parameters of these algorithms to provide SHO gain. SHO theoretically causes higher resource consumption as compared to the HHO (the higher the more users is involved in it), but it also improves link quality. Therefore the parameters must be found that the resource loss is compensated with improved quality.

Admission and load control

Admission and load control algorithms focus on maintaining network load at certain, predefined level. They are therefore closely related to the load monitoring. Admission control usually tries to prevent congestion by anticipating future load when a new user is to be admitted. If this load is supposed to be too high, the user is blocked. Load control is a set of resource management techniques whose main task is to prevent the load from exceeding the predefined level, among which call dropping is the most brutal but also the simplest approach. Much more reasonable is call dropping after certain minimum call duration. In UMTS there is no standardised support for these functionalities, but in every network they are inevitable. Therefore there are plenty of proposals in literature; however few of them are implementable. Those simplest techniques are based on observation of some basic load indicators (e.g. UL interference rise or DL TX power) and based on known theoretical models they seek to anticipate load changes. This is not very accurate approach; hence researchers still try to come up with new indicators and models.

Scheduling and HSDPA

Scheduling is relevant mainly in case of non-real time (NRT) services. In practice, in case of cellular networks this means data transmission. That means that its importance in contemporary networks is low – NRT traffic forms rather small fraction of all traffic. It will be however growing as there are more and more network-based applications available. Scheduling therefore aims at distributing bursty data traffic over time more evenly to avoid temporary congestions followed by idle periods. In current version of UMTS there is little support for data scheduling. It is limited to defining separate QoS class for NRT transmissions and possible usage of channel reallocation mechanisms to control data flow. In future releases the UMTS will be probably enhanced with High Speed Downlink Packet Access (HSDPA). Among others this technique proposes implementing DL scheduler in UMTS base stations where they could use the complete set of physical measurements to improve data throughput (data would be sent only in favourable conditions to save resources from the load caused by retransmissions and strong coding). The scheduling would be performed very quickly – scheduler step would be 2 ms to enable reactions to fast fading.

Priority levels and QoS techniques

GPRS was designed to support QoS but in its implementations it was very seldom used. However, the fact that the framework exists enables research on possible ways to utilise it for resource management. In literature common assumption is that certain services have lower priority than others. This priority level is the simplest QoS indicator and enables, e.g., pre-emption: dropping of lower priority calls when a higher priority call can’t be admitted to the network. More sophisticated QoS profile enables less brutal approach: when resources get scarce, the quality of lower priority connections could be degraded to provide necessary resources for the higher priority calls. QoS renegotiation, as this technique is called, is a softer version of call dropping. Similarly, a softer version of call blocking is QoS initial negotiation. In this case a new low priority call is not completely blocked in case of expected congestion, but admitted with lower than requested quality level (and thus also lower resource consumption).

MBMS
Multimedia Broadcast/Multicast Service (MBMS) is the most recent enhancement to the UMTS. The concept is based on the assumption that in future there will be “heavy” (i.e. requiring a lot of resource) multimedia services that will be used simultaneously by many users. If additionally it is assumed that these services would be of broadcast type that could be sent to all destination terminals in the same time (which does not mean the users would have to use them at the same time) then a natural conclusion is that perhaps they could share the same resource. It is therefore proposed to enable a channel to be dedicated for a group of users. In such channel DL power control would be very difficult, if not impossible (the DL TX power of such channel would need to be as big as it is required by the most remote user; on the other hand, however, in the DL the impact of the distance is very small). After initial interest this service seems to be loosing attention in the literature.

UMA
The unlicensed mobile access (UMA) forum aims at proposing standards that will enable service integration between the UMTS and unlicensed wireless technologies (mainly WLAN, but Bluetooth is also considered). UMA is not a separate type of resource management, but it is a very important approach from the project point of view – in short, it builds a bridge for smooth migration from UMTS to future All-IP systems. “Smooth” means here ability to provide users with their known UMTS applications over other access technologies, e.g. WLAN. The standardisation process is not, however, completed, so there are relatively few publications on this topic.

3.6.1.2 Simulations

The simulations were performed with a dynamic UMTS system level simulator created in CAUTION project (co-financed by the European Commission). All the main UMTS features and procedures (including the power control) have been implemented according to the ETSI specifications. Both dedicated channels, DPDCH and DPCCH, are modelled so it is possible to switch the DPDCH off and maintain the DPCCH. The DTX is controlled by the data generator. In case of NRT services there is a buffer between the generator and the channel model. The buffer stores data if the channel throughput is too low as compared to the throughput offered by the generator. The buffer accumulates data to send if the DPDCH is suspended, too. An example of simulation-based study of the resource management in UMTS is presented below. However, in the DAIMON project much more experiments were performed (ref. [54]).

In order to study the impact of the DL data transmission on the lost capacity in the system, two types of data service (called "heavy" and "light", because they differed from each other in the amount of the offered traffic) were implemented over 384, 144 and 64 kb/s UMTS dedicated channels. The idea of outage was based on the UMTS capacity model developed in VTT. The new model takes into account the dynamic processes in the network. In brief, outage occurs when a user whose signal quality is poor cannot be dropped immediately from the network. In order to avoid massive droppings whenever the radio conditions change, such outage users must be allowed to remain in the system, even though their transmissions are ineffective. However, the interference they generate decreases the overall system's capacity. This loss is called "lost capacity" and was analysed in the DAIMON simulations. The amount of lost capacity because of simultaneous data transmission is presented in Figure 12.

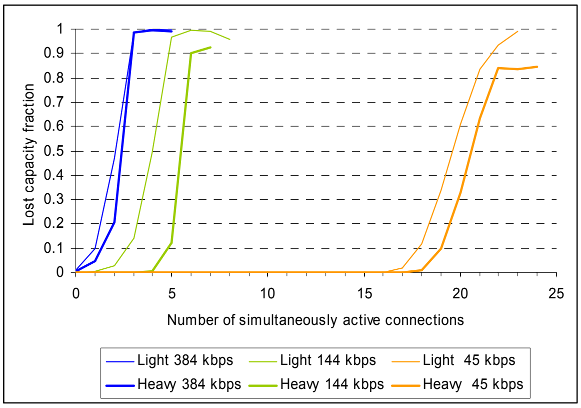

Figure 12. The outage caused by simultaneous data transmission in the DL UMTS radio interface.

The figure clearly indicates a need for scheduling: for every analysed case it is possible to find a limit, up to which the outage is negligible, but beyond which it raises very fast. This limit is the scheduler's input data. To verify the applicability of the resource management technique, the simulator was enhanced and the technique simulated. In this report only selected results are presented: in Figure 13 the Lost capacity fraction and the effective throughput for a heavy data service transmitted over 384 kb/s channel are presented for 4 arrival rates and 3 cases (no scheduling, scheduling with only 1 active transmission and scheduling with 2 active transmissions).

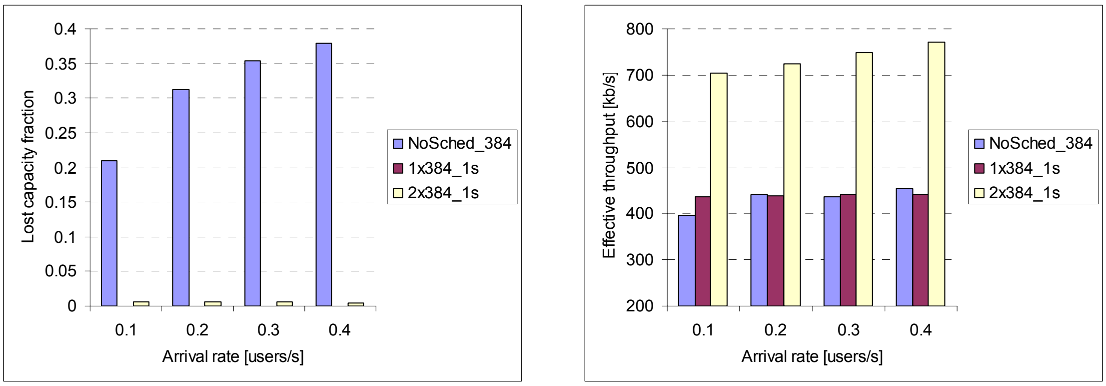

Figure 13. Impact of scheduling on the DL lost capacity (left) and effective throughput (right).

The plots clearly indicate the positive impact of the scheduling. This means utilisation of resource management in UMTS when the IP-based services are considered, is necessary.

3.6.1.3 Conclusions

Based on the results obtained in the DAIMON project for the UMTS it is possible to formulate more general conclusions that are applicable also for future All-IP networks. First is that despite of the relatively stiff standardisation (as compared to unlicensed systems, like WLAN), there is still a lot of space left for research. And it is used, since there are many papers published in this field. The research focuses mostly on enhancing the capacity, enabling QoS and quality of experience (QoE, i.e., a relative user's perception of service quality), and providing Internet-based services over UMTS network and integrating the system with other wireless technologies. This clearly indicates that the trend is to introduce the All-IP idea to the UMTS with a "back door": through services.

In the other part of the project, the problems related to providing IP-based services in UMTS were analysed practically through simulations. It has been shown that the radio access network is not well prepared for heavy DL data traffic. However, with usage of appropriate resource management techniques (scheduling) its performance can be improved significantly. In other simulations, that have not been presented here, impact of the data services on the voice services was analysed. Also in this case proper resource management (scheduling, too) enabled better coexistence of the two services. In still another set of simulations, the cell breathing in UMTS was tackled. This part of the project proved the need of resource management when IP-based services enter UMTS. In future, the research should focus more on UMA-like technologies that would target not only WLAN, but also WiMAX.

3.6.2 WLAN

3.6.2.1 Resource management in WLAN

Resource management in WLAN is a broad topic and transmission over the air interface can be controlled using several different techniques. These techniques include scheduling, admission control, link adaptation, power control and tuning the basic parameters, e.g. interframe spacing (IFS) and contention window (CW). WLAN uses carrier sense multiple access/collision avoidance (CSMA/CA) in order to avoid several terminals transmitting data at the same time. Before the transmission procedure can begin, the medium has to be idle for an IFS period. After this the station selects a random backoff parameter between values in the contention window. The packets are acknowledged with acknowledgement (ACK) frames.

The objectives for resource management must be identified since sometimes all objectives cannot be achieved at the same time. As an illustration, service differentiation is contradictory to fairness between stations since the concept of service differentiation excludes treating all stations equally. Furthermore, QoS for a specific user might be contradictory to maximizing the overall channel utilisation, the bandwidth utilisation and the throughput. Besides, adapting to the time-varying network load is also important in resource management.

Parameter Tuning for Optimal Performance

Some performance enhancements can be achieved by tuning the basic parameters, e.g. the Request-to-Send (RTS) threshold, fragmentation threshold and the retry limits. For larger packets the medium can be reserved beforehand by using RTS and Clear-to-Send (CTS) frames. By changing the IFS and the contention window, prioritized access to the channel can be given in order to provide service differentiation. Network adaptation depending on the load is also possible using the IFS and the contention window. In low network load conditions fast access to the channel is enabled by using short contention windows. As the network load increases the length of the contention window should increase. According to the literature review, the values of CWmin and CWmax should be changed dynamically and gradually. For service differentiation the arbitrary IFS (AIFS) parameter is more appropriate to use than the contention window. However, large differences in the AIFS parameter values can lead to starvation of low priority traffic.

Service Differentiation and QoS Provision

Service differentiation includes identifying different traffic classes that have different requirements on the channel in terms of delay, throughput and packet loss. Identifying traffic classes is important for providing sufficient QoS. The QoS concept includes controlling the delay, jitter and packet loss in the network in order to support delay-sensitive services (e.g. voice and video) and to allow high-priority traffic frequent access to the channel. The Point Coordination Function (PCF) enables a time division multiple access (TDMA)-like sharing of the channel. PCF uses a contention-free period, during which the stations are polled cyclically (round-robin polling) and allowed to transmit. In 802.11e the QoS issue has been further considered, using e.g. the AIFS parameter and adjustment of the contention window. The Hybrid Coordination Function (HCF) uses the same polling idea as PCF and scheduling using the HCF is one way of providing QoS. Using the AIFS parameter and adjusting the contention window improves QoS for high priority traffic but the performance of low priority traffic usually becomes worse. The literature review showed that in service differentiation and QoS research different radio resource management techniques are combined. Service differentiation can be achieved by:

- adapting the contention window, IFS and the backoff algorithm
- adjusting the transmission opportunities (TXOPs), the service interval or by additional polling.

Furthermore, admission control and link adaptation are also included in the QoS concept. Admission is usually granted based on transmission budgets while link adaptation is based on channel conditions. Apart from service differentiation, admission control and link adaptation, adapting to different network conditions is also included in providing QoS. Service differentiation works well as long as the network is not congested but under high traffic load the following methods can be used:

- admission control and bandwidth reservation
- tuning the IFS and contention window parameters further
- speeding up the backoff countdown when the channel is idle.

Scheduling

Scheduling can be used in order to achieve different objectives. Based on the literature these objectives include

- distributing TXOPs depending on how sensitive the traffic is to delays
- fair bandwidth allocation
- allowing the station with the best channel quality (i.e. the highest transmission rate) to transmit.

For packet scheduling the access to the medium can be controlled using e.g. contention window sizes and the length of the IFS. Scheduling in ad hoc networks may also take into account congestion in intermediate nodes as well as the remaining energy of the nodes.

Admission Control

Admission control can be based on several different strategies, which all aim at maintaining a reasonable QoS for the ongoing calls and providing a good enough QoS for the new call. First, the constraining parameters, e.g. maximum or average bandwidth utilisation, maximum delay, maximum collisions, minimum throughput, have to be identified and second, they have to be measured or modelled. A general survey of admission control schemes in 802.11e networks is presented in [55].

Both enhanced distributed channel access (EDCA) and HCF controlled channel access (HCCA) are considered. Admission control in EDCA is either measurement-based or model-based. The measurement-based methods admit calls based on e.g. a temporal admission to allow measurement of the throughput and delay. Model-based admission control can be based on models for the saturation throughput. With model-based admission control schemes optimization of the entire system is possible, but only in saturated conditions. Measurement-based schemes, on the other hand, are easier to implement. Also in [55] it is stated that the best solution could be to merge the measurement- and model-based approaches. Admission control for HCCA is not as challenging or researched as admission control for EDCA. An admission control scheme based on the minimum data rate and the corresponding TXOP parameter has been proposed by 802.11e. Instead of the minimum data rate the long-term average rate can also be used.

Link adaptation

Scheduling and admission control are resource management techniques in the MAC layer. However, resources should also be managed in the physical (PHY) layer. The 802.11 standard defines multiple transmission rates that are achieved using different modulation techniques but rate adaptation based on the channel conditions is left open. In 802.11a the transmission rate can be chosen between 6, 9, 12, 18, 24, 36, 48 and 54 Mbps. 802.11b offers the transmission rates 1, 2, 5.5 and 11 Mbps and link adaptation is also possible in 802.11g. The higher transmit rates offer larger throughput but they are also more sensitive to channel noise. According to the literature rate adaptation to channel conditions can be done based on e.g. received signal strength (RSS), packet error rate (PER), ACKs of transmitted frames, signal to noise ratio (SNR), payload and frame retry count. Naturally, the use of RSS excludes concurrent use of power control. Rate control can also be divided into statistic-based rate control, which uses e.g. throughput, frame error rate (FER) or retry counting, and SNR-based rate control. Statistic-based approaches respond slowly to channel conditions but SNR-based approaches that are responding faster have to deal with the problem of obtaining reliable SNR measurements.

Power Control

In 802.11 all packets are transmitted at the maximum power level. A high power level is unnecessary if the path loss is small. Additionally, a high power level is more likely to cause interference to the surrounding stations and it consumes energy leading to shorter battery life. In ad hoc networks power control can enable simultaneous transmissions, which has been shown in the literature. In this technique stations agree on the minimum transmission power that they require and then stations that do not disturb each other are transmitting simultaneously. According to the literature, power control can also be used to minimise hidden and exposed nodes. Hidden nodes are nodes that might transmit at the same time without being aware of other nodes. Exposed nodes are nodes that could have simultaneous transmissions but they are silenced by the carrier sense mechanism. The transmission power should be set in such a way that the carrier is sensed at a distance that exactly covers the range within which another node could interfere with the transmission. With strong transmit power the carrier is sensed at a distance that is larger than the interfering range and with weak transmit power the interfering range is larger that the carrier sense range. Furthermore, using a higher transmission power enables the use of a modulation technique that requires a higher SNR but that is able to transmit more information. On the other hand, power control might not always be feasible since many theoretical techniques cannot be efficiently implemented on WLAN cards.

3.6.2.2 Conclusions

WLAN has been developed to enable easy and fast network setup as well as distributed access. QoS has not been addressed from the beginning and consequently, much research on this topic can be found. For service differentiation and QoS provision the parameters that control access to the channel are tuned. Moreover, admission control and bandwidth reservation can be used. Adapting to different channel conditions by using link adaptation and power control is also included in radio resource management for WLAN networks.

3.6.3 WiMAX

3.6.3.1 Resource Management in WiMAX

WiMAX provides portable and mobile broadband wireless access. Two operational modes are possible: transmission between a base station (BS) and a subscriber station

(SS) located in its cell (point-to-multipoint) and direct transmission from SS to SS without a BS (mesh mode). Duplexing is enabled using either time division duplexing (TDD) or frequency division duplexing (FDD). The two most resent standards are 802.16d and 802.16e. The standard 802.16d (or 802.16-2004) is known as Fixed WiMAX and it was developed as an alternative to cable and digital subscriber line (DSL) techniques. Mobile WiMAX is based on the 802.16e standard and it includes support for mobility, e.g. handover and roaming.

WiMAX can provide reliable connections and take delay requirements into account and consequently, it can provide QoS. However, the scheduling and admission control algorithms have been left outside the 802.16 standard and therefore, these areas seem to be the most popular research areas.

QoS Classes in WiMAX

The QoS issue has been thoroughly addressed in WiMAX. The QoS classes can stand different amounts of service degradation and they have different requirements in terms of minimum reserved rate, tolerated jitter and maximum latency. Four QoS classes are included in 802.16 but Mobile WiMAX (802.16e) includes a fifth class. All classes are listed in Table 3. Except for the ErtPS class the other QoS classes are similar in 802.16 and 802.16e but “Polling” in the name is replaced with “Packet” for 802.16e.

Table 3. QoS classes in 802.16.

QoS Class	Description
Unsolicited Grant Service (UGS)	Designed for real time data streams, e.g. VoIP
Real-Time Polling/Packet Service (rtPS)	Data packets of variable size are transmitted at periodic intervals, e.g. MPEG
Extended Real-Time Packet Service (ErtPS)	Designed for voice transfer with activity detection, e.g. VoIP
Non-Real-Time Polling/Packet Service (nrtPS)	Designed for delay tolerant services that require a minimum data rate, e.g. FTP
Best Effort (BE)	Designed for services that have no requirements

Scheduling

Three schedulers are usually required for 802.16 TDD in point-to-multipoint mode. The BS requires one scheduler for the downlink and another one for allocating bandwidth (TXOPs) in the uplink. SS needs one scheduler in order to schedule packets belonging to different service flows. In the literature different kinds of round robin techniques have been proposed for these schedulers as well as weighted fair queuing. The literature review showed that UGS connections are usually allocated a fixed amount of bandwidth in accordance with the standard. Within the rtPS class packets with the earliest deadline are sent first. Within the nrtPS class weight fair queuing is often applied and the weight may depend on the ratio between the connection's average data rate and the total average data rate for the whole class. Within the BE class the bandwidth is usually distributed equally among the connections. If there is capacity left, it should be allocated for rtPS and BE connections in the first place and for nrtPS and BE connections in the second place. Apart from using different QoS classes, it has also been suggested that within one class the downlink connection should be higher prioritized than the uplink connection. A cross-layer (MAC and PHY) approach for scheduling is to assign priority not only depending on the service requirements but also depending on the current channel quality and QoS satisfaction. This way, the available bandwidth can be used more effectively. Scheduling in mesh networks is closely related to routing, e.g. identifying which nodes are interfering each other while transmitting. The scheduling algorithms enable simultaneous transmission between nodes that do not interfere with each other. Moreover, it has also been suggested that the bandwidth could be distributed fairly between the SSs in the first phase and in the second phase bandwidth would be distributed according to the required QoS.

Admission Control

In order to perform admission control the available bandwidth or capacity has to be estimated and, if possible, reallocated. For this purpose, the QoS class of the new connection has to be taken into account. From the literature it can bee seen that UGS connections are usually accepted if the required bandwidth can be provided all the time. rtPS and nrtPS connections are admitted if the required bandwidth is currently unused or if the existing connections can give up some bandwidth. BE connections can easily be admitted since no bandwidth has to be reserved for them. As far as capacity estimations are concerned, admission decisions can be based on the minimum reserved transmission rates for the stations as well as on the number of slots required at the nodes of a mesh network to satisfy the new connection. Furthermore, the token rate, the bucket size and the delay requirements can be taken into account.

Link Adaptation

WiMAX uses adaptive modulation in order to utilise a higher modulation scheme to increase capacity when the quality of the link is good. In Table 4 the modulation techniques are listed along with the required SNR.

Table 4. Adaptive modulation in WiMAX.

Modulation technique	64QAM	16QAM	QPSK	BPSK
Required SNR [dB]	22	16	9	6

The literature review showed that depending on how performance is measured, the SNR thresholds for the modulation techniques can be varied. The TCP delay can be used to identify the link quality and a set of appropriate SNR threshold values for acceptable TCP delays are presented in Table 5. Linking PER with SNR is another way of measuring the link quality.

Table 5. SNR threshold values for acceptable TCP delay.

Modulation technique	64QAM	16QAM	QPSK
Required SNR [dB]	25	19	12

Handover

The 802.16e standard includes mobility and therefore handovers with latencies below 50 ms are set as a goal. Three different handover methods are included in the standard: hard handover (HHO), fast base station switching (FBSS) and macro diversity handover (MDHO). FBSS includes tracking and switching without handover signalling. In MDHO communication with several BSs at the same time is possible. In order to optimize the handover process several schemes has been presented in the literature. As the 802.16e standard gains popularity, handover research might increase. Continuous scanning and association of possible target BSs waste resources. These processes should only be done for the BS that has the biggest mean carrier to interference ratio (CINR) and the shortest arrival time. A short arrival indicates that the BS is close in distance. During hard handover the connection to the serving BS is lost before the connection to the target BS is made. Therefore the packet flow is interrupted and especially real-time services may suffer. Consequently, at least downlink traffic should be enabled as fast as possible using novel management messages. Normally, transmission is only possible when the handover process has been completed. In mesh networks it has be proposed that the signal to interference plus noise ratio (SINR) and the estimated data rate can be used in the handover process. Mobility can also be supported also in the 802.16d standard by modifying some processes and protocols.

3.6.3.2 Conclusions

In the development of the WiMAX standard emphasis has been put on network performance and providing QoS through collision-free connections and bounded delay. Radio research management in WiMAX is quite a fresh topic but it can be observed that the focus is on scheduling and admission control. Differentiating between the QoS classes and taking their service requirements into account is included in most of the schemes. In the future handover might be further researched, particularly in Mobile WiMAX.

3.6.4 Summary

The research on resource management in UMTS focuses currently on following problems:

- Capacity enhancements: new theoretical models that take into account increasing traffic caused by IP-based services seek to make the capacity prediction more accurate and thus to enable better network planning.

- Admission and load control: load monitoring and its management is a crucial problem in CDMA-based UMTS system and the efficiency of any other resource management depends on it.

- Enabling IP-based services: the main focus is to improve the available throughput, especially for asymmetric services (HSDPA), to enhance the QoS framework and to make it more user-friendly.

- Integration with other systems: techniques that will enable providing UMTS services over WLAN and WiMAX and internet-based services over UMTS are mainly researched here.

In the project, some of the proposed techniques were implemented in a system-level simulator. That enabled verifying their practical usefulness and possibly improving them. In the simulations a UMTS capacity model improved in the VTT was used.

The research on resource management techniques in WLAN focuses on

- Service differentiation and providing QoS: the parameters that guard the access to the air interface are tuned and admission control and bandwidth reservation are used for this purpose.

- Adapting to channel conditions: within this area link adaptation and power control have been researched.

The QoS concept is quite developed in WiMAX through collision-free connections and bounded delay. Resource management in WiMAX focuses on

- Scheduling and admission control: these schemes have been left outside the standard and they are therefore popular research topics.

- Handover: as mobility becomes more important with the implementations of the 802.16e standard, research on handover is expected to increase.

3.7 Propagation Models

Propagation models are an important part of network planning and optimization. Prediction accuracy has a significant impact on the performance of the network. New technologies often demand novel propagation modeling especially if they take a new frequency band into use. There are several models that can be applied to a wide frequency range but still some propagation research is often carried out for specific systems, i.e. specific frequencies.

This report is structured in the following manner. In Chapter 3.7.1, propagation modeling in general is presented and wide-spread propagation models are described and summarized along with network planning tools. After this propagation models related to specific systems and frequency bands are presented in the Chapters 3.7.2 to 3.7.6.

In these chapters, propagation models that have been applied to a specific system or a specific frequency band are presented. The investigated systems are RFID, UMTS, WiMAX, WLAN and UWB and the frequency bands are the ISM-bands as well as some frequency bands above 5 GHz. Both commonly used and standardized models as well as research activities related to them are presented. For the research parts, articles in journals and conference proceedings have been surveyed.

3.7.1 Matters affecting propagation

The radio waves travel from a transmitter to a receiver along a direct path, and by reflection, diffraction, and scattering. The radio waves reflect from objects such as the ground, buildings, vehicles, etc. Diffraction occurs when the waves bend around sharp edges that can be mountains in rural areas and roofs and building corners in built-up areas. The radio energy is distributed in several directions when scattered from particles in the air or small surface irregularities or trees.

This behaviour of radio waves in different environments can be modelled in several ways. Deterministic (site-specific) models are the most accurate and they are either based on numerical techniques such as finite difference time-domain (FDTD) or ray-tracing. They require a detailed (preferably 3-D) environment database, positions for transmitters and receivers, antenna patterns and usually long computation times.

Empirical models are based on measurements and describe the radio propagation on an average. Path loss (PL) for a specific environment and frequency is in its simplest form given as a function of the transmitter-receiver distance d. This log-distance path loss model including shadowing effects is given by:

$$PL_{dB} = PL(d_0) + 10n\log_{10}\frac{d}{d_0} + S \ ,$$

where S is the lognormal shadowing (long-term fading) and $PL(d_0)$is the free-space path loss at a reference distance d_0. The path loss exponent n is 2 in free-space. Factors between 3 and 6 are used for indoor environments and n<2 are used for corridors or tunnels.

Path loss models are the most common, but depending on the equipment used and analyses made also other random factors have been modelled statistically. These include signal dispersion (delay spread), time variance (Doppler spread), angular dispersion (direction of arrival, direction of departure), polarization. Models derived from an extensive collection of measurement samples are also referred to as stochastic/ statistical.

3.7.1.1 Propagation Models in Network Planning Tools

There are several different propagation models implemented in commercial network planning tools. Consequently, there is no propagation model that is superior to the other. The empirical models have not yet lost their popularity since they provide fast predictions compared to ray-tracing although the results may not be accurate in all situations. The empirical models can also be used as reference models. Typically, the propagation models developed for propagation over irregular terrain are applied for point-to-point or point-to-multipoint links over large distances while the propagation models for build-up areas (including ray-tracing) are applied for cellular networks in urban or suburban areas.

The most popular models are listed in Table 6. The well-known Okumura–Hata and COST231–Walfisch–Ikegami models are the most popular ones in build-up areas and the Longley-Rice model is often used in irregular terrain. In addition to the models in the table, 13 empiric models have been implemented in two software products and 32 models have been implemented only in one. One rain model has been implemented in three products and the ITU-R recommendation for free space propagation (p. 525) has also been implemented in several products. Furthermore, at least 18 companies have products that include deterministic models, e.g. ray tracing or ray optics. These include both own solutions as well as support of a plug-in ray-tracing module.

It can be observed that also older diffraction models have been implemented, i.e. there are three implementations of the Epstein–Peterson model compared to four for Deygout. The Giovaneli model, which is supposed to improve the Deygout model, has only been implemented in one product.

Table 6. The most popular propagation models.

Scenario	Implemented Model	Nr. of software products including the model
Propagation in Build-Up and Open Areas	Okumura–Hata	5
	COST231–Hata	4
	Okumura–Hata–Davidson	3
	COST231–Walfisch–Ikegami	6
Propagation over Irregular Terrain	Longley–Rice	7
Multiple knife-edge diffraction	Epstein–Peterson	3
	Deygout	4
ITU-R recommendations	ITU-R P. 530 (design of terrestrial LOS systems)	3

Most implemented propagation models are standard ones. Few companies have developed their own solution, if ray-tracing is not considered. Many of the models have been implemented in only one software product but these are products that contain a lot of models. Although a great amount of models does not ensure accuracy, it can be observed that Astrix from Teleplan and Comsite from RCC Consultants are the products that include the largest number of propagation models, 13 and 14 respectively.

Competitiveness does not seem to be pursued through model performance for empirical models. With ray-tracing, on the other hand, the situation is slightly different. The companies involved in ray-tracing are assumed to perform some kind of product development. Several ray-tracing algorithms have been implemented but the implementation details are not accessible and therefore it is difficult to evaluate them against each other.

The trend in ray-tracing has been to increase the accuracy of the models and find techniques to decrease the calculation time, through for example pre-calculation optimisation search methods. Statistical elements (e.g. diffuse scattering) have been integrated into deterministic ray tracing tools to account for details that otherwise would be too complex to handle or require unknown environmental parameters. Ray tracing has been recently exploited for the modeling of Multiple-Input Multiple-Output (MIMO) channels and adaptive antennas, making use of the multidimensionality of the prediction.

3.7.1.2 Product Evaluation

Evaluating the products is not an easy task since only a few companies responded to a questionnaire sent to them and moreover, there was not enough time to try out the tools.

Therefore, in many cases, the information on the company web pages was the only source of information. Furthermore, few companies provide the accuracy of their propagation predictions.

In general, operators are not developing network planning tools of their own. They are using commercially available ones. Network vendors, on the other hand, often have their own solutions, e.g. Ericsson has TEMS and Motorola has the Planner products.

Most companies providing network planning tools are European or American. It can be observed that several companies have merged or have been bought over the years. The trend is definitely towards larger companies providing solutions for different scenarios. Support for multiple technologies is included in many tools and some provide multi-technology network planning, i.e. inter-system handover modeling. However, Motorola has a tool specialized for indoor WLAN network design and Aircom has tools for WiMAX networks.

The companies Siradel, Wavecall and AWE Communications seem to be the most advanced when providing network planning solutions. They all have implemented advanced ray-tracing algorithms and they have research activities on this topic. However, AWE Communications has also implemented a large number of empirical models, in addition to ray-tracing. Aircom's Enterprise suite is also a well-known network planning tool portfolio.

Several companies have formed strategic partnerships and support each other's products. Another trend that can be observed, especially regarding ray-tracing, is that the propagation models are implemented as modules that can be integrated into network planning tools. Also in this case Siradel's Volcano, Wavecall's Wavesight and AWE Communications' WinProp seem to be the most popular software tools to provide support for. Siradel has closely integrated environment database knowledge with ray-tracing, which might be appropriate in order to enhance product performance.

Many products include special features related to network planning, e.g. optimization as well as interference and handover analysis. Some companies have focused on the network designing and optimization process and not on accurate propagation models, e.g. Ericsson's TEMS CellPlanner has only empirical models but several process-specific features.

Frequencies supported by the products are usually between a few tens of MHz to a few tens of GHz, including most standard systems. On top of conventional propagation models estimating the path loss, models taking into account rain and other atmospheric attenuations are included especially in tools intended for radio link design. Furthermore, many software products include tools to tune the prediction results or the propagation model parameters with measurement data.

It can be noticed that most of the implemented propagation models are intended for outdoor scenarios. Only a few products have been developed for network planning indoors but predictions in outdoor-indoor scenarios seem to have been slightly overlooked.

3.7.2 RFID

General Aspects on Propagation

The reading distance for RFIDs in the frequency band of interest is short, generally about 4 m or 10 wavelengths. However, if the tag is located in a corridor with reflecting walls the path loss decreases and the reading distance can be significantly longer.

At short distances, the first Fresnel zone is usually free of obstacles, both outdoors and indoors. If the environment contains only non-moving objects, the effect of standing waves must be taken into account. Still, objects within the near field of the tag antenna have the greatest impact on the performance of the system and therefore, the antenna pattern plays an important role. Reflections from other objects (static or moving) than the tag cause multipath interference and possibly intersymbol interference at the reader.

The path loss for a dipole antenna located between two vertical walls is given below for a case in which the power is transmitter horizontally and the floor is ignored [56].

$$PL = 20 \cdot \log_{10} \left| \sum_{n=0}^{N} \frac{\lambda \cdot e^{\frac{-j \cdot 2\pi(x+2n(l_1+l_2))}{\lambda}}}{4\pi(x + 2n(l_1 + l_2))} + \sum_{n=0}^{N} \frac{\lambda \cdot e^{\frac{-j \cdot 2\pi(2l_1-x+2n(l_1+l_2))}{\lambda}}}{4\pi(2l_1 - x + 2n(l_1 + l_2))} \right| .$$

In the equation above, N represents the number of reflections, l_1 is the reader distance to the first wall, l_2 is the distance to the second wall, x is the location of the tag and λ is the wavelength. The plot of this function shows the typical multipath behaviour with local minima and maxima on top of a decreasing curve due to distance loss.

Model Research

In this section, path loss modeling is addressed first and then attenuation caused by material properties is presented.

A path loss model that is used to determine the safe distance between readers before collision occurs is presented in [57]. Based on earlier experimental data, a d^{-n}-law or one-slope path loss model is derived, with different path loss exponents for distances under and above 8 m. A similar model is also given based on measurements carried out within the project for $d > 8$ m.

The above-mentioned path loss models are referred to in [58], as well. However, it is stated that the path loss exponent should be determined for different areas using measurements. Within one room, a single path loss exponent can be used but encountered walls should increase the value of the path loss exponent.

The propagation through water at 915 MHz is investigated in [59]. It is stated that reflection and interference are the dominating behaviors – not absorption. In [60], the reduction in antenna gain due to the material to which the antenna is attached has been investigated. Also in this case the frequency has been 915 MHz. The measured average gain reductions are presented in Table 7.

Table 7. Measured average gain reduction at 915 MHz.

	Cardboard sheet	Acrylic Slab	Pine Plywood	De-ionized Water	Ethylene Glykol	Ground Beef	Aluminum Slab
Gain reduction [dB]	0.9	1.1	4.7	5.8	7.6	10.2	10.4

In [61] the attenuation of radio waves through walls has been investigated using a computer algorithm called Multi-Channel-Coupling. Four frequencies (433 MHz, 868 MHz, 2.4 GHz and 5.0 GHz) have been investigated. For wood the attenuation depends only on the frequency and not on the thickness of the wall. For concrete and plaster board both the frequency and the thickness of the walls affected the attenuation although the absolute value of the attenuation was naturally higher for concrete.

Conclusions

There has been very little research related to propagation modeling for RFID systems. In these systems, the transmission power is low and the signal is above the noise level only close to the transmitting antenna. Therefore, radio wave propagation has not been largely addressed. However, materials in the vicinity of the tag antenna affect the system performance.

3.7.3 UMTS

Commonly Used Propagation Models – Path Loss

For path loss prediction, the familiar COST231–Hata and COST231–Walfisch–Ikegami models seem to be the most popular ones. In [96], the COST231–Hata model is used for macrocell path loss prediction in suburban and urban areas. For microcells, the COST231–Walfisch–Ikegami model is applied. In [94], the Okumura–Hata and the COST231–Walfisch–Ikegami propagation models are used.

Commonly Used Propagation Models – Multipath Models

Detailed multipath channel models exist since the multipath components affect the performance of the system. In DS-CDMA systems, like UMTS, the power delay profiles are used in order to evaluate the Signal-to-Interference Ratio (SIR) and the Bit Error Rate (BER). On top of this, channel models are also important in order to determine the performance of smart antenna systems.

In simulations, the performance figures are usually determined using standardized multipath channel models. Two important sets are commonly in use, one specified by 3GPP and one specified by ITU. These sets of models have been presented in [95]. In addition to a static channel model, which is a channel without multipath or fading, 3GPP specifies five multipath fading channels. The 3GPP channel models differ in the amount of multipath diversity that they provide and in the user speed that they have been derived for.

The ITU channel models, which have been defined for “indoor office”, should be used indoors while the “outdoor-to-indoor and pedestrian” models are suitable for microcells of different kind. The “vehicular” models describe multipath environments in macrocells.

In addition to these multipath models, 3GPP has also defined Spatial Channel Models (SCM). The 3GPP SCMs consist of a calibration SCM and a simulation SCM [96]. These models have been derived for MIMO simulation purposes at 2 GHz with a bandwidth of 5 MHz. The models are also described in [92]. The calibration model is a simplified channel model representing stationary channel conditions. The angular spread and the mean direction of arrival are kept fixed. This model is intended for comparing different algorithm implementations. The simulation model is intended for performance evaluation. It has different parameter sets for three environments: urban macrocell, suburban macrocell and urban microcell. For these environments the parameters, like the angular spread and the delay spread, are different. There are six taps, whose delays and powers are chosen stochastically from a probability density function. Additionally, within each tap there are sub taps that have the same delay but different angle of arrivals.

An extension model to the 3GPP SCM called SCM Extension (SCME) has been specified in [106] and it is optimized for bandwidths up to 20 MHz, which are required for LTE. This model is backwards compatible with the original SCM models, which has a bandwidth of 5 MHz. In the SCME model the 20 sub-paths of SCM are divided into subsets and these are moved to different delays relative to the original path.

Model Research – Path Loss

Since there were quite many articles found related to propagation in UMTS, only the ones from the last few years could be included in this survey.

During the literature survey, no novel path loss models were found for the 2 GHz band. In addition to the well-known COST231–Hata and COST231–Walfisch–Ikegami models, the Sakagami and Kuboi model and the Maciel–Xia–Bertoni model have been investigated. Also shadowing and foliage attenuation have been considered.

In [76], measurements at 2 GHz show that the Sakagami and Kuboi model is appropriate for modeling radio wave propagation in urban environment. This model is an empirical one and it takes e.g. the height of the obstacles between the transmitter and the receiver into account. The model is based on a Japanese journal article from 1991 with the English name “Mobile Propagation Loss Prediction for Arbitrary Urban Environments” and the model should also be mentioned in the document COST231 TD (92) 11. However, a description of the model cannot be found on the web.

Tuning of the COST231–Hata model using a dual least-square approach is described in [77]. Instead of Continuous Wave (CW) measurements, this approach uses combined pilot aggregate Ec signals. Using this approach, each cell can have its own tuned propagation model based on its antenna height. The approach is verified by simulations.

In [77], propagation models for UMTS base stations at high sites were evaluated for urban areas. The heights of the BSs were 273 m and 134 m. It is stated that the Maciel–Xia–Bertoni model works only at large distances (smaller elevation angles) while the COST231–Walfisch–Ikegami model works well for small distances (up to 2 km). The Maciel–Xia–Bertoni model was first presented in [80] and it consists of a free space path loss term and an excess path loss term. The excess path loss is build up of one term representing the diffraction loss from the rooftop down to the street level and one term representing diffraction loss over the multiple rows of buildings.

In [78], peer-to-peer propagation is analyzed and modeled statistically by using a ray-tracing model. The path loss model takes the path loss exponent, distance and frequency into account. A model for shadowing is also given:

$$\sigma_{shadow}(d) = S \cdot \left(1 - e^{\frac{-(d-d_0)}{D_s}}\right).$$

In this model, d is the Tx-Rx distance, S is the maximum standard deviation and D_s is a growth distance factor. d_0 is 10 m. The parameters S and D_s are given in the paper for different scenarios. A model for the K-factor is also given in the article.

In [79], models for foliage attenuation have been evaluated against measurements at e.g. 2 GHz. According to the measurements, the attenuation decreases rapidly at first but after a few meters of vegetation the decrease flattens out. The computationally most expensive model, the Radiative Energy Transfer (RET) model, gives the best match to the measurements, but also the ITU-R models that only consider the frequency f and the vegetation depth d, perform quite well. The ITU-R model gives the excess attenuation as

$$L = 15.6 f^{(-0.009)} d^{0.26}.$$

Model Research – Multipath Models

Although channel models have been standardized by 3GPP and ITU, there is still some research in this area.

In [107], it is stated that the SCME model is suited to system simulations with several simultaneous users but for link level simulations some simplifications can be made. Tapped delay-line models for urban and suburban areas are presented in the article. The models include spatial correlation and polarization covariance matrices.

In [81], a space-time model is proposed, which is built on top of the Geometrically Based Single-Bounce Elliptical Model (GBSBEM) and the UMTS-IMT-2000 models. In the GBSBEM model, the scatterers are placed uniformly inside an ellipse with the BS and the MS at the foci. The model works in LOS scenarios. The Doppler effect and the spatial properties are missing from UMTS-IMT-2000 models but the microcell models "indoor" and "indoor-to-outdoor" can be enhanced by using the GBSBEM model.

In [82], a statistical geometric channel model for LOS conditions in microcells is presented. The scatterers are within a circle of the mobile and this circle also includes the BS. The model gives the power, time of arrival and direction of arrival of the multipath components. The probability density function for the direction of arrival has been evaluated against measurements in an indoor environment and the proposed model has proven to perform well.

In [83], multipath propagation in the duplex bands of UMTS Terrestrial Radio Access (UTRA) FDD has been investigated using measurements. It is stated that both channels have similar azimuth spread and delay spread characteristics. The multipath parameters, e.g. the number of paths, time of arrival and direction of arrival are identical.

In [84], clusterization of the radio channel at 2 GHz is considered. A cluster is a group of rays having similar delays and direction of arrival. The clusters are identified as power maxima. The BS and MS azimuth delay power profiles are computed and the BS and MS clusters are connected by comparing the relative delay.

In [85], an iterative method for identifying multipath clusters in macrocellular UMTS environment is proposed. Using the cluster characteristics, MIMO channels can be parameterized. In the iteration process, the interaction point of the strongest path forms the centre of the first ellipsoid and then all interaction points within this ellipsoid are identified.

Conclusions

The propagation models used for UMTS, in the 2 GHz band, are mostly the familiar COST231–Hata and COST231–Walfisch–Ikegami models. In addition to these, multipath channel models have been specified by 3GPP and ITU. Also for LTE, which introduces variable bandwidths, models have been specified by 3GPP. There has been a lot of research related to propagation in the 2 GHz frequency band, but no completely new models especially for UMTS has been presented.

3.7.4 WLAN and WPAN at the ISM-bands

The industrial, scientific and medical (ISM) radiofrequencies lie in the bands 430 MHz, 900 MHz, 2.4 GHz and 5.8 GHz, although some regional differences exist because of regulations. For example, most European countries use 433–435 MHz and 868–870 MHz whereas the US uses 902–928 MHz for ISM.

Standard Model for Indoor Scenarios

The ITU-R P.1238 model [86] can be used in indoor environments, where the transmitter and the receiver are in the same building, the frequency is between 900 MHz and 100 GHz, and the Tx-Rx distance is less than 1 km.

$$L_{total} = 20\log_{10} f + N\log_{10} d + L_f(n) - 28,$$

where N is the distance loss coefficient, f is the frequency in MHz, d is the separation distance between the transmitter and the portable terminal in meters ($d > 1$ m), L_f is the floor penetration factor in dB and n is the number of floors between the transmitter and the portable terminal. The standard includes tables with the factors N and L_f for residential, office and commercial environments. The indoor shadow fading statistics are log-normal and the standard deviation values are between 8 dB and 12 dB.

The P.1238 document also recommends the use of UTD and ray-tracing based techniques. The standard also gives an equation for the rms delay spread, which is dependant on the size of the room as well as median values encountered in the three different indoor environments. Other models that are suggested in the P.1238 recommendations for modelling indoors are statistical models (such as the Wide-Sense Stationary Uncorrelated Scattering (WSSUS) channel model), and site specific models (such as ray launching and mirror imaging approach ray tracing, or FDTD). The complex permittivity of different interior construction materials, relevant for site-specific models for calculating reflection and transmission coefficients at several frequencies, is also stated.

Standard Model for Outdoor Scenarios

Short range ($d < 1$ km) outdoor scenarios in the frequency range 300 MHz to 100 GHz can be modelled by the ITU-R P.1411 standard [87]. It recognizes the need for both empirical and deterministic modelling. The propagation is affected primarily by buildings and vegetation. The model is divided into four environments: urban high-rise, urban/suburban low-rise, residential, and rural with typical cell size, velocity of mobile terminals, etc. Path loss is modelled for LOS, NLOS over roof-tops, and propagation within street canyons. Multipaths, number of signal components, can also be calculated. The standard is mainly based on the COST–Walfish–Ikegami model.

Indoor Model Research

Research comparing different models for the 2.4 GHz indoor channel and comparing them to measurements was performed. The chosen models included the one-slope model as well as the multi-wall model [99] and models derived by editing the multi-wall model parameters. It includes further parameters, such as open/closed doors and especially metallic (fire safe) doors. No large differences were observed between the multi-wall models [88].

Also others have compared measurements to the one-slope and the multi-wall model and found the multi-wall model to be considerably more appropriate to model indoor offices with corridors and rooms [89]. Only two different type of wall material were taken into account; light wall and heavy wall. Although glass and metal walls (/windows) also existed in the environment the multi-wall model performed well on average without taking these into account. Furthermore, having doors open or closed was observed to cause 4–5 dB variations in the measurements. The one-slope model also performed well calculating with a power decay factor n of 1.4 in the corridor and n=4 in the office rooms (NLOS).

Indoor measured delay profiles were analyzed and simple one-slope parameters were derived for both LOS and NLOS cases at IEEE 802.11a/b frequencies (2.4 and 5.3 GHz) [90]. The results also give the standard deviation. The LOS path loss is less than free space path loss which is expected indoors, and the propagation exponent increases with increasing frequency.

Outdoor Model Research

A simple model for outdoor urban B3G (Beyond 3G) in the 5 GHz area for parallel LOS and perpendicular NLOS streets was developed in Finland [91]. The measurements were analyzed and fit to the one-slope model with different parameters for LOS and NLOS cases. The standard deviation for the LOS streets was σ_{LOS} = 2.6 dB.

Eleven perpendicular NLOS streets were measured at up to 400 meters distances d_2 from the closest LOS street and at LOS distances d_1 of 50 to 360 m. From these measurements two different equations were derived; one for LOS that depends on the LOS distance d_1 and one for NLOS that depends on both d_1 and d_2.

Conclusions

WLAN and WPAN systems are commonly planned for indoor environments where deterministic modelling (ray tracing and FDTD) can be used. The systems are short range and layouts of the buildings exist.

3.7.5 WiMAX

Commonly Used Propagation Models – Path Loss

In the deployment considerations for WiMAX at the 2.5 and 3.5 GHz frequency bands [63] the propagation model used is the one proposed by the IEEE 802.16 Broadband Wireless Access Working Group [64]. For suburban areas, the SUI path loss model is proposed and, for urban areas, the COST231–Walfisch–Ikegami model is described.

The SUI path loss model is originally described in [65] and it is derived from measurements in suburban areas at 1.9 GHz in the US. No corrections for urban or rural areas are included. Three different types of terrain are presented, namely A, B and C. Type A represents hilly terrain with moderate to heavy foliage and consequently, a high path loss. Type B environment is mostly flat with moderate to heavy foliage or hilly terrain with light foliage. Type C terrain is flat with light foliage and therefore a small path loss. However, relating the terrain types to commonly available clutter or terrain databases is not straight-forward [97]. The SUI model path loss equation below includes a frequency dependent factor X_f and a factor X_h, which depends on the Customer-

Premises Equipment (CPE) height. A is the free space path loss at d_0, which is usually 100 m.

$$PL = A + 10\gamma \log_{10}\left(\frac{d}{d_0}\right) + X_f + X_h + s \quad \text{, for } d > d_0,$$

The path loss exponent γ depends on the area type (A, B, and C) and is as a function of the base station height h_b (10 m < h_b < 80 m).

Commonly Used Propagation Models – Multipath Models

The SUI channel models SUI-1 to SUI-6 are described in [64] and [92]. The models SUI-1 and SUI-2 are for flat terrain (type C) whereas the models SUI-5 and SUI-6 are for hilly terrain with moderate or heavy foliage (type A). The models SUI-3 and SUI-4 are intended for environments in between (type B). All models consist of three taps. The attenuation is given relative to the first path and the tap parameters are averaged. Different delay, attenuation, and rms delay spread values can be found for omnidirectional and 30 degree directional antennas can be found [64]. The first tap is Ricean distributed (known to be a good model for LOS) for models SUI-1 to SUI-4 while the other taps of the models are Rayleigh distributed (NLOS). The channels SUI-1 to SUI-3 have small delay spread values whereas the last three models show more multipath propagation characteristics. The model SUI-4 shows the highest frequency selectivity.

The SUI models were originally developed for macrocellular fixed wireless access at 2.5 GHz but they have been enhanced in the development of the IEEE 802.16 standard. The restrictions of the models are that the cell radius should be below 10 km, the mobile terminal should be at about rooftop level and the base station above the rooftop level. The bandwidth is restricted between 2 and 20 MHz. The models are still valid for a Tx-Rx distance of 7 km [92]. No directional information is included in the models. Because of the limitations of the models, they are best suited for system dimensioning and not for detailed network planning, according to [97].

Channel models for the upcoming IEEE 802.20 standard operating in the 3.5 GHz band and offering peak data rates of over 1 Mbps (similar goals as IEEE 802.16e) have been presented in [98]. MIMO models are presented and these models are relevant also for WiMAX since the frequency band is the same. The MIMO channel models are generated for each scenario separately (urban, suburban or indoor, macro-, micro or picocell) by first determining the parameters, i.e. the angular spread, shadowing, delay spread, path loss, orientation, speed and antenna gains. Next, the MIMO channel coefficients are generated for all multipath components and one channel coefficient consists of a U x S matrix of complex amplitudes where U and S are the linear elements of the MS and BS arrays, respectively.

Fixed broadband systems are usually designed for a high reliability (99.9% or higher) and therefore the fading phenomena must be carefully considered [97]. Not only multipath and shadow fading affect the system performance but also rain and other fading due to the atmosphere.

Model Research – Path Loss

In this section, the focus is on the 3.5 GHz band but also other frequencies related to WiMAX are considered.

In [66], the propagation models ECC-33, SUI and COST231–Hata are evaluated against measurements at 3.5 GHz in Cambridge, UK. The comparison was done for rural, suburban and urban environments. The SUI and COST231–Hata models tended to predict a too high path loss in all environments while the ECC33 model yielded the best results, especially in urban environments.

The ECC33 model is based on Okumura's measurements but these measurements have been extrapolated and the assumptions have been modified in order to represent a Fixed Wireless Access (FWA) system in the 3.4–3.8 GHz band. The ECC33 model gives the path loss as follows:

$$PL = A_{fs} + A_{bm} - G_b - G_r \,.$$

A_{fs} is the free space attenuation and A_{bm} is the basic median path loss, which is dependant on the transmitter-receiver distance d and the frequency f. G_b is the BS height gain factor, which is dependant on the base station height h_b and d. G_r is the CPE height gain factor for medium city environments dependant on the frequency f and the receiver antenna height h_r

The rest of the path loss models presented in the literature are simpler. A statistical path loss model is derived from measurements at 3.5 GHz in urban environments in [67]. The base station was at a height of 20 m ± 5 m and the mobile antenna was at about 2.5 m. The path loss model is valid for distances between 100 m and 2 km and it has been developed by a least square approximation of the measurement results. The path loss model consists only of a free space term, a distance-dependent term including the path loss exponent and a fading error term.

The path loss model presented in [68] includes the path loss at 1 km and a distance-dependent term including the path loss exponent. No fading is considered. The path loss exponent and the path loss at 1 km both depend on the CPE antenna height. This model is based on measurements at 3.5 GHz in a relatively flat suburban environment in Cambridge, UK, during the summer months. The BS was at a height of 15 m during the measurements and the CPE antenna was varied from 4 to 10 m in steps of 1 m.

Measurements at 3.5 GHz in an urban environment in Rio de Janeiro show path losses of about 50 dB/decade for distances below 1 km, according to [69]. It is stated that for such large path losses, the most appropriate modeling technique would be ray-tracing.

Next, the relationship between signal strength and data rate is presented. In [70], the modulation schemes Quadrature Phase Shift Keying (QPSK), 16QAM and 64QAM are considered. QAM stands for Quadrature Amplitude Modulation. QPSK does not require a high SIR but it also gives lower throughput than 16QAM and 64QAM. By using the free space propagation model, COST231–Hata and COST231–Walfisch–Ikegami (WI), the maximum distance for each modulation scheme is obtained at a minimum required data rate (100 Mbps or 30 Mbps). The results are presented in Table 8 for 3.5 GHz. Results for 5 GHz are also given in the paper.

Table 8. Cell range for 3.5 GHz at minimum required data rates 100 Mbps and 30 Mbps.

Modulation	SIR	Maximum path loss [dB]		Free space [m]		WI-LOS [m]		COST231–Hata [m]		WI – NLOS [m]	
		100 Mbps	30 Mbps	100 Mbps	30 Mbps	100 Mbps	30 Mbps	100 Mbps	30 Mbps	100 Mbps	30 Mbps
QPSK	7.3	120	125	6800	12100	1775	2740	175	230	75	90
16-QAM	15.2	115	120	3850	6800	1140	1775	110	175	50	75
64-QAM	21.5	110	115	2150	3850	730	1140	80	110	35	50

In [62], a link budget calculation for Mobile WiMAX at 2.5 GHz is presented. The maximum allowable path loss is 128.2 dB, giving a downlink data rate of 5.76 Mbps using 16QAM (code rate = 1/2) and an uplink data rate of 115 kbps using QPSK (code rate = 1/2). The channel bandwidth has been 10 MHz while it was 100 MHz in the previous case. The relations between modulation, required Signal-to-Noise Ratio (SNR) and data rate are listed in Table 9 for downlink traffic- Partial Usage of SubChannels (PUSCs).

Table 9. Relation between modulation and required SNR in the downlink.

Modulation	QPSK ½	16QAM ½
Required SNR [dB]	3.49	8.93
Data rate [Mbps]	2.88	5.76
Allowed path loss [dB]	133.7	128.2

It can be seen that the required SNR and the data rate is lower in the latter case. Consequently, the allowed path loss is also bigger and the coverage area will be larger.

Model Research – Multipath Models

A spatial channel model has been developed based on the SUI models and the 802.16 standards. It is presented in [93] and described in [92]. The taps in the power delay profiles of the SUI models can be represented by ellipses containing a specific number of scatterers. This approach enables scaling to other Tx-Rx distances than the 7 km that the SUI models are valid for. The presented scattering model characterizes the MIMO channel and the channel characteristics are calculated using a ray-based method. Simulations and experiments support the presented approach.

In [71], measurements at 3.5 GHz in a suburban environment have been used to derive an impulse response model for the Single-Input Single-Output (SISO) channel. The channel can be described with a 3-tap model with the taps at 0, 0.2 and 0.4 μs. These delays are smaller than the delays of the SUI models. The tap gain for the separate taps varies with the CPE antenna height and the tap gain decrease with increasing antenna height. Furthermore, the height of the antenna has a greater impact on the delay spread than the distance between BS and CPE. The Ricean K-factor was also observed to correlate with the excess path loss. The same measurements at 3.5 GHz were also used to investigate the rms delay spread in [68]. During the measurements, the CPE antenna height was varied between 4 m and 10 m in steps of 1 m. The average delay spread was observed to decrease with increasing antenna height, which was also the case in the previous article. For all antenna heights except for 7 m, 90% of the rms delay spread values were below 100 ns. For 7 m the values were below 130 ns in 90% of the cases. The maximum rms delay spread was less than 270 ns. In [73], measurements at 3.5 GHz show that the delay spread is lower for circularly polarized antennas than for horizontally polarized ones in outdoor FWA systems. Also these measurements were carried out in a suburban environment.

Variations in the channel conditions at 3.5 GHz are presented next. In [69], measurements at 3.5 GHz in an urban environment in Rio de Janeiro were used to investigate the fading behavior. The large scale fading can be described by log-normal statistics whereas the fast fading can be modeled as a Rayleigh distribution in NLOS conditions and as a Rice or m-Nakagami distribution in LOS conditions. This agrees with results at 900 MHz. However, the level crossing rate and the average fade duration were not well represented by the models.

Measurements in an urban environment at 3.5 GHz taken during one year were used to investigate the long-term variation in the channel conditions in [72]. The variations in path loss can be described as Rician. A formula for the median *K* factor is derived and it includes the excess path loss, average wind speed and the season:

$$K = \frac{D_0 A(s)^{D_1}}{\overline{w}^{D_2}}$$

in which $A(s)$ is the median excess path loss and $\overline{w}$ is the average wind speed. The parameters D_0, D_1 and D_2 depend on the season. The *K* factor during winter is approximately 3.2 times higher than during summertime.

Impulse response models have been created and tested for WiMAX also at other frequency bands. Measurements at 2.3 GHz at more than 25 sites in Seoul, Korea were used as a basis for creating channel impulse response models for several different environments, in [74]. Separate models with 10 or 20 taps are given for rural, suburban, microcell hilly and urban environments.

Measurements at 1.95 GHz in a suburban environment have been used to evaluate the SUI channel models in [75]. The evaluation has been done with respect to power delay profile, *K*-factor and Doppler spread. Based on these parameters and the environment it is not always evident, which channel model that suits a specific site best. Measurement results and models match well regarding the power delay profiles but as far as the *K*-factor and the Doppler spread are concerned, the models assume a higher time variability of the channel.

Conclusions

The most well-known channel models for WiMAX, the SUI models, have been developed with primary focus on lower frequency bands than the 3.5 GHz band. These models also have limitations in their parameter range and they do not provide directional information. Additionally, it is not evident which model to choose for a certain environment. Other channel models have been presented in the literature but more research and, more importantly, standardization is required. For path loss prediction in the 3.5 GHz band the most appropriate model seems to be the ECC-33 model.

3.7.6 UWB

Standard Models Applied for UWB

The frequency band 3.1–10.6 GHz has been especially planned for the use of UWB systems, systems with more than 20% relative bandwidth or alternatively more than 500 MHz absolute bandwidth. The IEEE 802.15 has two recommended models for different range UWB systems.

The IEEE 802.15.3a propagation model [101] describes the characteristics for short range, i.e. shorter than 10 meters, indoor propagation channel and high data rate. The multipath channel model is so-called modified Saleh–Valenzuela model, which consists of four different scenarios are described in the model: CM1 describes a LOS situation with a Tx-Rx distance less than 4 m. CM2 describes a NLOS situation with Tx-Rx distance less than 4 m. CM3 describes a NLOS situation within the Tx-Rx range 4–10 m, and CM4 describes the worst case scenario with strong delay dispersion resulting in a delay spread of 25 ns.

The mean and rms delay terms give the length of the channel impulse response. NP_{10dB} and $NP_{85\%}$ give the number of paths that are within 10 dB relative to the strongest path and the number of paths that convey 85% of the entire energy, respectively. Other parameters for the IEEE 802.15.3a model include the cluster arrival rate, the ray arrival rate, the cluster decay factor, the ray decay factor, cluster – and ray fading, and the mean and standard deviation of the channel energy.

The IEEE 802.15.4a propagation channel model [100] includes indoor environments for longer range, i.e. > 10m, as well as outdoor environments up to few hundred meters and low data rate. The frequency range is 2 to 10 GHz. There is a MATLAB code available for the generation of the impulse responses. Six scenarios are included in the model: indoor residential, indoor office, industrial, Body-Area Network (BAN), outdoor and open outdoor areas. The IEEE 802.15.4a model usually distinguishes between LOS and NLOS.

The main goal of the 802.15.4a model is to describe the attenuation (frequency dependant path loss and shadowing) and the delay spread (power delay profile & small scale fading statistics). From this other parameters, such as rms delay spread, number of multipath components carrying the given percentage of the energy, etc. can be derived. The model is a modified Saleh–Valenzuela model.

Model Research

The Cassioli–Molish–Win (CMW) model is a dual slope model, which can be used indoors. It can be seen as an extreme case, where the free space model would be the other extreme [102].

Different propagation scenarios have been studied in high rise buildings in Korea, and the measurements have resulted in a statistical UWB model. The model covers parameters such as average number of clusters, the Multipath Components (MPCs) distribution within a cluster and the clusters' and MPCs' arrivals. The number of clusters and number of MPCs per cluster have larger values than those in the original Saleh–Valenzuela model, probably due to UWB. Unclustered models tend to overestimate the capacity is the MPCs are clustered. [103]

Another type of indoor scenarios was studied in Japan with double directional UWB channels, namely wooden house. No standard models (IEEE 802.15.3a/4a) include this directional description simultaneously on the Tx and Rx side. [104]

Three outdoor UWB scenarios; forest, hilly and suburban, were studied, and from the measurement campaigns a statistical outdoor model was proposed. The path loss exponent was found to vary from 2 to 3.5 (depending on scenario and antenna height), the local mean of the received power experienced a log-normal shadowing with a standard deviation that may depend on the azimuth position, log-normal distribution could also describe the statistics of the first received echo in the small scale analysis, and the delay spread was small (10 ns in the forest and less than 32 ns in the suburban environment). [105]

Conclusions

UWB has recently gained much attention as a promising technology for high data rate short range communications. Many measurement campaigns have been carried out, and efforts have been made to gather information and create standard models for UWB in the IEEE 802.15.3a/4a task groups. Indoor UWB environments have also been modelled by the ITU-R P.1238-2 model and the CMW-model. In the outdoor case ITU-R P.1411 [87], free-space and COST231 [99] models have been used.

3.8 Synthetic Fingerprints

One of the major concerns of the fingerprinting methods (e.g. Database Correlation Method, [121], [121] and [123]) used in mobile positioning is the burden of collecting reference fingerprints. If the network topology is not static, new measurements have to be carried out frequently to be able to sustain the achieved positioning accuracy level.

By using synthetic fingerprints instead of measured ones, the time needed for creating and updating the database can be reduced. The synthetic fingerprints can be created either by a computational network planning tool [108] or by combining measured and calculated information [109].

Within the T1DAIMON project, a 3D tool for analysing different propagation models and generating reference fingerprints for DCM was implemented. The data used to verify the created fingerprints was collected with a terminal measurement tool [110] developed in T1MGIS project.

In Chapter 3.8.1, an overview of the different techniques for creating synthetic fingerprints is presented. A more detailed description of different propagation models and network planning tools can be found in [111]. Chapter 3.8.2 introduces the implemented 3D-Tool. Input data for the developed algorithm is listed in Chapter 3.8.3 and the algorithm itself is presented in Chapter 3.8.4. Results are analysed in Chapter 3.8.5 and conclusions presented in Chapter 3.8.6.

3.8.1 Techniques for creating synthetic fingerprints

The synthetic fingerprint creation can be approached from two directions. One method is to use a network planning tool to calculate coverage areas for all cells. The coverage areas can then be used to collect a set of received signal strength values for each generated sample point. This method relies on accurate information about cells, antennas and environment. Therefore it's best suitable for network operator's who have necessary tools and information at hand.

Alternative technique extends measured fingerprint set with new values. Direct interpolation between fingerprints is already covered by DCM algorithm itself, so next step is to use environment information to account for terrain and building effects. In order to properly estimate propagation paths, it's necessary to have at least approximate position of all cells. Exact cell positions are normally available only to network operators, but measured samples can be used to estimate rough positions for the cells.

Propagation modelling is used extensively in network planning tools to calculate signal strengths for coverage areas. Several techniques exist for modelling radio signal propagation in outdoor and indoor environments. Some commonly used techniques are ray tracing, empirical methods and profile based methods.

Ray Tracing

Ray tracing uses 3D environment information to calculate reflection, and penetration of radio waves. Very detailed information about environment is needed to obtain accurate results. Even tough ray tracing quite computationally heavy, it's good for estimating coverage areas in very small ells or indoors. A variation of this method uses random rays to expand on traditional log-linear decay model [112].

Empirical methods

Empirical methods rely on extensive measurements to provide simple statistical model, which can be used to calculate signal strengths. Typically very little information about environment is used and results are only meant to give rough estimates. In early planning state fast empirical methods can be used to estimate far cells coverage areas extend.

3.8.2 3D-tool

Analysis of 3D environment data and different propagation models used in fingerprint generation required 3D enabled analysis tool. The analysis tool was based on OpenSceneGraph (OSG) 3D library and included visualisation and calculation tools to compute and visualise different methods of fingerprint generation.

Main features of the tool are:

- Loading from various 3D file formats including format used in TerraSolid data.
- Saving models
- Importing XY data used in measurements and fingerprints
- Line of sight, path profile and view frustum queries to 3D data
- Ray traced reflection and penetration calculations
- Library of propagation models including
- Okumura–Hata
- Knife edge diffraction
- COST–Walfisch–Ikegami
- Modular design
- C# visualisation component for OSG models
- C++ calculation backend
- Easy to add new propagation models.

The users interface of the toll is presented in Figure 14.

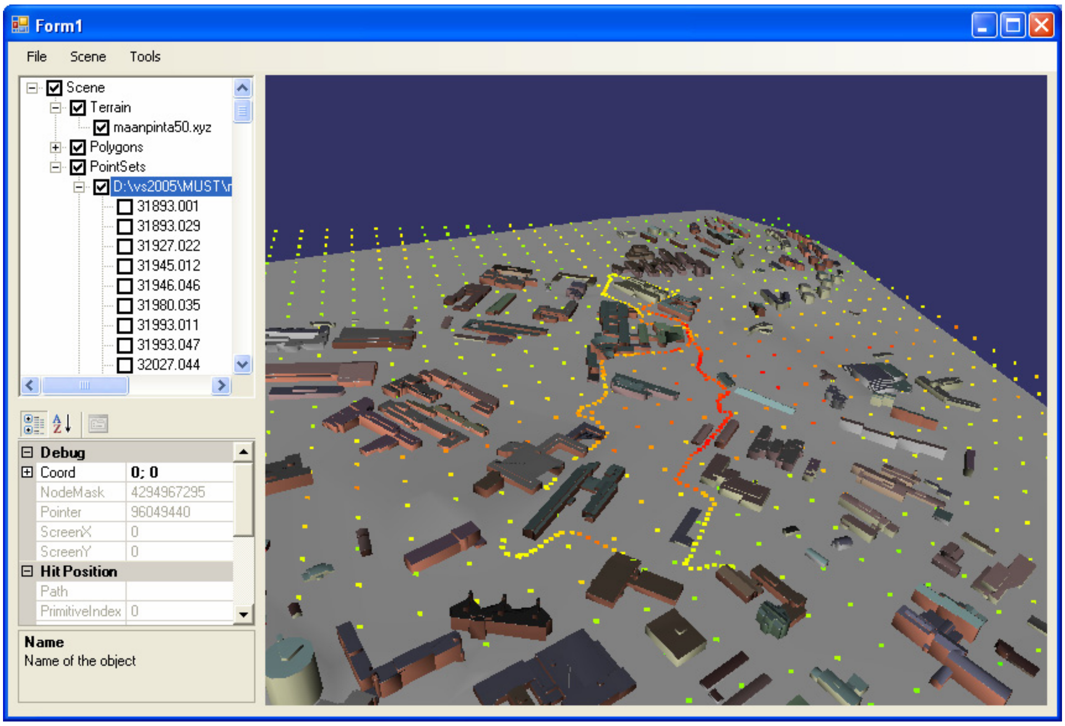

Figure 14. Measured RSS values and generated RSS values visualised over 3D model of Otaniemi. Red colour shows high signal strength value and yellow and green lower values.

3.8.3 Input data

Terrain elevation data and 3D model if buildings in Otaniemi area were obtained from TerraSolid and are based on laser scanning the area from helicopter.

3.8.3.1 Elevation

Data is based on taking aerial images and laser scanning the area from helicopter. Initial accuracy for height information was 0.5 meters and it was represented as cloud of XYZ points. 3D surface of the terrain was constructed by first filtering input data to 1 meter resolution in XY plane and feeding the points to Delaunay triangulation. Obtained triangle mesh was then simplified to keep calculation time reasonable (Figure 15).

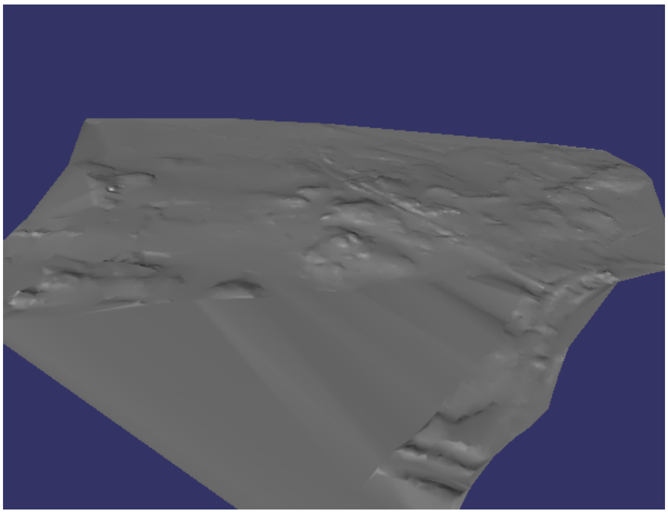

Figure 15. 3D model of terrain in Otaniemi area.

3.8.3.2 Buildings

Building information is based on laser scanning and aerial images and almost all buildings in the area included in the model with very high precision. Only Dipoli building and newly built VTT digitalo are missing from the data.

Raw building models were represented as list of polygons. Polygon information was directly converted to 3D primitives. This process caused some errors in larger buildings, but their effect to calculation results were considered very small. Therefore no extra effort was done to fix them. Figure 16 presents an example of building primitives and Figure 17 buildings over a terrain in the user interface of the tool.

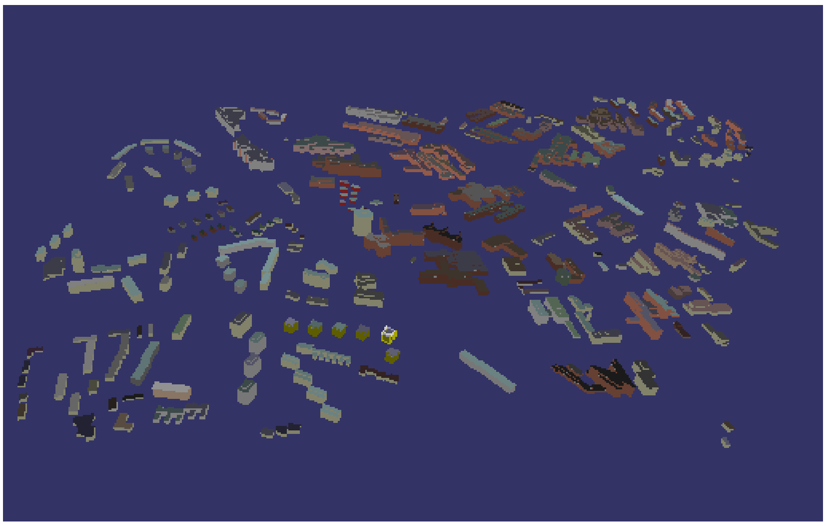

Figure 16. A 3D-model of buildings in Otaniemi area.

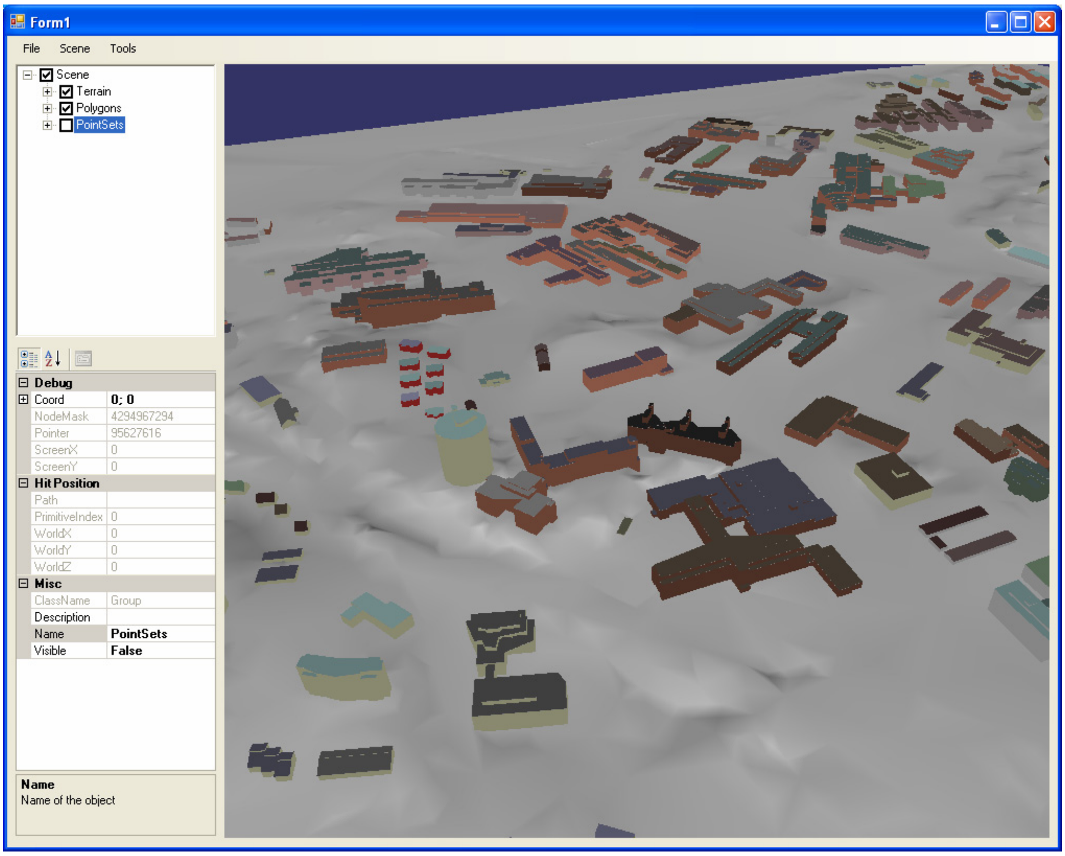

Figure 17. More detailed view of buildings over terrain.

3.8.3.3 Terminal measurements

Terminal measurements proved to be one of hardest part of input data. This problem stems from limited set of available measurement tools. Two measurement tools were used: Wink measurement tool developed in T1MGIS project and simple scripts. Both methods used similar approach where a GPS device and GSM phone were connected to laptop and phones NetMonitor was used to obtain received signal strength values.

NetMonitor gives good CellId-TRX pair for serving cells signal strength, the neighbouring cell information contains only TRX identifier. Therefore additional step is needed to map TRX identifiers to right cells. The problem comes more challenging as the same TRX channels are reused in the area. Simple distance based method was used to bind TRX channels to cells so that closest cell with same TRX channel was used. Other problem with NetMonitor was that if phone made a handover while signal levels were queried, occasionally the CellId and TRX of serving cell came from different cells. Therefore all measurements were manually checked and erroneous measurements were removed.

Most of the measurements were done by walking around the Otaniemi area. In early measurements Wink tool was consuming too much battery and therefore more light weight alternative was implanted. Simple Python script was used to combine GPS information to NetMonitor data. NetMonitor data was read using Gammu [113].

Following figures shows combined routes of all measurements in Otaniemi area, training measurement routes (with car) and positioned target route (walking).

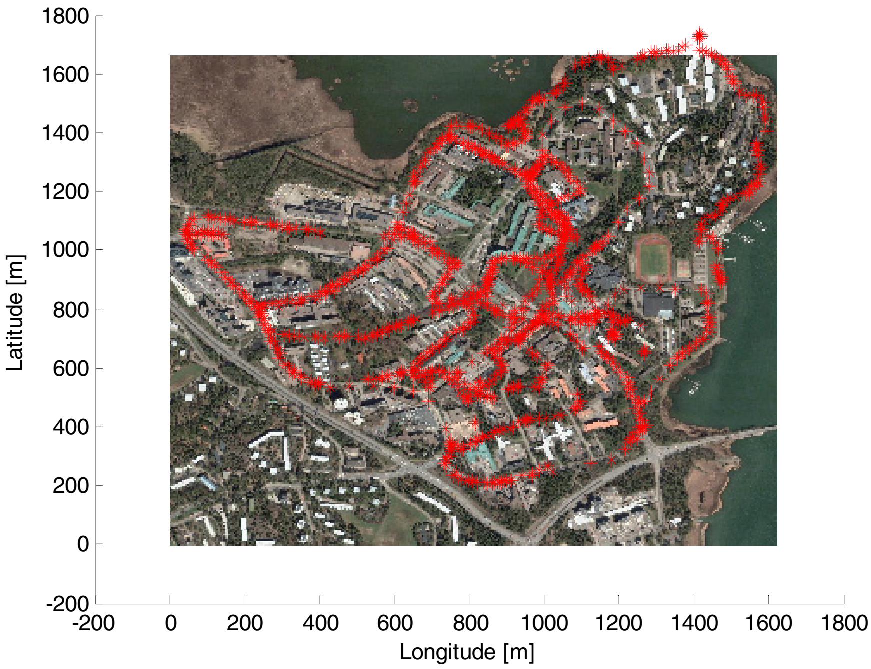

Figure 18. All measurement points in Otaniemi.

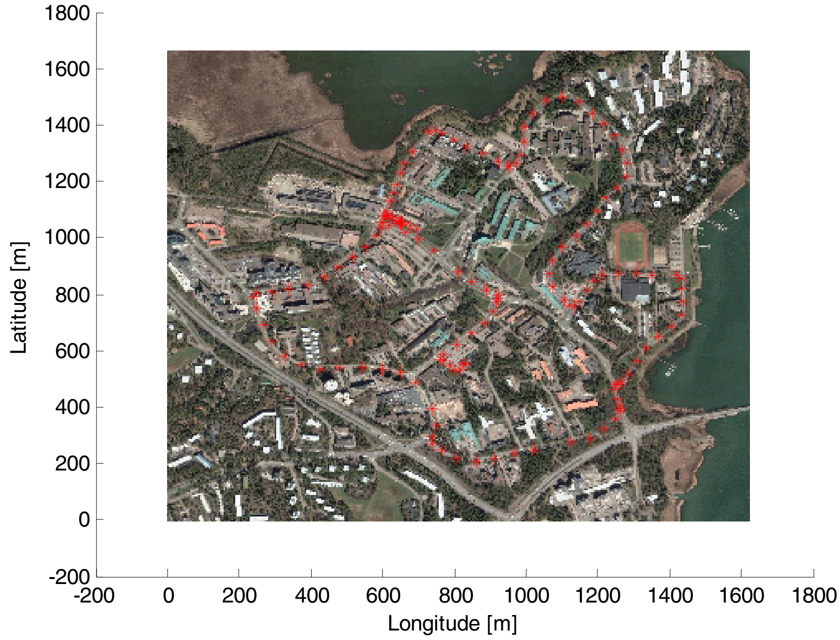

Figure 19. Measurements with car, which were used as training set for DCM and synthetic fingerprint generation.

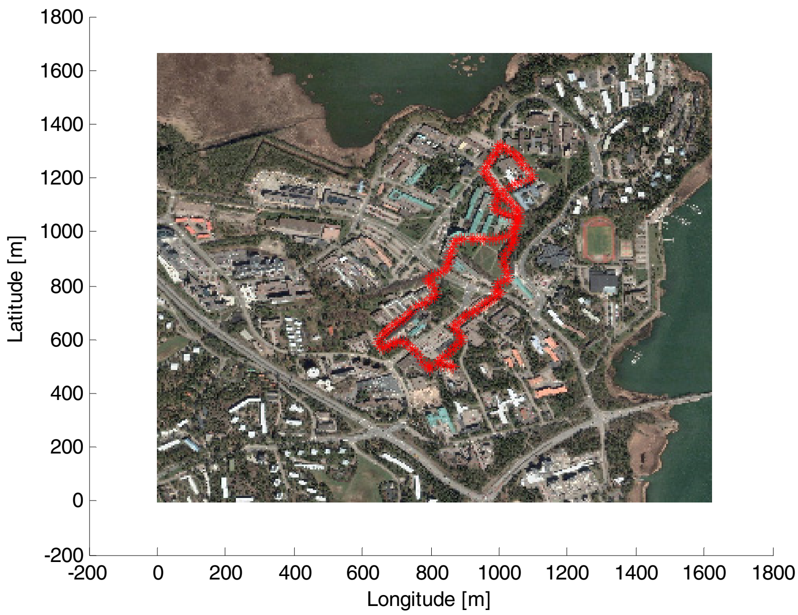

Figure 20. Positioned target route.

3.8.3.4 Cell information

Operator level cell information was not available, so alternative approach was used. After extensive field trials, the measurement samples were analysed to pinpoint rough cell positions and to collect CellId-TRX mappings. In some positions cell locations were visually confirmed. Transmitted height was simply set as either 12 meters or 1 meter above building roof. Antenna parameters and transmission powers were not approximated because the intention was to estimate antenna radiation pattern and transmitter power from measurements values.

3.8.4 Algorithm

3.8.4.1 Basic fingerprint generation algorithm

Algorithm works in two phases. At first phase measured samples are loaded and processed. Each sample, propagation paths between each cell and terminal are analysed using profile query to 3D data. Profile data consists of information about every building and terrain feature along path from cell to terminal. Each item in the path is compared to Fresnel zone to find out the biggest obstacle along the propagation path. The biggest obstacle is considered as dominating obstacle and knife edge diffraction is used to estimate attenuation caused by the obstacle. Reference value for fingerprint generation is then calculated by subtracting effect of distance attenuation and obstacle attenuation from the sample value. Reference values are stored along with information about obstacles in the propagation path, distance and obstacle attenuation and direction of the sample.

During fingerprint generation similar process to find propagation path and biggest obstacles is used. Then reference samples are searched for similar propagation path. Matching is based on direction, distance, and number of same obstacles. Reference values from best matches are averaged to obtain reference transmission power. Then distance attenuation and obstacle attenuation to generated position are added to value to obtain generated value. This process is repeated for each generated fingerprint.

3.8.4.2 Tweaks to DCM algorithm

Simple implementation of fingerprint generation neglects information about non heard cells. Therefore generated fingerprints tend to have higher RSS values than in reality. Other related problem is that antenna tilting is not taken into account and further away from the base stations the signal strength may stay long time above -110 threshold value. Accordingly most of the time there will be much more heard cells in the generated sample set than in actual measured sample.

DCM has a penalty term that penalises samples that hear a cell that is not heard in positioned sample. One solution could be to limit measured sample set to nine samples, but this may have adverse effects if many cells have same signal strength and are competing for the ninth position. Other simple solution, which was employed, was to downgrade penalty term. In these tests penalty term was lowered from power of two to power of 1.5.

3.8.5 Results

Location method relies on accurate estimations of received signal strengths at sample points. Therefore first an example of estimated radio maps is presented and then DCM based positioning results are compared.

3.8.5.1 Cell coverage for cell 43059.550

One quite well serving cell was 43059.550, which most likely was situated on top of HUT Computer Science building. Measured samples show that RSS values have mostly predictable pattern (Figure 21 and Figure 22). Estimated sample values quite well interpolate new sample values around exiting ones (Figure 23). One notable artefact in the radio map is high peak value toward South-East. Most likely this is caused by some erroneous input value and proper averaging may be able to cover up the error.

Use of terrain and building information is clearly visible in the image as radial lines have alternating stronger and weaker points. Examination of points within 3D model (Figure 24) further strengthens this notion.

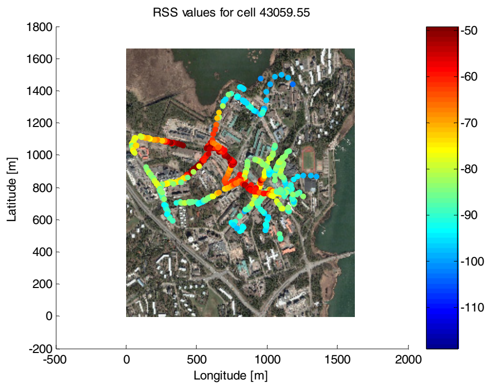

Figure 21. Signal strength values for cell 43059.550 from all measurement samples except target route.

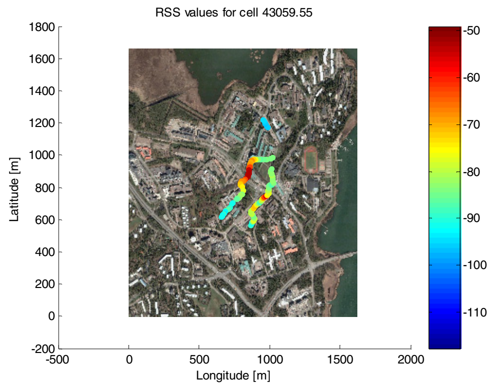

Figure 22. Signal strength values for cell 43059.550 from target route.

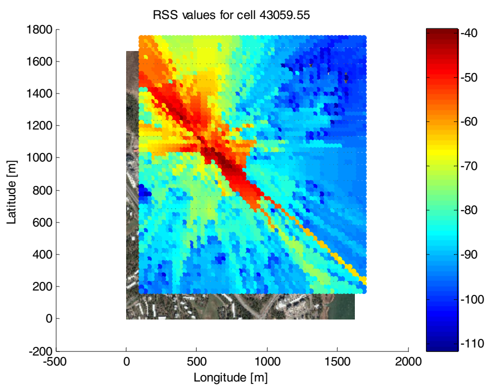

Figure 23. Calculated samples at 25 meter resolution.

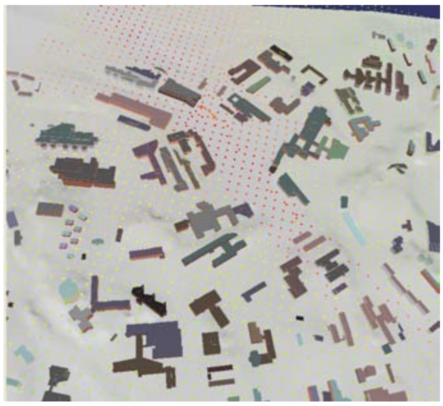

Figure 24. 3D view of measured and calculated samples.

3.8.5.2 DCM positioning accuracy

Next generated samples points are used in positioning the target route. Goal of generated fingerprint generation was to allow fewer field measurements. Therefore only car based measurements of one round around Otaniemi is used as training samples. Another predicted sample set is formed from first samples set using fingerprint generation method. Two resolutions were tested: 50 meter and 25 meter.

DCM positioning with original samples

The first sample points were directly used in DCM method to position target route. This result is as reference result. Figure 25 and Figure 26 present the results. DCM method is quite good at positioning the samples, but at some locations it clearly loses track of the target and gives larger errors. Also some hot spots are visible in the middle of the route.

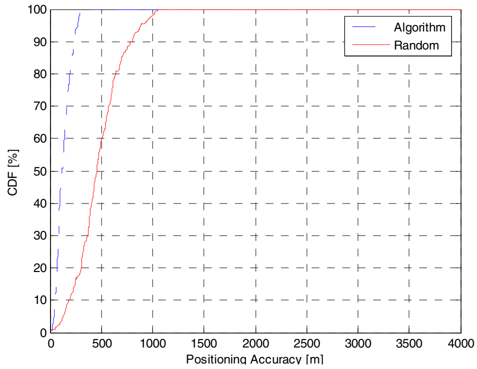

Figure 25. CDF distribution for direct DCM method.

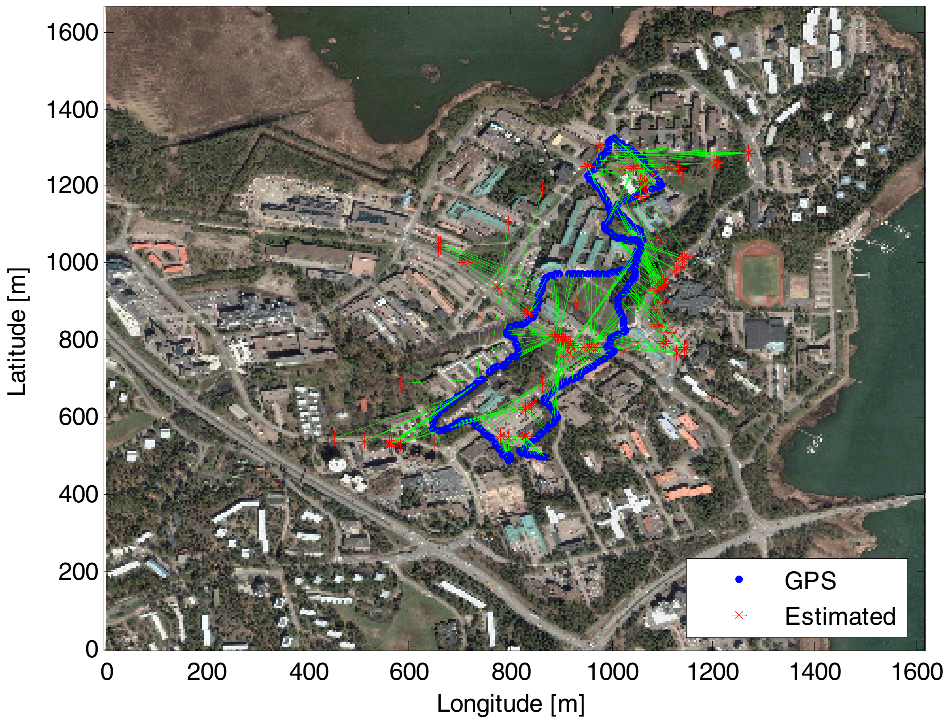

Figure 26. GPS versus estimated positions using direct DCM method.

DCM positioning with generated fingerprints at 50 m resolution

First fingerprints were generated at 50 meter resolution. This resolution is quite low, but it's used as quick check that the fingerprint generation is working at all. Results presented in Figure 27 and Figure 28 show that generated fingerprints can position target route in the right area, but still cannot outperform direct DCM method. In comparison to direct DCM, the generated fingerprint spread estimated positions more than direct DCM, where certain hit spots are clearly distinguishable. Positioning errors are almost always bigger than in direct DCM and especially amount of large errors

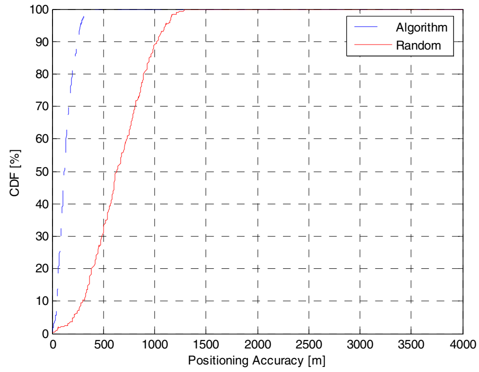

Figure 27. CDF for generated fingerprints at 50 meter resolution.

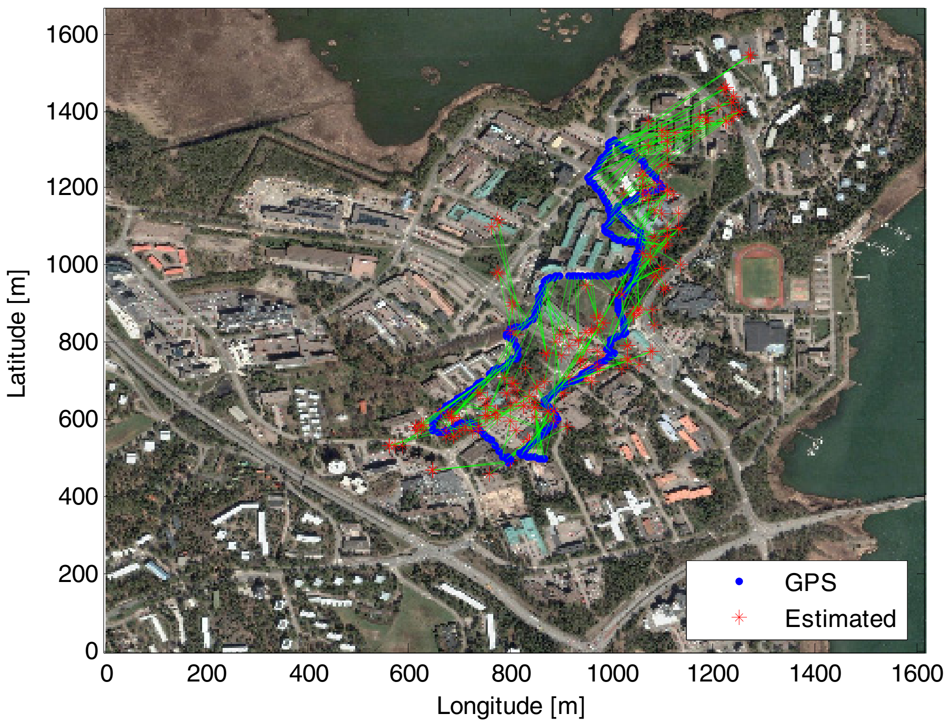

Figure 28. GPS vs. estimated positions using generated fingerprints at 50 meter resolution.

DCM positioning with generated fingerprints at 25 meter resolution

Higher fingerprint resolution is able to pull position estimates closer to real positions (Figure 30). Some large errors are present but as Figure 29 shows, the overall accuracy rises slightly above standard DCM method.

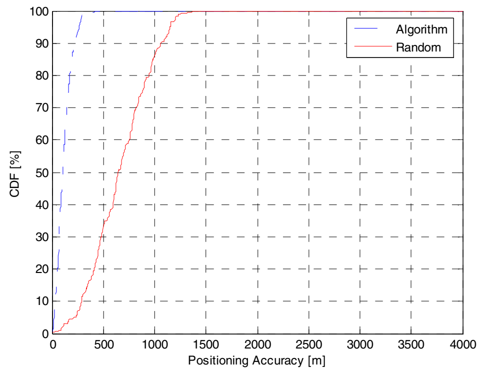

Figure 29. CDF for generated fingerprints at 25 meter resolution.

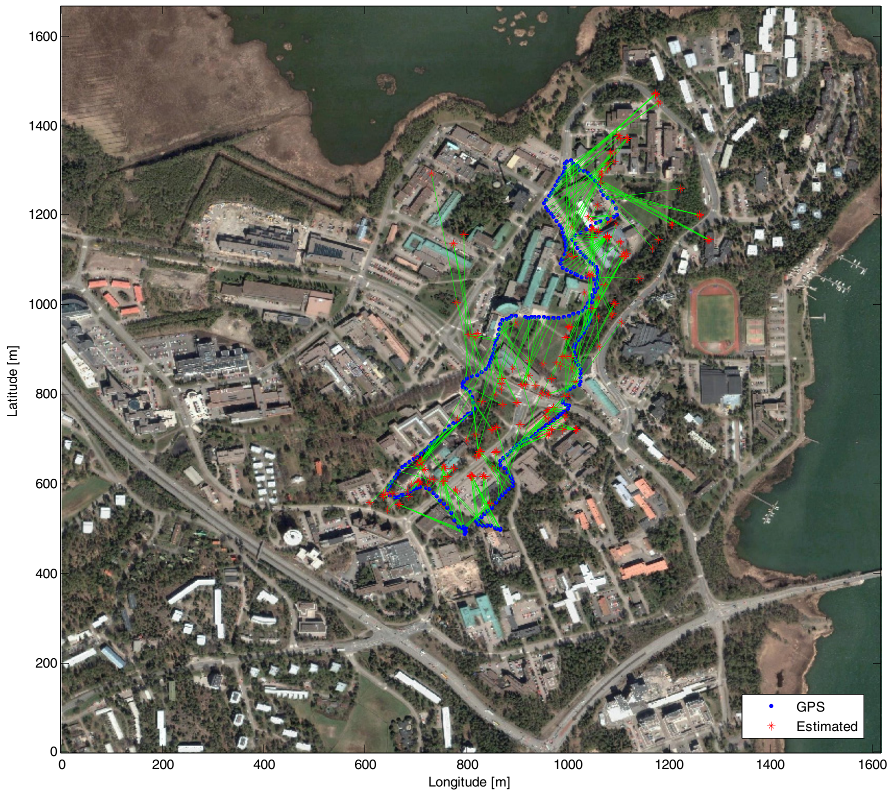

Figure 30. GPS vs. estimated positions using generated fingerprints at 25 meter resolution.

3.8.6 Conclusions

Results show that even simple generated fingerprints provide some promise of better accuracy than standard DCM, where weighted interpolation is used to go outside training route. Still the accuracy that was achieved was not significantly better than standard method, so better signal estimation algorithm is required to make synthetic fingerprint generation realistic alternative to more extensive field measurements.

More detailed analysis large positioning errors was also performed and showed that at some points CellId-TRX mappings were rather inconsistent and resulted in badly formed radio maps for that cell. This problem is even worse at edges of trial area as several cells are heard across Laajalahti and their positions and TRX channels were mostly just thrown in right directions. Together with TRX channel reuse this caused large good match areas near edges of trial area. Two approaches could be used to mitigate the problem. Either use measurement device that can collect CellIds for neighbouring cells or make such generation algorithm that uses only TRX channels and allows multiple transmitters per channel. First alternative is much better, but if it’s not possible then second alternative should be studied.

Cell information was other big uncertainty, which was just lightly touched during the research. Because it was impossible to position all cells and TRX channels to exactly correct positions, some radio maps had strange looking artefacts. If cell information independent algorithm is required, then more research should be done to estimate most probable cell positions.

When biggest uncertainties in cell information are solved, the more spatial aware fingerprint generation method could be used to push accuracy up. For example vegetation models could be included in the model and knife-edge diffraction model could be augmented with more detailed models when distances are short. Also new models are needed to support indoor positions.

3.9 Indoor Positioning

3.9.1 Introduction

In the positioning field, the Global Positioning System (GPS) [114] has rapidly become more common in use and, at the same time, new satellite navigation systems (Galileo [115] and GPS-III [116]) are being developed. Regardless of this, indoor environment continues posing challenges for these solutions that utilize weak radio signals transmitted from the orbiting satellites. To solve this problem, ground based transmitters (aka. pseudolites) [117] have been introduced to replace the space-born satellite constellation indoors. However, the current positioning systems based on pseudolites are rather expensive and require line-of-sight in between the pseudolites and the receiver. Other various positioning techniques utilizing cellular networks have also been introduced but none of them are proven to be accurate enough indoors.

Among all the handheld devices used in locating a user, besides the cellular networking capabilities, present-day mobile phones support many alternative short-range wireless communications, e.g. Wireless Local Area Network (WLAN), Bluetooth, Zigbee [118], mobile WiMAX [119] and Ultra Wide Band (UWB) [120]. WLAN presents already now an existing infrastructure for indoor positioning, as it has become more and more popular at home, in public areas and at work with an increasing number of mobile terminals having support for it.

The purpose of the work carried out in T1DAIMON project was to examine the existing indoor positioning solutions and to implement a test bed for indoor positioning techniques. In addition, the goal was to enhance the Database Correlation Method (DCM) [121]–[123] developed earlier at VTT to be applicable to indoor environments. The implemented software components are being utilized in IST-Motive project and in a joint project together with Nokia Research Centre.

3.9.2 Technologies used for indoor positioning

Indoor positioning techniques can be classified based on many different aspects. One of them is to focus on the access technology used. Availability of the technology (e.g. WLAN vs. UWB) and additional power consumption caused by the positioning have a significant impact on the applicability of the positioning technique. The required technologies also affect the pricing of the mobile terminals. In this section, the most relevant technologies used for indoor positioning are listed.

3.9.2.1 Cellular (GSM, UMTS)

Cellular networks, especially GSM, provide coverage in many areas and thus offer a possibility of locating the mobile phone user. Typically, positioning is exploited outdoors, but research has been done for the indoor as well, e.g. [130] presents a study, in which high accuracy for indoor positioning was attained using GSM network. In general, the achievable accuracy depends on cell deployment and average cell size. With smaller cells, UMTS can provide user location with higher accuracy. However, one drawback of it is the fact that it is not available as widely as GSM.

3.9.2.2 WLAN

Wireless local area networks are popular both indoors and outdoors. Many laptop computers already have WLAN card installed by the manufacturers. WLAN is common in PDAs and is embedded increasingly also in mobile phones. Thus, WLAN presents an existing network infrastructure and a feasible technology for mobile positioning for both indoor and outdoor environments.

Positioning in WLAN can be based on various measurements. Typically it is accomplished based on received signal strength measurements [131], [132]. Approaches utilizing time measurements (TDOA) have been presented as well [133].

3.9.2.3 Bluetooth

The availability of Bluetooth in mobile terminals has increased considerably lately. It is more commonly supported than WLAN by mobile phones; it costs less and requires less power. Bluetooth access points, on the other hand, are not as common as WLAN access points. In an office environment, laptop computers equipped with Bluetooth capabilities could act as access points. But their locations are not usually fixed and thus cannot serve as reference points for user positioning.

Several studies address Bluetooth positioning. In [134] it is pointed out that the main source of inaccuracy in the positioning is the unreliability of RSSI measurement. This is due to the fact that RSSI does not correspond linearly to the received power level (which is used for location estimation) and the resulting measurement range of received power level is quite narrow. However, in [135], a solution for mitigating that problem is proposed: a variable attenuator is installed to each Bluetooth access point widening the readable received power range. In [136], the Bluetooth positioning system has to resort to Cell-ID positioning only, since the RSSI measurements are not available in the equipment used in the study.

Another problem associated with Bluetooth positioning is pointed out in [137] and [138]: delay or latency. The Bluetooth device inquiry time can be long and it is unpredictable. A proposal solving the latency problem is made in [138]. The connection between a mobile device (client) and the access points (or guides in the system), is established in the other way than the usual: the guides connect to the client. By this way, the system is centrally controlled and once a mobile client is registered in the main server, guides can take care of establishing the connections to the client. Other studies addressing Bluetooth positioning can be found, e.g. in [139].

3.9.2.4 UWB

Investigated in [140] was a theoretical study about ranging accuracy in both High Data Rate (HDR) and Low Data Rate (LDR) UWB signals, obtainable for UWB signal formats proposed within the IEEE 802.15.3a and IEEE802.15.4a Task Groups. The analysis took into account the emission limits set by the FCC for indoor UWB transmission.

In [141] a 3D location system utilizing UWB-based location network was presented. The location network consists of UWB sensors and tags. The proposed location system takes advantage of UWB characteristics such as low power transmission, multi-path fading robustness, ultra-fine time resolution and multiple simultaneous transmissions. The positioning algorithm is based on round-trip time-of-arrival ranging measurements and Recursive Least Square (RLS) method. The performance of the proposed location system is estimated using simulations.

An alternative solution, using a time-difference of arrival (TDOA) method together with angle-of-arrival (AOA), is presented in [142]. The proposed hybrid technique uses also NLOS identification and mitigation technique (an adjustable extended Kalman filter) to reduce the error caused by multi-path effect. Simulations are used to evaluate the algorithm.

3.9.2.5 RFID

Radio Frequency Identification (RFID) is an old but newly evolved short-range transmission technology that uses radio frequency waves to transfer data between a tag and a reader. Tags can be either active or passive. Passive tags do not send their own signal but use the power of the received signal to send a response back to the reader. Among other information, the spatial coordinates of the tag itself can be stored into the tag's memory. By reading this location information, equipment with RFID reader can determine its location. Because passive tags are inexpensive, lightweight, and battery free, a grid of tags could be installed permanently into the infrastructure to form a positioning system with no dependency on a centralized database or wireless infrastructure for communications. An RFID based information grid system with a reader integrated into the user's shoe is presented in [144]. The established system helps blind children and adults to move around independently. The same principle has also been used to improve the localization of mobile robots [145] and motor vehicles [143].

3.9.2.6 Other

In addition to the common RF-based technologies, studies exist about user positioning with other alternatives.

Utilization of DTV signal together with A-GPS [146] provides accurate, reliable location in dense urban areas and also indoors. [147] discusses the usage of FM radio for estimating user's location. The location estimation is based on signal strength values and Bayes' rule. However, it is pointed out in the paper that different devices (of different manufacturers) might yield measurement values that do not correspond to each other exactly. To tackle that issue, the authors propose to use relative received signal strengths of radio antennas, i.e. the signal level fingerprint would only indicate that, e.g. signals are stronger from antenna A than from antenna B in a certain location instead of holding the absolute signal level values.

Since sound propagates in a speed that is far lower than RF waves, measuring time delays (to be used for positioning) is easier and it yields more accurate results. Also, the interaction of sound with the environment (walls, ceiling, and obstacles) is different from that of electromagnetic waves. Systems and studies that have used sound in connection with RF waves for user positioning can be found e.g. in [148] (Cricket) and [149]. Also, there are IR-based solutions for user positioning. One example is the Active Badge location system [150].

3.9.3 Algorithms

Even after selecting appropriate network technologies to be used in positioning, it is still possible to resort to multiple different algorithms to calculate the user location. This part is especially interesting from the point of view of research, since with the availability of exactly same measurements, different levels of positioning accuracy can be attained. When choosing or developing the positioning algorithm, the following criteria should be taken into account:

- precision
- complexity
- scalability
- required input data (e.g. 3D model of a building).

3.9.3.1 Cell-ID / Strongest Access Point

Usually the simplest way of estimating the location of the mobile terminal is to assume that the user resides close to the serving cell (GSM) or the strongest access point

(WLAN). The identification information of the serving cell/AP is used to find out the corresponding location of the signal source. This location is estimated to be the location of the mobile terminal. Since the mobile terminal can be anywhere in the cell dominance area, the accuracy often depends on the size of the cell/AP. The smaller the cell/AP size is, the better the method performs. However, especially in WLAN, the strongest AP is not always the closest one due to the attenuation of the signal caused by walls, floors, ceilings and other obstacles.

3.9.3.2 Signal strength

One way to improve the positioning accuracy compared to pure Cell-ID / Strongest AP location technique is to utilize information about the received signal strengths. Network type and topology influence the number of cells/access points a lot, from which the mobile terminal is capable of extracting signal strength measurements. In GSM, for example, the mobile terminal measures continuously the signal strength of the serving and up to six neighbour cells. In free-space propagation, the signal strength can be assumed proportional to the distance between the transmitter (e.g. base station) and the mobile terminal. By using propagation models, the location estimation for the mobile terminal can be solved geometrically. However, the line-of-sight (LOS) assumption is often invalid due to the disturbances in the propagation environment. Non line-of-sight propagation environment can also be modelled to some extent, but the results are usually poorer than in case of LOS visibility. In addition, the number of detected cells/access points affects directly the performance of the signal strength technique. Signals from at least three cells are needed to solve the location of the mobile terminal unambiguously.

3.9.3.3 Angle of arrival

Angle of arrival method is more often utilized in outdoor positioning, but indoor scenarios [142] have also been studied. In the angle of arrival (AOA) method, terminal location is determined by using the AOA measurements from several, at the minimum two, base stations. Each AOA measurement determines a line of bearing of the terminal's signal. With two AOA measurements the estimated location can be determined by the intersection of these two lines. By using more measurements, the location estimate becomes more unambiguous. The AOA method is entirely network-based and requires base stations to be equipped with an antenna array. The method performs best in areas, where line-of-sight paths between the mobile terminal and the base stations are prevalent.

3.9.3.4 Timing measurements

The indoor location can be calculated by triangulating the propagation time delay between the mobile terminal and at least three transceivers. An essential requirement for this method is to have accurate enough timing equipment. Pseudolite systems (e.g. [158]) utilize high-quality clocks in the GNSS signal generators synchronized by a separate monitoring component. In [141] a 3D location system utilizes the ultra-fine time resolution of UWB data transmissions.

3.9.3.5 Fingerprint-methods

The basic idea of the fingerprint methods is to create a radio map of the area where mobile terminals are to be located. A radio map is usually a database of reference fingerprints, that is to say, locations mapped with the signal information of the base stations detected at those locations. Positioning is performed by matching the signal information of the request fingerprint, received from the mobile terminal, to the signal information of the reference fingerprints. The utilized signal information can be, for instance, measured signal strength values of the serving and neighbour GSM cells [121], power delay profiles [122] of the detected UMTS cells. It is also possible to combine measurements from multiple networks [123].

The radio maps can be created either by using an empirical or mathematical method. The empirical method involves a site-survey to collect the reference fingerprints. The physical coordinates of each reference fingerprint are obtained e.g. using a floor layout map as reference or GPS location estimation if available. Reference fingerprint can be pre-processed before they are used for positioning. The pre-processing may consist of dimensionality reduction (reduce unnecessary elements) or clustering [124]. The empirical method has a significant drawback, that is, after every change in the network (e.g. addition of a new cell), the site survey must be carried out again to update the radio maps. One way to decrease the burden of collecting fingerprints is to interpolate the existing measurement samples by using surface fitting [108]. Instead of performing a site-survey and covering the entire area by a rectangular grid of measurement points, the output from a network planning tool [108], [125] can be used to generate the reference fingerprints mathematically.

Fingerprint-based location estimation algorithms can be classified into deterministic and probabilistic types [126]. Deterministic techniques represent the signal information of a fingerprint by scalar values. For example, the positioning estimation can be calculated using the nearest neighbour method by comparing the mean values of the signal strength [127]. Probabilistic techniques like the one presented in [128] utilize the distribution of the signal levels instead of the mean value. In addition to the probability distribution related to the signal level differences, probabilistic methods can utilize additional probability information e.g. maps of the buildings. Taking into account that the users do not usually walk through the walls or float in the air, a Voronoi diagram can be generated to represent the logical walking routes inside buildings and a particle filtering can be applied to estimate the user movement [129].

3.9.4 Existing applications

The section briefly introduces some of the most interesting indoor positioning applications currently on the market. It should be noted that the presented list is not complete and new companies emerge continuously in this field.

3.9.4.1 Cambridge Positioning Systems Limited

Cambridge positioning systems Limited [156] offers Matrix, Matrix3G and E-GPS solutions for terminal positioning. The location request and measurement sending can utilize SMS or GPRS. The location estimation is based on timing measurements and triangulation (sub 100 m accuracy and calculation time less than 3 seconds). The E-GPS technology is a combination of Matrix and GPS technologies: GPS in open areas and Matrix/Matrix3G in urban and indoor environments.

3.9.4.2 AeroScout

AeroScout [151] real-time location system utilizes Time Difference of Arrival (TDOA) and Received Signal Strength Indication (RSSI) methods for locating assets and people. In November 16th, 2006, Royal Philips Electronics announced a new RFID asset tracking solution together with AeroScout. The asset tracking solution is designed especially to be used in hospitals to track equipments such as infusion pumps, beds, monitors and wheelchairs.

3.9.4.3 Ekahau Positioning System

Ekahau's [152] Positioning Engine 4.0 is a software-based real-time location system that leverages any existing 802.11a/b/g networks. The positioning is based on advanced probabilistic fingerprinting method. Before the method can be applied, a site survey has to be carried out to collect reference fingerprint for the system. Ekahau's software is focused on monitoring and tracking its Wi-Fi tags that can be attached to any mobile asset or carried by people. The field of healthcare (e.g. hospitals) is one of the main customer groups for Ekahau. Emergency management, patient monitoring and equipment management benefit remarkably from the fact that healthcare professional are able to quickly locate patients, caregivers and medical equipment.

3.9.4.4 PanGo

Like AeroScout and Ekahau, PanGo [153] has developed an 802.11-based asset tracking system and Active RFID tags. Tags include motion detection sensor that enables them to operate in different modes (stationary/in-motion) and thus, consume less battery power.

3.9.4.5 Skyhook Wireless

Skyhook Wireless [154] has a Wi-Fi Positioning System (WPS). The WPS acquires a location reading in less than a second calculated by triangulating signals from detected Wi-Fi access points. The system utilizes a nationwide (only in the US) database of known Wi-Fi access point locations. Both device centric and network centric operation modes are supported.

3.9.4.6 Navizon

Navizon [155] is a system that provides user location by triangulating signals from both Wi-Fi access points and cellular towers. It works with Windows smartphones, Pocket PCs and Symbian S60 phones equipped with Wi-Fi and/or cellular phone. Users that own a GPS can use their devices to collect data (access point and cellular tower locations) from their neighbourhood and contribute to the Navizon database. Navizon also offers API to its positioning engine so that software developers can utilize it in their own mobile and web applications.

3.9.4.7 Intel Precision Location System

Intel Research [157] is developing high precision location system that uses WLAN-based location technology to complement GPS. The distance between the terminal and fixed WLAN access points is determined using a Time-Of-Arrival (TOA) technique. By knowing the AP locations, the terminal can then triangulate its position.

3.9.4.8 NAVIndoor

Space System Finland (SSF) has developed an innovative NAVIndoor [158] solution to extend the usage of satellite based positioning methods into environments where the GPS signal coverage is unsubstantial. The NAVIndoor is a synchronised pseudolite system based on the GSG-L1 signal generators developed by the SSF. As a standalone system the accuracy of NAVIndoor is equal to single frequency GPS positioning, but with the advanced navigation algorithms a sub-decimetre accuracy can be achieved. The system requires line-of-sight connection to at least four pseudolites. Thus, it suits best to large open spaces like industrial halls.

3.9.4.9 Ubisense Precise Real-time Location

Ubisense [159] has developed a precise, real-time location system (RTLS) utilizing ultra-wideband (UWB) technology. UWB sensors send the tag location information several times per second to the Ubisense software platform, which creates a detailed, real-time view of the environment. The technology enables the people and assets to be located within ~30cm in 3D. The system is also scalable and can be used in very large complex sites to track tens of thousands of tags in real time. So far, the system is available only in the United States. In Europe, the commissioning of the UWB technology has been delayed due to the concern that the technology would cause interference to other radio communication technologies.

3.9.4.10 Sapphire DART

Similarly to Ubisense RTLS, Sapphire DART [160] is using UWB technology to provide real-time positioning with ~30cm accuracy in 3D. The solution is promised to work also in high multi-path environments (e.g. factories and warehouses) where conventional active tag technologies have failed.

3.9.4.11 Parco

Parco [161] offers yet another real-time location system that is utilizing UWB technology like Ubisense and Sapphire DART. Future updates of the system will include historical tracking of assets and ability to perform modelling analysis related to spread of infectious diseases based on the movement of people carrying Parco tags.

3.9.4.12 BlueLon

BlueLon [162] offers intelligent Bluetooth tags for tracking and locating personnel, animal and assets. The company is planning to add these tags to its existing Smart Access Control (SAC). The resulting system will eliminate the need of outdoors card readers and exit buttons as the access points will register the location of all the tags inside the coverage area.

3.9.4.13 IndoorGPS

Global locate [163] offers A-GPS technology to the full spectrum of mobile wireless devices including PDAs, smart phones and asset tracking devices. They have created world's first single-chip A-GPS receiver named as Hammerhead. It is based on advanced low-power 0.13 micron RFCMOS technology. The receiver supports both control plane (RRLP & RRC) and user plane protocols (SUPL). Due to the high sensitivity (~-160dBm) the chip can also be used indoors to some degree.

3.9.4.14 Rosum TV-GPS

Rosum TV-GPS [164], [146] provides accurate, reliable location indoors, outdoors and in dense urban locations. It integrates TV-based positioning together with Global Locate's Hammerhead A-GPS chip. The synchronization signals of digital television (DTV) have a power advantage over GPS by more than 40dBm. A wider bandwidth (~6MHz) together with substantially superior geometry of the TV towers (in the US) enables more accurate triangulation of the lateral position in a harsh GPS signal propagation environment. The drawback of the system is that the locations of the TV towers need to be known and additional hardware for detecting the synchronization signals is required.

3.9.5 Indoor positioning test-bed

Two different architectural approaches for indoor positioning were implemented within the project.

3.9.5.1 The Client-Server approach

The Client-Server approach is composed of three stand-alone components (Figure 31): the client running at the mobile terminal, the server agent handling the location requests and other data services, and a GIS monitor to display terminals' current locations. The design and implementation of the server and mobile terminal client program have been partly based on the thesis work [165].

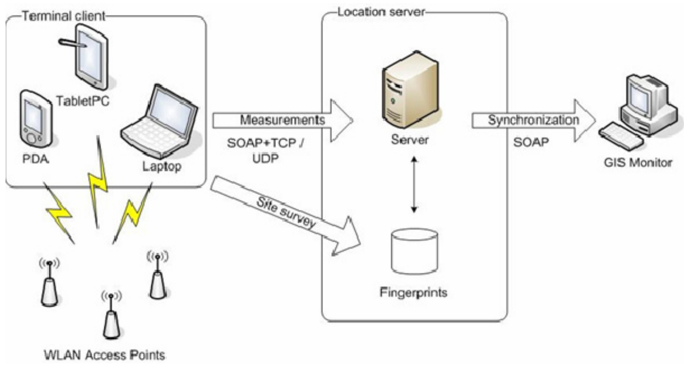

Figure 31. Test bed architecture for WLAN positioning (Approach 1).

When a WLAN enabled mobile terminal is connected to the network, the client program can be started. It collects Received Signal Strength (RSS) information from all the detected access points, wraps the data and sends the package out. Messaging between the client and server is based on SOAP Web services. For terminals with limited resources, such as PDAs, messages are sent over UDP instead of TCP. After the running server agent receives the package, it calculates the estimated location using DCM/Strongest AP method. The estimated locations are then stored in the server for later positioning requests. Such requests can come from the mobile client itself or another party. The actively located terminals' positions can then be displayed and viewed on top of a loaded map (e.g. the floor plan of the building) with GIS software, based on the received response from the server to its synchronization request.

3.9.5.2 The self locatable approach

The second approach, named as Self-Locator, was implemented in order to provide ubiquitous positioning without continuously interacting with the server. Necessary data are pre-loaded from the server when the user enters the building for the first time (or some updates are available). The data include the fingerprints and the access point locations for WLAN positioning that utilizes different location methods, and the geographical maps for visualizing the estimated location. After the data is loaded, the position estimate calculations are performed locally and thus, the delays and possible costs caused by continuous data transmission between the client and server are avoided. This approach has also combined GPS with WLAN positioning, so that the user has the flexibility to get more accurate results when s/he is outside.

Self-Locator uses pre-calibrated raster maps. A geo-referencing tool shown in Figure 32 helps to make the calibration. Known coordinates (in WGS84) of three points are all that needed to geo-reference a map or a building floor plan. During positioning phase, when there is no map loaded or the estimated position is out of the current loaded map, Self-Locator always automatically switches the most appropriate map and auto-focuses to the position. If multiple maps are available covering the area of current place of location, the most accurate map is always selected initially. If no suitable maps are found locally, a proper one(s) can be queried and downloaded from the server.

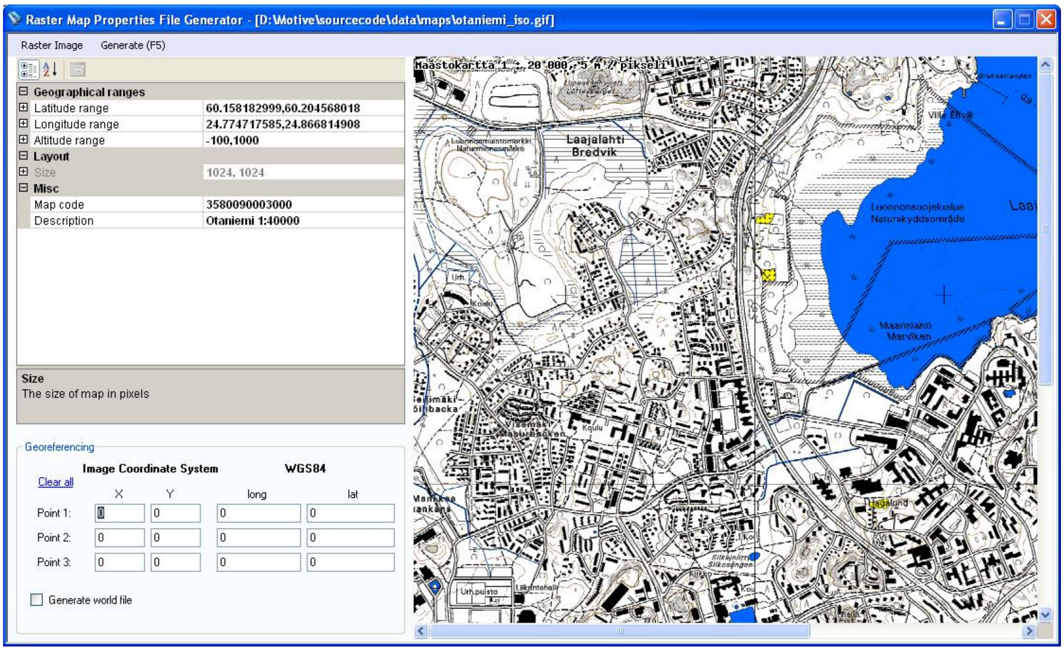

Figure 32. Georeferencing tool for creating pre-calibrated maps (Approach 2).

Figure 33 depicts the Self-Locator's user interface. In addition to the current location estimate (red dot), the program shows the precision estimate (red circle) and also a set of previous location estimates (green dots). The precision estimate is currently based on the covariance matrix of the 3D Kalman filter (and initial estimation of the standard deviation of the location estimate).

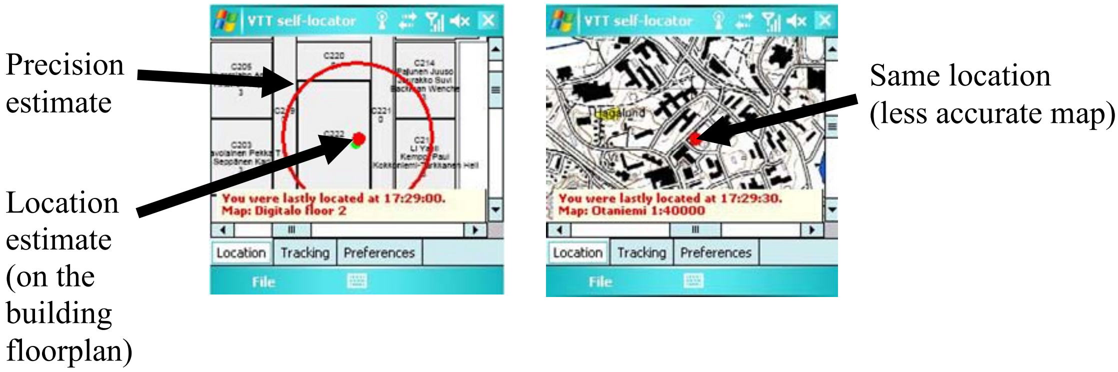

Figure 33. The location representation in the Self-Locator (Approach 2).

The Self-Locator supports two methods for indoor WLAN positioning: fingerprinting and strongest AP. The fingerprinting method is a *k*-nearest-neighbour approach that selects the *k* best matching fingerprints and calculates the weighted average of their locations. The Preferences tab (Figure 33) allows user to adjust all the parameters related to the algorithms and Kalman filter to get better results. WLAN and GPS tracking can be enabled/disabled in the Tracking tab. If WLAN tracking and GPS tracking are both enabled, the location is determined based on the more accurate method.

3.9.5.3 Trial of the test-bed

Both of the implemented approaches were tested in Digitalo office building in Espoo, Finland. The building is covered by WLAN access points scattering on each floor. The placement of the access points on 2nd floor and the dimensions of the building are shown in Figure 34. The 1st and 3rd floor have similarly nine access points.

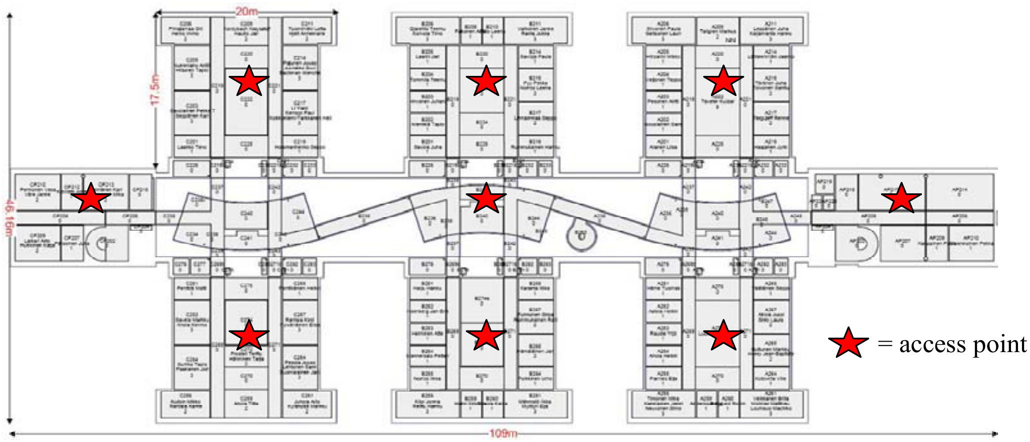

Figure 34. Dimensions of the Digitalo office building and the access point placement.

Altogether 289 reference fingerprints were collected for the fingerprinting algorithm. Only corridors and public areas were covered to avoid invading office workers' privacy. The average spacing between the fingerprints was around 5 metres. Fingerprints were collected using Site Survey tool implemented for PocketPC 2003, Windows Mobile 5.0 and Windows XP operating systems. In addition to fingerprint collection, Site Survey can be used to visualize coverage areas of the access points (see Figure 35).

It took 2 hours and 35 minutes to collect all 289 fingerprints. With a better planning, the elapsed time could have been notably shorter. 10 measurement samples were taken in each location to calculate average signal level. The average number of detected access points per fingerprint was 6.05 and the standard deviation was 3.23. Fingerprints were collected using Fujitsu Siemens Pocket Loox t830. Self-locator software was tested both with Pocket Loox and HP iPAQ 5550 (see Figure 36).

Earlier measurements were done for the client-server approach where we had mainly used a TabletPC and the HP pocket PC (in Figure 36) as the clients, and the TabletPC as the server.

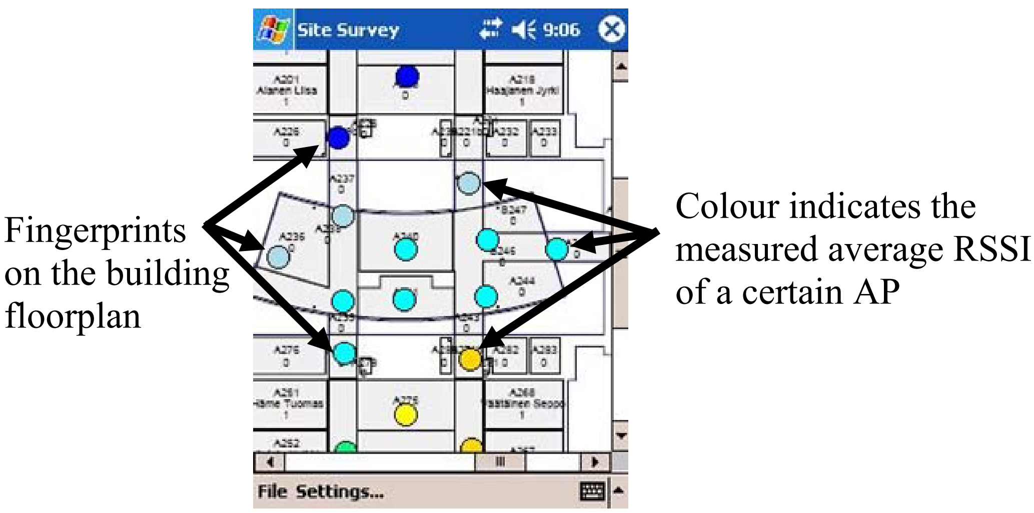

Figure 35. Site Survey tool for fingerprint collecting.

Figure 36. Fujitsu Siemens Pocket Loox t830 (left) and HP iPAQ 5550 (right).

3.9.5.4 Results and conclusions

The WLAN indoor positioning methods were tested both with client-server and self-locator approach. The accuracy of the fingerprinting method is depicted in Figure 37 in case of a test measurement containing 140 samples. Kalman filtering improves the accuracy significantly: 67th percentile is within 2.5 meters and the maximum error is less than 6 meters.

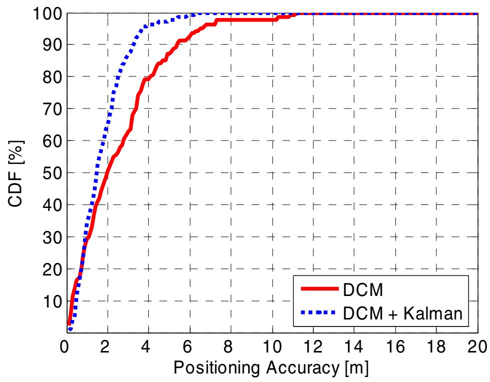

Figure 37. Cumulative distribution of the positioning accuracy of the trial route.

The poorest accuracy was detected along the narrow 2nd floor pathways in the central hall (Figure 38). Even though the corridor is covered by thin walls, the signal propagation environment is almost equal to the first floor below the pathway and thus, the algorithm failed to predict the floor number correctly for a short while.

Figure 38. Narrow pathways resulted in the poorest accuracy.

By increasing the number of coverage-overlapping access points, the positioning accuracy can be improved to a certain degree. However, due to the random variations of RSS utilised in location fingerprinting, positioning techniques like DCM will not be able to provide centimetre-level accuracy.

Modifications of the access point placement and in the indoor space (e.g. new walls or large pieces of furniture) will degrade the positioning accuracy if the reference fingerprints are not updated according to the change. Thus, the precision of the positioning estimates needs to be monitored closely in order to be able to detect changes in the propagation environment. On the other hand, site survey measurements and positioning estimates can also be exploited in network planning and resource management. For example, the QoS information together with location estimates can be utilised by the network administrator to adjust the access points to serve the clients more efficiently.

The hybrid WLAN-GPS positioning solution provides an interesting concept for ubiquitous positioning. Only the cold start causes a delay in getting the GPS fix when going outside. But it could be avoided by using an A-GPS receiver. If possible, fingerprints should be collected outdoors too to cover the neighbourhood of the building. By this way, the switching from WLAN fingerprinting to GPS will be smoother.

The client-server approach will be utilised in IST-Motive project as a part of the platform for ubiquitous terminal assisted positioning, supporting the Secure User Plane Location (SUPL) and OMA Mobile Location Protocol (MLP). The self-locator was demonstrated to people from Nokia Research Centre in December 2006 and as a result, a joint project will start in the first quarter of the year 2007.

4. Summary

Existing implementations and concepts of All-IP wireless networks

The evolution of commercial WLAN wide area deployments does not go hand in hand with ongoing standardisation efforts. The importance of mesh networks is growing especially in urban areas. Future All-IP networks were found to require more planning and maintenance. The possibilities for including e.g. QoS are yet rarely used in real implementations.

Resource allocation and management in wireless systems

In UMTS, the resource management research focused on scheduling, QoS provisioning and system integration with other access technologies. In the project an example scenario with a heavy downlink transmission was simulated and analysed to find possible traps and methods to avoid them. The project results clearly indicate the positive effect of scheduling. In WLANs QoS has not been addressed from the beginning and consequently, much research on this topic can be found. For service differentiation and QoS provisioning the parameters that control access to the channel are tuned. Moreover, admission control and bandwidth reservation can be used. Adapting to different channel conditions by using link adaptation and power control is also included in the radio resource management of WLAN networks. The focus in WiMAX is on scheduling and admission control. Most of the proposed solutions consider the QoS classes and their service requirements. In the future, handover might be studied further, particularly in Mobile WiMAX.

Traffic modelling

The lack of generic traffic models for access networks where the level of traffic aggregation is low is a problem. In the DAIMON project a new approach was found which helps to clarify the applicability of such traffic models which are based on the concept of a flow.

Modelling of radio wave propagation

Propagation prediction has a great importance for any telecommunication system based on wireless access. Therefore in this project a review of known propagation models for several selected radio technologies was performed. The technologies, used commercially or being still developed, were selected based on their applicability for IP-based services.

Indoor positioning in wireless systems

The indoor environment is the most challenging positioning problem. General purpose positioning systems, like GPS or Galileo, do not work indoors. In the project several solutions were reviewed, starting from cellular-based positioning to the short-range

RFID and Bluetooth. The theoretical study was backed up with a trial based on the WLAN and two positioning algorithms. One of those methods, DCM, requires knowledge about the signal propagation that had to be obtained with measurements. In order to avoid this time-consuming step, a software tool for generating the measurements based on the propagation models was created. This tool enables also visualising results of positioning trials.

Network architectures and configuration

As the transport network evolves to an All-IP network, the network architecture becomes more straightforward and more open. The straightforwardness is caused by the fact that many network elements, necessary in today's combined circuit-packet networks, become obsolete and disappear from the network. The openness is an inherent part of the IP technology enabling all sorts of players to implement their networking solutions and services to the network. The counter part of the All-IP architecture is that it poses high dependability requirements for the system components.

Mobile and wireless backhaul

The mobile backhaul network evolves from the conventional PDH/SDH transport towards less expensive solutions, i.e. the Ethernet or IP transport. Both these lack many important features, such as protection of transport paths, restoration of lost connections and efficient QoS supported provisioning of transport capacity, commonly available in the conventional transport networks. The advanced layer 2 and layer 3 VPN solutions seem to be the answer to these shortcomings. The mobile All-IP architecture study helped to identify relevant development topics and problems in the All-IP networks and to direct our research work towards substantial problems, such as reliability of All-IP networks and problems in the mobile backhaul network. Discussions with the industry and network operators have clarified the picture even more and some follow-up projects have already been launched, one dealing with the dependability evaluation methods for All-IP networks and another dealing with the mobile backhaul problems. A co-funded project to study and develop solution for OAM and provisioning of transport capacity in the mobile All-IP networks is under discussion. Additionally, we are involved in preparing a couple of project initiatives to EU's 7th Framework Programme.

Dependability study

The availability of several access networks increases the dependability of the user's IP connectivity considerably. However, certain network literacy is required from the user to grasp the affordances and to interpret the variations in quality of service.

Human-technology interaction

The methodological starting point in considering design issues of All-IP mobile networks from the human-technology interaction perspective was to combine approaches of user-centred design and human factors studies of safety-critical complex systems. In building a concept to tackle the user perspective of All-IP mobile networks a bridge was build from engineering-oriented measures of quality of service (QoS) to the user experience of the service. It was shown that the traditional approach to comprehend user experience, i.e. via measures of perceived quality, is necessary but not sufficient. Deficiencies relate to inability of considering the context of use and the social and collaborative nature of technology usage. A new model, extended model of quality of service (exQoS), was developed to tackle user experience and acceptance in more comprehensive way. For example following qualities of experience were proposed: trustworthiness, sensitivity, engagement, tactfulness, and harmony. Included in the framework is the idea that All-IP network creates a new environment for human activity the intrinsic characteristics of which are connectivity, location awareness and adaptability. People must create ability to grasp these new affordances in order to make full use of the new environment. The connectivity affordance was analysed in more detail and it was claimed that creating "network literacy" currently taking place. This learning process takes place in new types of activity and communication systems. The depth of the learning process is supposed to have an effect not only on the user experience and acceptance of technology but also on the users' ability to become sovereign members of the developing knowledge society. The results of the project are in the next phase utilised in development of empirical methods to study peoples' conceptions of IP and IP-based services and practices of in using them. These studies are planned to take place in the "Living lab" -type innovation and research environments.

References

[1] DAIMON project final report, March 2007.

[2] Castells, M., Fernandez-Ardevol, M., Qiu, J. L. & Sey, A. The mobile communication society: A cross-cultural analysis of available evidence on the social uses of wireless communication technology. The International Workshop on Wireless Communication Policies and Prospects: A Global Perspective, the Annenberg School for Communication, University of Southern California, Los Angeles, 2004.

[3] Green, N. On the move: technology, mobility, and the mediation of social time and space. The Information Society 18(2002)4.

[4] Perry, M., O'Hara, K., Sellen, A., Brown, B. & Harper, R. Dealing with mobility: understanding access anytime, anywhere. ACM Transactions on Computer-Human Interaction 8(2001)4.

[5] ITU-T E.800. Telephone network and ISDN – quality of service, network management and traffic engineering; terms and definitions related to quality of service and network performance including dependability.

[6] ITU-T E.860. Framework of a service level agreement.

[7] Hardy, W. C. QoS. Measurement and evaluation of telecommunications quality of service. Chichester, NY: Wiley, 2001.

[8] Kilpi, J. & Lassila, P. Micro- and macroscopic analysis of RTT variability in GPRS and UMTS networks. F. Boavida et al. (Eds). NETWORKING 2006, LNCS 3976, 2006. Pp. 1176–1181.

[9] Kilpi, J. & Norros, I. Call Level Traffic Analysis of a Large ISP. In: Proceedings of the 13th ITC Specialist Seminar on IP Traffic Measurement, Modeling and Management, September 18–20, 2000, Monterey, California, USA, 2000.

[10] Vicari, N. & Köhler, S. Measuring Internet User Traffic Behavior Dependent on Access Speed. In: Proceedings of the 13th ITC Specialist Seminar on IP Traffic Measurement, Modeling and Management, September 18–20, 2000, Monterey, California, USA, 2000.

[11] Kilpi, J., Lassila, P. & Muscariello, L. On the dependence of Internet flow traffic. Extended abstract in the Second EuroNGI Workshop on New Trends in Modelling, Quantitative Methods and Measurements (WP IA.8.1), Aveiro, Portugal, November 24–25, 2005.

[12] Markovich & Kilpi, J. Bivariate statistical analysis of TCP flow sizes and durations. Extended abstract in the EuroNGI Workshop on Stochastic Performance Models for Resource Allocation in Communication Systems, CWI, Amsterdam, November 8–10, 2006.

[13] Ivanovich, M., Fitzpatrick, M., Beresford, M. & Saliba, A. An empirical 3-D user satisfaction model in wireless data networks. 15th IEEE International Symposium on Personal, Indoor and Mobile Communications, 2004.

[14] Ling, R. & Haddon, L. Mobile telephony, mobility and the co-ordination of everyday life. In Katz, J. (Ed) Machines that Become Us: The Social Context of Personal Communication Technology. New Brunswick, NJ, Transaction Publishers, 2003. Pp. 245–66.

[15] Tamminen, S., Oulasvirta, A., Toiskallio, K. & Kankainen, A. Understanding mobile contexts. Proceedings of Mobile HCI 2003, LNCS, Springer, 2003. Pp. 17–31.

[16] Koivisto, M. & Urbaczewski, A. The Relationship between quality of service perceived and delivered in mobile Internet communications. Information Systems and e-Business Management 2:4, October 2004, pp. 309–323.

[17] Gibson, J. The ecological approach to visual perception. Boston, Houghton Mifflin, 1979.

[18] Bader, F., Pinart, C., Christophi, C., Tsiakkouri, E., Ganchev, I., Friderikos, V., Bohoris, C., Correia, L. & Ferreira, L. User-centric analysis of perceived QoS in 4G IP mobile/wireless networks. 14th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'2003), Beijing (China), Sept. 7–10, 2003.

[19] Leont'ev, A. N. Activity, Consciousness, and Personality. Englewood Cliffs, Prentice Hall, 1978.

[20] Vygotsky, L. S. Mind in Society. The Development of Higher Psychological Processes. Cambridge, Mass., Harvard University Press, 1978.

[21] Rabardel, P. & Beguin, P. Instrument mediated activity: from subject development to anthropometric design. Theoretical Issues in Ergonomics Science 6(5), 2005, pp. 429–461.

[22] Rückriem, G. Tool or medium? The Meaning of Information and Telecommunication technology to Human Practice. A quest for Systemic Understanding of Activity Theory. Invited talk at Toiminta 2003 -conference held in Kauniainen, Finland in December 2–3, 2003. http://www.iscar.org/fi/, University of Helsinki, Center for Activity Theory and Developmental Work Research.

[23] Lister, M., Dovey, J. et al. New media: A critical introduction. London and New York, Routledge, 2003.

[24] Pietilä, V. Kaiken takana on teknologia: Harold Innis ja Marshal McLuhan tekivät välineistä viestintäteoriaa. Mediatutkimuksen vaeltava teoria. T. Mörä, I. Salovaara-Moring and S. Valtonen. Helsinki, Gaudeamus, 2004. Pp. 137–164.

[25] McLuhan, M. & McLuhan, E. Laws of media. The new science. Toronto, University of Toronto Press, 1988.

[26] Rückriem, G. Die Erziehungswissehschaft und der Kongress der Pferdekutscher, Bund demokratischer Wissenshcaftlerinnen und Wissenschaftler – Pädagogik +Medien = Medienpädagogik? 2004.

[27] Hoffman, M. & Blake, J. Computer literacy: today and tomorrow. Hamden, CT, Consortiumfor Computing in Small Colleges, 2003. Pp. 221–233.

[28] Dawes, L. First connections: teachers and the National Grid for Learning. Computers and Education(33), 1999, pp. 235–252.

[29] Luke, T. W. Governance. Unspun. Key concepts of World Wide Web. T. Swiss, New York, New York University Press, 2000. Pp. 73–87.

[30] Bolter, J. D. Identity. Unspun. Key concepts for understanding the Word Wide Web. T. Swiss, New York, New York University Press, 2000. Pp. 17–29.

[31] Cubitt, S. Multimedia. Unspun. Key concepts for understanding the Word Wide Web. T. Swiss. New York, New York University Press, 2000. Pp. 162–186.

[32] Viherä, M.-L. Digitaalisen arjen viestintä. Miksi, millä ja miten. Helsinki, Edita, 2000.

[33] Bachelard, G. La poétique de l'espace. Presses Universitaires de France, 1957.

[34] MuniWireless, portal for news about citywide wireless broadband projects, http://www.MuniWireless.com (link checked 7.1.2007).

[35] Zonet roaming cooperation, www.zonet.fi (link checked 7.1.2007).

[36] panOulu web pages, http://www.panoulu.net/index.shtml.fi (link checked 7.1.2007).

[37] Rotuaari research project: http://www.rotuaari.net (link checked 7.1.2007).

[38] "TAITO Oulu 400" research program, http://www.ouka.fi/taito/ (link checked 7.1.2007).

[39] SparkNet webpage, http://www.sparknet.fi (link checked 7.1.2007).

[40] FON WLAN community homepage, http://en.fon.com/ (link checked 7.1.2007).

[41] BT plan for citywide WLAN. http://www.btopenzone.com/news/news_2006_05_17.jsp (link checked 7.1.2007).

[42] The Cloud press release, http://www.thecloud.net/content.asp?section=5&content=49&expand=280 (link checked 7.1.2007).

[43] van Drunen, R., van Gulik, D.-W., Koolhaas, J., Schuurmans, H. & Vijn, M. Building a wireless community network in the Netherlands. Proc. of the FREENIX Track: 2003 USENIX Annual Technical Conference, TX, USA, June 9–14, 2003. Pp. 219–230.

[44] Tropos MetroMesh white paper, bout the Chaska case, http://www.tropos.com/pdf/chaska_performance.pdf (link checked 7.1.2007).

[45] San Francisco TechConnect homepage, http://www.sfgov.org/site/tech_connect_index.asp (link checked 7.1.2007).

[46] Hughlett, M. Wi-Fi town a learning center. Chicago Tribune, published June 11, 2006.

[47] Packethop mobile-meshcommunication systems, http://www.packethop.com (link checked 7.1.2007).

[48] Cisco white paper: "Using radio resource management to deliver secure and reliable wlan services," 10p, 2005, http://www.cisco.com/application/pdf/en/us/guest/products/ps6307/c1244/cdccont_0900aecd802c949b.pdf

[49] Nortel mesh product, http://products.nortel.com/go/solution_content.jsp?segId=0&parId=0&prod_id=47160&locale=en-US

[50] Doyle, J.C., Carlson, J., Low, S.H., Paganini, F., Vinnicombe, G., Willinger, W., Hickey, J., Parrilo, P. & Vandenberghe, L. Robustness and the Internet: Theoretical Foundations. Draft. March 2002. http://netlab.caltech.edu/internet.

[51] Ahola, K., Myötyri, E., Norros, I., Norros, L., Pulkkinen, U., Raatikainen, P. & Suihko, T. The dependability of an IP network – what is it? A baseline paper of the IPLU project. VTT, May 16, 2006. Available at http://iplu.vtt.fi/iplu_baseline_2006.pdf.

[52] Markovich & Kilpi, J. Bivariate statistical analysis of TCP flow sizes and durations. submitted.

[53] Kordybach, K., Backman, W. & Kilpi, J. The 1st technical report. DAIMON project internal report, 2005.

[54] Kordybach, K. & Raatikainen, P. Data traffic, scheduling and lost capacity in UMTS downlink radio interface. Proc. 13th International Conference on Telecommunications, ICT, May 2006.

[55] Gao, D., Cai, J. & Ngan, K. N. Admission control in IEEE 802.11e wireless LANs. IEEE Network, Vol. 19, Issue 4, July–August 2005, pp. 6–13.

[56] The Palomar project (PAssive LOng distance Multiple Access UHF RFID system), Deliverable D7, January 2002.

[57] Kin Seong Leong, Mun Leng Ng & Cole, P. H. The reader collision problem in RFID systems. Proc. of IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications MAPE 2005, vol. 1, August 2005, pp. 658 – 661.

[58] Kin Seong Leong, Mun Leng Ng & Cole, P. H. Operational considerations in simulation and deployment of RFID systems. Proc. of 17th International Zurich Symposium on Electromagnetic Compatibility, 2006 EMC-Zurich 2006, February–March 2006. Pp. 521–524.

[59] Fletcher, R., Marti, U. P. & Redemske, R. Study of UHF RFID signal propagation through complex media. Proc. of IEEE Antennas and Propagation Society International Symposium 2005, July 2005. Vol. 1B. Pp. 747–750.

[60] Griffin, J. D., Durgin, G. D., Haldi, A. & Kippelen, B. RF tag antenna performance on various materials using radio link budgets. Antennas and Wireless Propagation Letters, Vol. 5, 2006, pp. 247–250.

[61] Ali-Rantala, P., Ukkonen, L., Sydanheimo, L., Keskilammi, M. & Kivikoski, M. Different kinds of walls and their effect on the attenuation of radiowaves indoors. Proc. of IEEE Antennas and Propagation Society International Symposium 2000, June 2003. Vol. 3. Pp. 1020–1023.

[62] WiMAX Forum, Mobile WiMAX – part I: a technical overview and performance evaluation. Whitepaper, March 2006. Available at http://www.wimaxforum.org/news/downloads (link checked 20.12.2006)

[63] WiMAX Forum, WiMAX deployment considerations for fixed wireless access. Whitepaper, June 2005. Available at http://www.wimaxforum.org/news/downloads (link checked 21.12.2006)

[64] Erceg, V. et.al, Channel Models for Fixed Wireless Applications. IEEE 802.16 Broadband Wireless Access Working Group, June 2003. Available at http://www.ieee802.org/16/tga/docs/80216a-03_01.pdf (link checked 21.12.2006)

[65] Erceg, V. et.al, An empirically based path loss model for wireless channels in suburban environments. IEEE Journal on Selected Areas in Communications, Vol. 17, Issue 7, July 1999, pp. 1205–1211.

[66] Abhayawardhana, V. S., Wassell, I. J., Crosby, D., Sellars, M. P. & Brown, M. G., Comparison of empirical propagation path loss models for fixed wireless access systems. Proc. of IEEE 61st Vehicular Technology Conference VTC 2005-Spring, May–June 2005. Vol. 1. Pp. 73–77.

[67] Walden, M. C. & Rowsell, F. J., Urban propagation measurements and statistical path loss model at 3.5 GHz. Proc. of IEEE Antennas and Propagation Society International Symposium 2005, July 2005. Vol. 1A. Pp. 363–366.

[68] Hong, C. L., Wassell, I. J., Athanasiadou, G., Greaves, S. & Sellars, M. Wideband channel measurements and characterisation for broadband wireless access. Proc. of 12th International Conference on Antennas and Propagation ICAP 2003, March–April 2003. Vol. 1. Pp. 429–432.

[69] Siqueira, G. L., Ramos, G. L. & Vieira, R. D. Propagation measurements of a 3.5 GHz signal: path-loss and variability studies. Proc. of 2001 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference IMOC 2001, August 2001.Vol. 1. Pp. 209–212.

[70] Plitsis, G. Coverage prediction of new elements of systems beyond 3G: the IEEE 802.16 system as a case study. Proc. of IEEE 58th Vehicular Technology Conference VTC 2003-Fall, October 2003. Vol. 4. Pp. 2292–2296.

[71] Chia Leong Hong, Wassell, I. J., Athanasiadou, G. E., Greaves, S. & Sellars, M. Wideband tapped delay line channel model at 3.5 GHz for broadband fixed wireless access system as function of subscriber antenna height in suburban environment. Proc. of 2003 Joint Conference of the Fourth International Conference on Information, Communications and Signal Processing 2003 and the Fourth Pacific Rim Conference on Multimedia, December 2003. Vol. 1. Pp. 386–390.

[72] Crosby, D., Abhayawardhana, V. S., Wassell, I. J., Brown, M. G. & Sellars, M. P. Time variability of the foliated fixed wireless access channel at 3.5 GHz. Proc. of IEEE 61st Vehicular Technology Conference, VTC 2005-Spring, May–June 2005. Vol. 1. Pp. 106–110.

[73] Hong, C. L., Wassell, I. J., Sellars, M. P., Greaves, S. D. & Noakes, M. Switchable-polarisation antenna for measuring polarisation dependence of multipath in 3.5 GHz FWA systems. Electronic Letters, Vol. 41, Issue 4, February 2005, pp. 164–165.

[74] Jeong, K. et al. Multipath channel models for wireless local and metropolitan area networks. Proc. of 3rd International Conference on Information Technology and Applications ICITA 2005, July 2005. Vol. 2. Pp. 295–298.

[75] Goerner, S., Ahrens, A., Rockmann, R., Jaeckel, K. & Schiffel, R. Measurement and modelling of a radio channel for wireless local loop applications. Proc. of 4th International Workshop on Mobile and Wireless Communications Network 2002, September 2002. Pp. 510–514.

[76] Chi Yung Ho, Kwok, T., Kiu Lam & Van Nguyen Tran. Third generation wireless signal profiling. Proc. of IEEE Radio Frequency Integrated Circuits (RFIC) Symposium 2003, June 2003. Pp. 539–542.

[77] Chen, Y. H. & Hsieh, K. L. A dual least-square approach of tuning optimal propagation model for existing 3G radio network. Proc. of IEEE 63rd Vehicular Technology Conference VTC 2006-Spring, May 2006. Vol. 6. Pp. 2942–2946.

[78] Zhenyu Wang, Tameh, E. K. & Nix, A. R. Statistical peer-to-peer channel models for outdoor urban environments at 2 GHz and 5 GHz. Proc. of IEEE 60th Vehicular Technology Conference VTC2004-Fall, September 2004. Vol. 7. Pp. 5101–5105.

[79] St Michael, H. & Otung, I. Characterization and prediction of excess attenuation of microwave radio signals by vegetation forms. Proc. of 12th International Conference on Antennas and Propagation, ICAP 2003, March–April 2003. Vol. 2. Pp. 637–640.

[80] Maciel, L. R., Bertoni, H. L. & Xia, H. N. Unified approach to prediction of propagation over buildings for all ranges of base station antenna height. IEEE Transactions on Vehicular Technology, Vol. 42, Issue 1, February 1993, pp. 41–45.

[81] Zhai Mingyue & Li Hua. New space-time wireless channel model and its computer simulation method. Proc. of IEEE 60th Vehicular Technology Conference VTC2004-Fall, September 2004. Vol. 1. Pp. 1–5.

[82] Mahmoud, S., Hussain, Z. M. & O'Shea, P. A multipath mobile channel model for microcell environment. Proc. of IEEE Eighth International Symposium on Spread Spectrum Techniques and Applications 2004, August–September 2004. Pp. 87–91.

[83] Foo, S. E., Tan, C. M. & Beach, M.A. Spatial temporal characterization of UTRA FDD channels at the user equipment. Proc. of 57th IEEE Semiannual Vehicular Technology Conference VTC 2003-Spring, April 2003. Vol. 3. Pp. 793–797.

[84] Conrat, J.-M. & Pajusco, P. Clusterization of the propagation channel in urban macrocells at 2 GHz. Proc. of The European Conference on Wireless Technology 2005, October 2005. Pp. 39–42.

[85] Fugen, T., Maurer, J., Sorgel, W. & Wiesbeck, W. Characterization of multipath clusters with ray-tracing in urban MIMO propagation environments at 2 GHz. Proc. of IEEE Antennas and Propagation Society International Symposium 2005, July 2005. Vol. 3B. Pp. 410–413.

[86] ITU-R P.1238-3 Recommendation: Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 900 MHz to 100 GHz, April 2003.

[87] ITU-R P. 1411-2 Recommendation: Propagation data and prediction methods of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz, April 2003.

[88] ITU-R M.1225 Recommendation: Guidelines for the evaluation of radio transmission technologies for IMT-2000, February 1997.

[89] Zvanovec, S., Pechac, P. & Klepal, M. Wireless LAN networks design: site survey or propagation modelling. Radioengineering Vol. 12, No. 4, December 2003, pp. 42–49.

[90] Lim, J., Shin, Y. & Yook, J. Experimental performance analysis of IEEE802.11a/b operating at 2.4 and 5.3GHz. Proceedings of 10th Asia-Pacific conference on communications, 2004, pp. 133–136.

[91] Zhao, X., Rautiainen, T., Kalliola, K. & Vainikainen, P. Path-loss models for urban microcells at 5.3 GHz. IEEE Antennas and wireless propagation letters, Vol. 5, 2006, pp. 152–154.

[92] Almers, P. Survey of Channel and Radio Propagation Models for Wireless MIMO Systems. Network-of-excellence for Wireless Communications (NEWCOM), Draft, May 2006. Available at http://www.amadeus.eurecom.fr/SurveyMIMOmodels_submitted.pdf (link checked 21.12.2006).

[93] Oestges, C., Erceg, V. & Paulraj, A. J. A physical scattering model for MIMO macrocellular broadband wireless channels. IEEE Journal on Selected Areas in Communications, Vol. 21, Issue 5, June 2003, pp. 721–729.

[94] Holma, H. & Toskala, A. WCDMA for UMTS. John Wiley & Sons, 2002.

[95] Laiho, J., Wacker, A. & Novosad, T. (eds) Radio Network Planning and Optimization for UMTS. John Wiley & Sons, 2002.

[96] 3GPP, 3rd Generation Partnership Project Technical Specification Group Radio Access Network, "Spatial channel model for Multiple Input Multiple Output (MIMO) simulations (Release 6)," 3GPP TR 25.996, September 2003.

[97] Anderson, H. R. Fixed Broadband Wireless System Design. John Wiley & Sons, 2003.

[98] IEEE 802.20-PD-08. 802.20 Channel Models Document for IEEE 802.20 MBWA System Simulations – 802.20-PD-08. September 2005. Available at http://www.ieee802.org/20/P_Docs/IEEE_802.20-PD-08.doc (link checked 21.12.2006).

[99] COST231, Damasso, E. & Correia, L. M. (editors) Digital Mobile Radio towards Future Generation Systems, Final Report. COST Telecom Secretariat, Brussels, Belgium, 1999.

[100] Molisch, A., et. al. IEEE 802.15.4a channel model – final report, revision 1. IEEE 802.15-04/662r0, Nov. 2004, 40 p, IEE, USA, [cited Dec 19th, 2006] www.ieee802.org/15/pub/04/15-04-0662-02-004a-channel-model-final-report-r1.pdf

[101] Foerster, J. Channel modelling sub-committee; Final report. IEEE P802.15-02/490r1-SG3a, Mar 2003, p. 52.

[102] Cassioli, D., Win, M.Z. & Molisch, A.F. The ultra-wide bandwidth indoor channel: from statistical model to simulations. IEEE Journal on Selected Areas in Communications. Special Issue on Channel and Propagation Models for Wireless System Design, 20(6)2002, pp. 1247–1257.

[103] Chong, C.-C. & Yong, S. K. A statistical based UWB multipath model for indoor environments WPAN applications. Proc. of the IEEE 16th Int. Symposium on Personal, Indoor and Mobile Radio Communications. Pp. 916–920.

[104] Haneda, K., Takada, J. & Kobayashi, T. Cluster properties investigated from a series of ultrawideband double directional propagation measurements in home environments. IEEE Transactions on Antennas and Propagation, Vol. 54, No. 12, December 2006.

[105] Di Renzo, M. et. al. The ultra-wide bandwidth outdoor channel: From measurement campaign to statistical modelling. Mobile Netw Appl 2006, 11, pp. 451–567.

[106] 3GPP TSG RAN WG4 Tdoc R4-050854. Spatial radio channels for systems beyond 3G. August–September 2005. Available at ftp://ftp.3gpp.org/ (link checked 10.01.2007).

[107] Asplund, H., Medbo, J., Göransson, B, Karlsson, J. & Sköld, J. A simplified approach to applying the 3GPP spatial channel model. Proc. of IEEE 17th International Symposium on Personal, Indoor and Mobile Radio Communications 2006, September 2006. Pp. 1–5.

[108] Zimmermann, D., Baumann, J., Layh, M., Landstorfer, F., Hoppe, R. & Wölfle, G. Database Correlation for Positioning of Mobile Terminals in Cellular Network using Wave Propagation Models. in Proc. IEEE 60th VTC, 2004, vol. 7, pp. 4682–4686.

[109] Juurakko, S. & Backman, W. Database Correlation Method with Error Correction for Emergency Location. In Proc Wireless Personal Communications, Vol. 30, No: 2–4 (2004), pp. 183–194.

[110] Lattunen, A., Pajunen, J., Kemppi, P. & Yanli Li. Measurement Tool for Multi-Network Fingerprint based Positioning. In Proc 15th IST Mobile Summit, Myconos, Greece, 2006.

[111] Backman, W. & Hjelt, A. Propagation Modelling in All-IP Networks and Other Scenarios. Research Report, T1DAIMON, December 2006.

[112] Xiaoyan Li & Martin, R.P. A simple ray-sector signal strength model for indoor 802.11 networks. In: Mobile Adhoc and Sensor Systems Conference, 2005. IEEE International Conference, 7–10 Nov. 2005.

[113] Gammu.org wiki, *www.gammu.org*

[114] NAVSTAR Global Positioning System, http://gps.faa.gov/GPSbasics/index.htm

[115] GALILEO, http://ec.europa.eu/dgs/energy_transport/galileo/index_en.htm

[116] GPS Modernization, http://gps.faa.gov/gpsbasics/GPSmodernization-text.htm

[117] Pseudolite, http://en.wikipedia.org/wiki/Pseudolite

[118] World's first mobile phone with Zigbee, http://www.3g.co.uk/PR/December2004/8787.htm

[119] World's first mobile WiMAX smart phone, http://www.hexus.net/content/item.php?item=5084

[120] Samsung's UWB phone, http://www.gizmodo.com/gadgets/tag/samsungs-uwb-phone-34469.php

[121] Laitinen, H., Lähteenmäki, J. & Nordström, T. Database Correlation Method for GSM Location. In Proc 53rd IEEE Vehicular Technology Conference (VTC 2001 Spring), Rhodes, Greece, May 6–9, 2001.

[122] Ahonen, S. & Laitinen, H. Database Correlation Method for UMTS Location. In Proc 57th IEEE Vehicular Technology Conference (VTC 2003 Spring), Jeju, Korea, April 22–25, 2003.

[123] Kemppi, P. & Nousiainen, S. Database Correlation Method for Multi-System Positioning. In Proc 63rd IEEE Vehicular Technology Conference (VTC 2006 Spring), Melbourne, Australia, May 7–10, 2006.

[124] Youssef, M., Agrawala, A. & Shankar, A.U. WLAN Location Determination via Clustering and Probability Distributions. In Proc IEEE PerCom2003, 2003.

[125] Wertz, P., Wölfe, G., Hoppe, R., Zimmermann, D. & Landstorfer, F.M. Enhanced Localization Technique within Urban and Indoor Environments based on Accurate and Fast Propagation Models. In Proc. European Wireless Conference, 2002.

[126] Youssef, M. & Agrawala, A. On the Optimality of WLAN Location Determination Systems. In Tech. Rep. UMIACS-TR 2003-29, and CS-TR 4459, University of Maryland. College Park, 2003.

[127] Bahl, P., Padmanabhan, V. & Balachandran, A. A Software System for Locating Mobile Users: Design, Evaluation, and Lessons. In Microsoft Research Technical Report, April 2000.

[128] Youssef, M., Agrawala, A. & Shankar, A.U. A Probabilistic Clustering-Based Indoor Location Deternimation System. In Technical Report UMIACS-TR 2002-30 and CS-TR 4350, University of Maryland, College Park, 2002.

[129] Evennou, F., Marx, F. & Novakov, E. Map-aided Indoor Mobile Positioning System using Particle Filter. In Proc WCNC 2005, 2005.

[130] Otsason, V., Varshavsky, A., LaMarca, A. & de Lara, E. Accurate GSM Indoor Localization. In: Beigl, M., Intille, S.S., Rekimoto, J., Tokuda, H., eds. Ubicomp. Volume 3660 of Lecture Notes in Computer Science, Springer, 2005. Pp. 141–158.

[131] Elnahrawy, E., Li, X. & Martin, R.P. The Limits of Localization Using Signal Strength: A Comparative Study. In Proc First IEEE International Conference on Sensor and Ad hoc Communications and Networks (SECON), 2004.

[132] Hatami, A. & Pahlavan, K. A comparative performance evaluation of RSS-based positioning algorithms used in WLAN networks. In: Proc Wireless Communications and Networking Conference, 2005, Vol. 4. Pp. 2331–2337.

[133] Yamasaki, R., Ogino, A., Tamaki, T., Uta, T., Matsuzawa, N. & Kato, T. TDOA location system for IEEE 802.11b WLAN. In: Proc Wireless Communications and Networking Conference, 2005, Vol. 4. Pp. 2338–2343.

[134] Kotanen, A., Hannikainen, M., Leppakoski, H. & Hamalainen, T.D. Experiments on local positioning with Bluetooth. In: Proc ITCC2003, 2003. Pp. 297–303.

[135] Bandara, U., Hasegawa, M., Inoue, M., Morikawa, H. & Aoyama, T. Design and implementation of a Bluetooth signal strength based location sensing system. In: Proc Radio and Wireless Conference, 2004. Pp. 319–322.

[136] Aalto, L., Göthlin, N., Korhonen, J. & Ojala, T. Bluetooth and WAP Push-Based Location-Aware Mobile Advertising System. In: Proc 2nd Int'l Conf. Mobile Systems, Applications, and Services (MobiSys04), ACM Press, 2004. Pp. 49–58.

[137] Koponen, R., Jäppinen, P. & Porras, J. Utilization of Predictive Bluetooth Network for Implementation of Location-Aware Guidance System. In: Proc WAWC'04, 2004.

[138] Hallberg, J., Nilsson, M. & Synnes, K. Positioning with Bluetooth. In: Proc 10th International Conference on Telecommunications, 2003. Vol. 2. Pp. 954–958.

[139] Feldmann, S., Kyamakya, K., Zapater, A. & Lue, Z. An indoor Bluetooth-based positioning system: concept, implementation and experimental evaluation. In: Proc ICWN'03, 2003.

[140] Cardinali, R. et. al. UWB ranging accuracy in high- and low-data-rate applications. IEEE Trans. on microwave theory and techniques, Vol. 54, No. 4, pp. 1865–1875.

[141] Chu, Y. & Ganz, A. A UWB-based 3D location system for indoor environments. In: Proc 2nd Int. Conf. On broadband networks, Oct. 2005, pp. 1147–1155.

[142] Wann, C. et al. Hybrid TDOA/AOA indoor positioning and tracking using extended kalman filters. In: Proc IEEE Vehicular Technology Conference, 2006. Pp. 1058–1062.

[143] Chon, H.D., Jun, S., Jung, H. & An, S.W. Using RFID for Accurate Positioning. In: Proc. GNSS2004, 2004.

[144] Willis, S. & Helal, S. A Passive RFID Information Grid for Location and Proximity Sensing for the Blind User. Technical Report number TR04-009, University of Florida, http://www.cise.ufl.edu/tech_reports/tr04/tr04-009.pdf

[145] Hähnel, D., Burgard, W., Fox, D., Fishkin, K. & Philipose, M. Mapping and Localization with RFID Technology. In: Proc 2004 IEEE International Conference on Robotics & Automation, New Orleans, LA, April 2004.

[146] Rabinowitz, M. & Spilker, J. A New Positioning System Using Television Synchronization Signals. In: Rosum IEEE transactions on broadcasting, 2005. Vol. 51. Pp. 51–61.

[147] Krumm, J., Cermak, G. & Horvitz, E. RightSPOT: A Novel Sense of Location for a Smart Personal Object. UbiComp, 2003.

[148] Priyantha, N.B., Chakraborty, A. & Balakrishnan, H. The cricket location-support system. In: Proc MOBICOM 2000, 2000. Pp. 32–43.

[149] Hii, P. & Zaslavsky, A. Improving Location Accuracy by Combining WLAN Positioning and Sensor Technology. In: Proc REALWSN'05, 2005.

[150] Want, R., Hopper, A., Falcao, V. & Gibbons, J. The active badge location system. In: Proc ACM T. on Information Systems, 1992, Vol. 10, No. 1, pp. 91–102.

[151] AeroScout, http://www.aeroscout.com/

[152] Ekahau, http://www.ekahau.com

[153] PanGo, http://www.pangonetworks.com/

[154] Skyhook Wireless, http://www.skyhookwireless.com/

[155] Navizon, http://www.navizon.com/

[156] Cambridge Positioning Systems Limited, http://www.cursor-system.com

[157] Intel Research, http://www.intel.com/research/index.htm

[158] NAVIndoor, http://www.ssf.fi/products/data/attachments/NAVIndoor_sheet.pdf

[159] Ubisense, http://www.ubisense.net/

[160] Sapphire DART, http://www.multispectral.com/

[161] Parco, http://www.parcomergedmedia.com

[162] BlueLon, http://www.bluelon.com/

[163] IndoorGPS, http://www.globallocate.com/

[164] Rosum, http://www.rosum.com/

[165] Yanli Li. A Database-driven XML-based Application on mobile Devices. Master's thesis, Dept. of Computer Science and Engineering, Helsinki University of Technology, May 2005.

Published by

Series title, number and report code of publication

VTT Research Notes 2376
VTT–TIED–2376

Author(s)
Raatikainen, Pertti (ed.)

Title
Design Issues in All-IP Mobile Networks

Abstract
The report summarises the results of the "Design of All-IP mobile network" (DAIMON) project, whose objective was to develop new networking technology solutions for an All-IP mobile network. The presented results form a complete concept for a future All-IP mobile system. The concept addresses both, the technical problems and social implications of such a system. The technical part focuses mainly on the radio propagation issues, radio resource management, services and QoS, positioning and heterogeneity. All addressed problems have been analysed from the user's and network's perspective. Several new methods and solutions, related to the above mentioned research areas, have also been developed and utilised in the project and are presented in this report.

ISBN
978-951-38-6928-1 (soft back ed.)
978-951-38-6929-8 (URL: http://www.vtt.fi/publications/index.jsp)

Series title and ISSN
VTT Tiedotteita – Research Notes
1235-0605 (soft back edition)
1455-0865 (URL: http://www.vtt.fi/publications/index.jsp)

Project number
4127

Date	Language	Pages
June 2007	English	136 p.

Name of project
DAIMON

Commissioned by

Keywords
Mobile networks, wireless telecommunication, All-IP, networking technology, resource management, services, positioning, quality of service, network dependability, propagation models

Publisher
VTT Technical Research of Finland
P.O.Box 1000, FI-02044 VTT, Finland
Phone internat. +358 20 722 4404
Fax +358 20 722 4374

VTT RESEARCH NOTES 2376 Design Issues in All-IP Mobile Networks

VTT Tiedotteita – Research Notes

2368 Technology roadmap of security research. Rouhiainen, Veikko (ed.). 2007. 33 p.

2369 Googlen mainokset ja muita sosiaalisen median liiketoimintamalleja. Kangas, Petteri, Toivonen, Santtu & Bäck, Asta (toim.). 2007. 59 s.

2370 Huhta, Hanna-Kaisa, Rytkönen, Jorma & Sassi, Jukka. Estimated nutrient load from waste waters originating from ships in the Baltic Sea area. 2007. 58 p. + app. 13 p.

2371 TBT-BAT MANUAL – Organotinapitoisten sedimenttien ruoppaus ja käsittely. Menettelytapaohje. Vahanne, Pasi & Vestola, Elina (toim.). 2007. 76 s. + liitt. 3 s.

2372 Nylund, Nils-Olof, Erkkilä, Kimmo & Hartikka, Tuukka. Kaupunkibussien polttoaineen kulutus ja pakokaasupäästöt. Uusimman dieseltekniikan suorituskyky. 2007. 47 s. + liitt. 1 s.

2373 Nylund, Nils-Olof, Erkkilä, Kimmo & Hartikka, Tuukka. Fuel consumption and exhaust emissions of urban buses. Performance of the new diesel technology. 2007. 48 p. + app. 1 p.

2374 Wessberg, Nina. Ympäristöturvallisuus. Ympäristöriskien arvioinnin osaaminen ja haasteet. 2007. 38 s. + liitt. 8 s.

2375 Oksman, Virpi, Noppari, Elina, Tammela, Antti, Mäkinen, Maarit & Ollikainen, Ville. News in mobiles. Comparing text, audio and video. 2007. 37 p.

2376 Design Issues in All-IP Mobile Networks. Raatikainen, Pertti (ed.). 2007. 136 p.

2377 Holopainen, Riikka, Hekkanen, Martti, Hemmilä, Kari & Norvasuo, Markku. Suomalaisten rakennusten energiakorjausmenetelmät ja säästöpotentiaalit. 2007. 104 s. + liitt. 2 s.

2378 Tallgren, Markus, Pihlajamaa, Olli & Törönen, Juha. Ubiquitous Customer Loyalty Services. Technology and Market Outlook. 2007. 77 p. + app. 52 p.

2379 Paiho, Satu, Ahlqvist, Toni, Lehtinen, Erkki, Laarni, Jari, Sipilä, Kari, Ala-Siuru, Pekka & Parkkila, Tommi. Talotekniikan kehityslinjat. Teknologiat ja markkinat. 2007. 55 s. + liitt. 60 s.

2381 Hirvonen, Juhani, Sallinen, Mikko, Maula, Hannu & Suojanen, Marko. Sensor Networks roadmap. 2007. 47 p.

2382 Cronvall, Otso, Männistö, Ilkka & Simola, Kaisa. Development and testing of VTT approach to risk-informed in-service inspection methodology. 2007. 43 p.

2383 Hakkarainen, Tuula. Talo- ja turvatekniikka tulipalotilanteessa. Nykytilanne ja tarvekartoitus. 2007. 55 s.

2384 Kangas, Petteri, Toivonen, Santtu & Bäck, Asta (eds.). ”Ads by Google” and other social media business models. 2007. 59 p.

2385 Löfman, Jari, Keto, Vesa & Mészáros, Ferenc. FEFTRATM. Verification. 2007. 103 p. + app. 4 p.

2386 Loikkanen, Torsti, Hyytinen, Kirsi & Koivusalo, Salla. Yhteiskuntavastuu ja kilpailukyky suomalaisyrityksissä. Nykytila ja kehitysnäkymät. 2007. 118 s.

2387 Henttonen, Katja. Stylebase for Eclipse. An open source tool to support the modeling of quality-driven software architecture. 2007. 61 p. + app. 15 p.

Julkaisu on saatavana	Publikationen distribueras av	This publication is available from
VTT	VTT	VTT
PL 1000	PB 1000	P.O. Box 1000
02044 VTT	02044 VTT	FI-02044 VTT, Finland
Puh. 020 722 4404	Tel. 020 722 4404	Phone internat. + 358 20 722 4404
Faksi 020 722 4374	Fax 020 722 4374	Fax + 358 20 722 4374

ISBN 978-951-38-6928-1 (soft back ed.)
ISSN 1235-0605 (soft back ed.)

ISBN 978-951-38-6929-8 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN 1455-0865 (URL: http://www.vtt.fi/publications/index.jsp)