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MOBILE SERVICE USAGE AND BUSINESS MODELS IN WIRELESS LOCAL AREA NETWORKS

Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Technology.

Espoo, 21 September 2009

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Abstract of the Master's Thesis

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Name of the Thesis:	Mobile Service Usage and Business Models in Wireless Local Area Networks		
Date:	21 September 2009	**Number of pages:**	12 + 103
Department:	Department of Communications and Networking		
Professorship:	Radio Communications		
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The usefulness of knowing end-user behavior is becoming important for all key players of the mobile industry (including mobile service providers, device manufacturers and mobile operators) in order to promote new mobile services and win customers in the highly competitive market. Here end-user behavior refers to when and where people use mobile devices, and for what purpose and which access technologies they use.

This thesis studies the end-user behavior by analyzing the data (using statistical and visualization tools available in *SPSS* and Excel) collected from Finnish panelists owning a Nokia phone based on the S60 platform. The results of the handset-based measurement analysis highlight the usage of different applications, the usage of different access networks (e.g. WCDMA, GPRS, EDGE and WLAN) and the daily data usage of WLAN and non-WLAN users with mobile handsets.

In addition to the handset-based measurement analysis, in this thesis, a system dynamics model is proposed (using Vensim PLE software) to study how network connectivity will be provided to indoor located devices in the future. The model is developed based on the scenarios for the future of the local area access provisioning and consists of four interrelated domains: *User (Demand) domain*, *Infrastructure (Supply) domain, Spectrum Regulation and Technology (Supply) domain* and *Market Share domain*. The domains focused on end-user dynamics, infrastructure dynamics, spectrum regulation and technology dynamics and market share dynamics, respectively. The main objective of developing the model is not to find and simulate exact numerical values but to gain a broad level of understanding about the dynamics of forces that affect the future of local area access provisioning.

The system dynamics model proposed in this thesis mainly addresses the question, "what are the possible evolution paths (business models) of the future of the local area access provisioning?" and highlight the dynamics of forces that influence the structure and development of network connectivity to indoor located devices over the next 6 years (2009-2015).

Keywords: Business Model, Local Area Access Provisioning, Mobile Service, System Dynamics

Acknowledgments

Thanks to Prof. Heikki Hämmäinen (TKK), Timo Smura (TKK), Thomas Casey (TKK), Klaus Hugl (NRC) and Antti Sorri (NRC).

Thanks to my colleagues from room F301, Antero Kivi, Antti Riikonen, Juuso Olli Aleksi Karikoski and Mikko Heikkinen.

Thanks to my friends Aftab, Adnan, Anzil, Aydin and others.

Thanks to William Martin, the faculty's language support specialist.

Special thanks to my family for supporting me during my studies.

Preface

This Master's Thesis has been written as a partial fulfilment for the Master of Science degree in Helsinki University of Technology. The work was carried out at the Department of Communications and Networking at the Helsinki University of Technology as a part of MOMI[1] project and in collaboration with Nokia Research Center (NRC).

Espoo, 21 September 2009

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[1] MOMI (Modeling of Mobile Internet Usage and Business) is an academic project of Helsinki University of Technology, Finland. MoMI takes a techno-economic standpoint on the evolution of the mobile service market.

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Abbreviations

2G	*Second Generation*
3G	*Third Generation*
3GPP	*Third Generation Partnership Project*
4G	*Fourth Generation*
8-PSK	*8 Phase Shift Keying*
AMPU	*Average Margin Per User*
AP	*Access Point*
ARPU	*Average Revenue Per User*
BS	*Base Station*
CDMA	*Code Division Multiple Access*
DSL	*Digital Subscriber Line*
EDGE	*Enhanced Data rates for Global Evolution*
ETSI	*European Telecommunications Standards Institute*
FDD	*Frequency Division Duplex*
GPRS	*General Packet Radio Service*
GSM	*Global System for Mobile communication*
HSDPA	*High Speed Downlink Packet Access*
HSPA	*High Speed Packet Access*
HSUPA	*High Speed Uplink Access*
HTML	*Hypertext Markup Language*
HW	*Hardware*
IEEE	*Institute of Electrical and Electronic Engineers*
LA	*Local Access*
LAN	*Local Area Network*
LTE	*Long Term Evolution*
MMS	*Multimedia Messaging Service*
MIMO	*Multiple Input Multiple Output*
NRC	*Nokia Research Center*
OFDMA	*Orthogonal Frequency Division Multiple Access*
OPEX	*Operating Expenditure*
PDA	*Personal Digital Assistant*

SC-FDMA	*Single Carrier - Frequency Division Multiple Access*
SD	*System Dynamics*
SMS	*Short Messaging Services*
SW	*Software*
TDMA	*Time Division Multiple Access*
UMA	*Universal Mobile Access*
UMTS	*Universal Mobile Telecommunications System*
UNC	*UMA Network Controller*
WA	*Wide Area*
WAP	*Wireless Application Protocol*
WCDMA	*Wideband Code Division Multiple Access*
WEP	*Wired Equivalent Privacy*
Wi-Fi	*Wireless Fidelity*
WLAN	*Wireless Local Area Network*
WPA	*Wi-Fi Protected Access*
WPA-PSK	*WPA - Pre - Shared key*

1 Introduction

In this chapter, first the motivation of the research is discussed. After that the research questions and objectives are presented, along with the scope and the methods used in the thesis. Finally, an outline of the thesis structure is presented.

1.1 Motivation

The global mobile industry is showing a truly stunning progress after the introduction of third-generation wireless technologies (e.g. 3G) and IEEE 802.11-based WLAN systems (e.g. Wi-Fi). Nowadays, mobile device ownership is no longer considered being a luxury item; rather it is considered being a necessity item. By the end of 2013, the global mobile industry is expected to see more than 5.3 billion mobile subscriptions, according to a recent study (Informa, 2008). In the developed countries, the penetration of mobile subscriptions already exceeds 100%, so the focus is shifting from subscription growth to revenue generation and improvements in average revenue per user (ARPU) and average margin per user (AMPU). The subscription growth in the developing countries, particularly in China and India, will continue to increase tremendously.

An increase in mobile subscriptions means the mobile service usage can grow, which causes the mobile service industry to grow rapidly in the number of mobile services. There are various key factors which affect the growth of mobile services; some of them are – consumer (end-user) behavior, technological progress and regulatory actions to induce higher level of competition between services.

Consumer behavior: The usefulness of knowing end-user behavior is becoming important for all key players of the mobile industry (including mobile service providers, device manufacturers and mobile operators) in order to promote new mobile services and sustain themselves in a rapidly expanding and competitive mobile services market. Here end-user behavior refers to when and where people use mobile devices and for what purpose. One method of studying the end-user behavior is collecting data from mobile devices (using different data collection mechanisms) and analyzing the collected data (using various tools).

Technological progress: Currently, there are two main types of technologies that provide network connectivity to mobile devices. These are: 1) WLAN based local networks and systems which provide network connectivity to indoor located mobile devices (e.g. Wi-Fi), and 2) wide area networks using cellular technology which mainly provide network connectivity to both indoor and outdoor located mobile devices (e.g. 2G, 3G).

Nowadays, due to the rapid increase of mobile users, 2G/3G networks have become more congested which creates a problem in providing network coverage and high capacities especially in indoor locations such as offices, houses and public transportation stations. In order to solve this problem, network operators are focusing on indoor access solutions. 3G/HSPA and Wi-Fi indoor access points are among the solutions. However, there is considerable uncertainty about which solution will be deployed in the future. Therefore, one of the main questions regarding access provisioning to indoor located mobile devices is, “how will network connectivity to indoor located devices be provided in the future?”

The thesis studies how people (end-users) use mobile devices (especially indoor located devices) with different access technologies (e.g. WCDMA, GPRS, EDGE and WLAN). The study utilizes empirical data (collected at a panel attended by Finnish smartphone users) with statistical analysis methods. The thesis also explores how network connectivity is provided to indoor located devices in the future and proposes a system dynamics model for the future of the local area access provisioning.

1.2 Research questions and objectives

There are two key research questions in this thesis. These are:

1. *How do people use mobile devices (especially indoor located devices) with different access technologies?*
2. *How will network connectivity to indoor located devices be provided in the future?*

The main objectives of the thesis are:

- *To identify similarities and differences in mobile service usage between local (e.g. WLAN) and wide area networks (e.g. WCDMA, GPRS, EDGE and HSPA).*
- *To study the dynamics of forces that influence the structure and development of network connectivity to indoor located devices over the next 6 years (2009-2015) by applying the concept of system dynamics modeling.*

1.3 Scope

In the first research question, devices are limited to handsets in the Finnish mobile industry and markets, while the second research question includes all mobile and portable devices (e.g. handsets, PDAs, laptops, etc). However, we focus more on handsets and laptops since they are the key drivers of the rapid growth in network traffic. The study period of the future of the local area access provisioning is from 2009 to 2015.

1.4 Methodology

The research methods in the thesis include a literature review, handset-based mobile service usage measurement, system dynamics and brainstorming session.

A *literature review* is conducted to get an overall understanding of the mobile industry. Various definitions of mobile services, mobile applications and business models are discussed. The literature review includes both the technical and business background.

A *handset-based measurement platform* (developed for Nokia S60 class of mobile devices) is used to collect data from panels attended by Finnish smartphone users. The platform consists of a Symbian application monitoring software client which is installed in the mobile devices. The collected data is analyzed using statistical and visualization tools available in *SPSS* and *Excel.*

A method, called *system dynamics*, is used to understand the dynamics of forces that influence the structure and development of network connectivity to indoor located devices in the future. *Vensim PLE* software is used to implement a system dynamics model.

A *brainstorming session* is conducted to model the interactions of main forces related to local area access provisioning and to understand spectrum regulation interactions with the local area ecosystem.

1.5 Structure

The thesis is structured as follows:

- *Chapter 1* states the motivation, objectives and scope of the research as well as the methods and tools used in the thesis.
- *Chapter 2* discusses the technological progress (evolutionary path) in the mobile industry. In addition, it introduces the concept of mobile services, business models and value networks in the mobile industry.
- *Chapter 3* introduces the research methods used in the thesis. First the handset-based measurement method is introduced. After that an introduction to system dynamics is presented together with the modeling process and other elements used in the model construction for the future of the local area access provisioning. Finally, the brainstorming session is introduced which was held as a part of the model construction process.
- *Chapter 4* presents the results (e.g. usage of different applications, usage of different access networks, and daily data usage of WLAN and non-WLAN users) from handset-based measurement analysis.
- *Chapter 5* proposes a system dynamics model for the future of the local area access provisioning.
- *Chapter 6* discusses the conclusions from this research and makes recommendations for future work.

2 Overview of mobile industry

Year by year, the global mobile industry is showing a truly stunning progress. In addition to very fast market growth, the industry is experiencing rapid technological change. The average penetration rate of mobile subscriptions was 50.7% of the global population at the end of 2007. Total subscriptions are expected to rise to 5.32 billion by 2013 from 3.42 billion at the end of 2007 (Informa, 2008).

The rapid development of this industry is influenced by two major factors: *technological progress* and *regulation* (Gruber, 2005). The basic technological concept in the mobile industry is *radio spectrum,* necessary for transmission between the end-user and access points/base stations. Radio spectrum is a scarce resource so it should be utilized in an efficient manner (better *spectral efficiency*). Technological progress permits greater efficiency in spectrum usage which leads to better performance, capacity and quality of mobile communications, and, of course, a greater number of mobile subscriptions. The amount of spectrum allocated to the industry is determined by a regulatory body.

In the mobile industry, providing *coverage* is one of the primary tasks for mobile operators. The network coverage is provided by two types of technologies: *wide area network technologies,* such as *GSM* and *local area network technologies,* such as *Wi-Fi* technology.

In this chapter, first we introduce the technological progress (evolutionary path) of both wide area and local area network technologies. After that the concept of mobile services is discussed. Lastly the business models and value networks in the mobile industry are presented.

2.1 Evolution of wide area mobile network technologies

Figure 2.1 presents the evolution of wide area mobile network technologies from GSM (Global System for Mobile Communications) to GPRS (General Packet Radio Service) and to 3G (Third Generation) and to HSPA (High Speed Packet Access). Sandrasegaran (2002) stated that this evolution will manifest in the form of new techniques for modulation, multiaccess, multiplexing, radio resource management, mobility management, traffic management, parallel circuit and packet switched networks, compression, ciphering, authentication, handover, roaming, switching and transmission technologies, communication protocols, user terminals, services, etc.

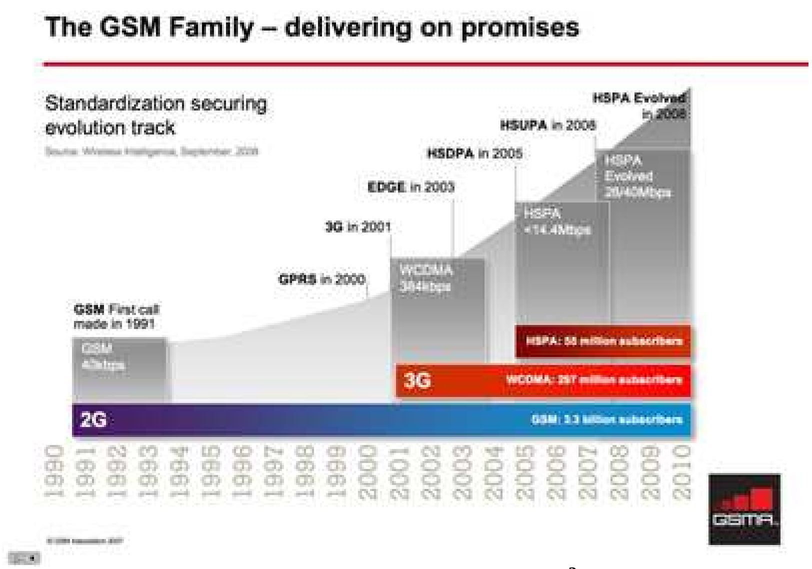

Figure 2.1 Evolution from 2G[2]

GSM (Global System for Mobile communications)

GSM is the European standard digital cellular phone system that supports voice calls and slow data transmission (up to 9.6 kbit/s), together with the transmission of SMS (Short Message Service). In Europe, GSM has been deployed at 900MHz and 1800MHz and using a TDMA radio propagation scheme. It also operates in 850MHz in Australia, Canada and many South American countries. Currently, 80% of the world's population is covered by terrestrial GSM networks[3]. In areas where terrestrial coverage is not available, access is provided by the GSM satellite roaming service.

GPRS (General Packet Radio Service)

GPRS is the second phase ETSI GSM specification for data-over-packet radio access. In contrast to GSM's dedicated-channel dial access, the GPRS radio interface supports shared-

[2] http://www.gsmworld.com/technology/hspa.htm [Accessed 08.08.2009]
[3] http://www.gsmworld.com/technology/gsm/index.htm [Accessed 08.08.2009]

media packet access. Existing GSM network infrastructures are used to deploy GPRS. However, new network elements are required to link the core mobile network to the public packet network. GPRS could provide data rates up to 40 kbit/s and can be used for services such as Wireless Application Protocol (WAP) access, Multimedia Messaging Service (MMS), and for Internet communication services such as e-mail and World Wide Web access.

EDGE (Enhanced Data rates for GSM Evolution)

EDGE provides further enhancements to GSM networks using enhanced modulation technique - the eight-phase shift key (8-PSK). It provides up to three times the data capacity of GPRS. Thus it allows the delivery of advanced, feature-rich data services such as the downloading of video and music clips, multimedia messaging, high-speed Internet access and e-mail on the move. EDGE is built on top of an existing GSM/GPRS networks. Only a simple software upgrade is required[4].

3G/WCDMA (Third Generation / Wideband Code Division Multiple Access)

WCDMA is the "UMTS standard for 3G digital mobile networks, using CDMA technology. It is the evolution path for GSM and EDGE to UMTS and offers increased voice capacity and theoretical peak data speeds of up to 2 Mbps" (Gartner, 2008). In addition to voice, text and MMS services, it supports richer mobile multimedia services such as music, TV and video, entertainment content and Internet access[5].

HSPA (High Speed Packet Access)

HSPA is an evolution of WCDMA and uses the FDD transmission scheme. It improves downlink and uplink data speeds by using HSDPA (High Speed Downlink Packet Access) and HSUPA (High Speed Uplink Packet Access). The theoretical maximum downlink and uplink reach 14.4 Mbps and 5.7 Mbps, respectively[6]. HSPA has the high capability for providing efficient voice and data services that many other mobile broadband technologies do not have.

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[4] http://www.gsmworld.com/technology/edge.htm [Accessed 10.08.2009]
[5] http://www.gsmworld.com/technology/3gsm/index.htm [Accessed 10.08.2009]
[6] http://www.gsmworld.com/technology/hspa.htm [Accessed 11.08.2009]

LTE (Long Term Evolution)

LTE is an evolution of HSPA. It includes objectives "such as 100 Mbps download and 50 Mbps upload peak data rates in 20MHz of spectrum, full mobility to speeds of up to 500 km per hour, support for 3G network overlay and handovers between 3G and LTE" (Gartner, 2008). LTE uses MIMO (Multiple In Multiple Out), OFDMA (Orthogonal Frequency Division Multiple Access) and single carrier frequency division multiple access (SC-FDMA) in the link layers, and it is likely to be deployed over the next few years by several major mobile operators. The "Japanese mobile operator NTT DOCOMO has said that it is aiming to launch a commercial LTE network by the end of 2009, while in the U.S., the largest CDMA operator, Verizon Wireless, is currently trialing LTE with a view to launching a commercial LTE service in 2010"[7].

2.2 Emerging local area network technologies

Users on the go can use GSM/GPRS/EDGE/3G data services for connecting to the Internet with a wide network coverage. The data rates achievable are not very high, though. Wireless Local Area Networks (WLANs) are another alternative for building wireless networks with high data-transfer rates. However, the coverage of local area networks is limited to indoor locations such as offices, houses, public transportation stations, etc. In WLANs, there are high capacity radio networks with a small diameter, and so called *Access Points* connecting the local wireless networks to the network backbone.

WLANs are typically only access networks, providing no core network. They are *unlicensed networks*. This means that they are networks where the devices themselves need to be certified, but they can be installed and used without separate licenses from the authorities. The traditional cellular networks are *licensed networks*, and installing and operating them requires licenses from the authorities. As for licensed networks, the unlicensed networks operate on regulated radio frequency bands that have been reserved for

[7] http://www.gsmworld.com/technology/lte.htm [Accessed 12.08.2209]

use of specific unlicensed network types. WLAN networks are typically designed for radio access networks in small office or home environments.

Currently, IEEE 802.11 (Wi-Fi) is the most popular emerging local area network technology and expands through businesses, homes, and public hotspots very rapidly. It is a set of standards that can be used to connect computers and mobile devices to each other, to the Internet, and to wired networks (Figure 2.2). Wi-Fi networks operate in the unlicensed 2.4 GHz and 5 GHz radio bands and provide high speed data services.

Figure 2.2 Summary of IEEE 802.11 standards[8]

	802.11a	802.11b	802.11g	802.11n
Standard approved by IEEE	January 2000	December 1999	June 2003	December 2009[9]
Throughput (Mbps)	27	~5	~22	144
Maximum data rate (Mbps)	54	11	54	600
Different data rate configurations	8	4	12	576
Typical range (feet)	75	100	150	150
Modulation technologies	OFDM	DSSS,CCK	DSSS,CCK ,OFDM	DSSS,CCK,OFDM+
RF band (GHz)	5	2.4	2.4	2.4 and 5
Number of spatial streams and antennas	1	1	1	Up to 4
Channel width (MHz)	20	20	20	20 or 40
Number of channels	23	3	3	26

Wi-Fi may be thought of as similar to 3G since both are wireless access technologies and offer broadband data service. Though, it is completely different from 3G in issues such as business models/deployment, spectrum policy and management and stage of technology development (Lehr and McKnight, 2006).

A seamless connectivity between 3G and Wi-Fi can be supported by network architecture, called the UMA (Universal Mobile Access). UMA is the 3GPP global standard for

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[8] http://www.ddj.com/mobile/193500531?pgno=3 [Accessed 10.08.2009]
[9] http://grouper.ieee.org/groups/802/11/Reports/802.11_Timelines.htm [Accessed 10.08.2009]

providing access to the mobile service cores over IP-based networks thorough an interface, called the UMA Network Controller (UNC). Figure 2.3 presents the overview of UMA architecture. Mobile users, having a dual-mode handset, can roam and handover automatically between 3G and Wi-Fi access without any interruptions in services.

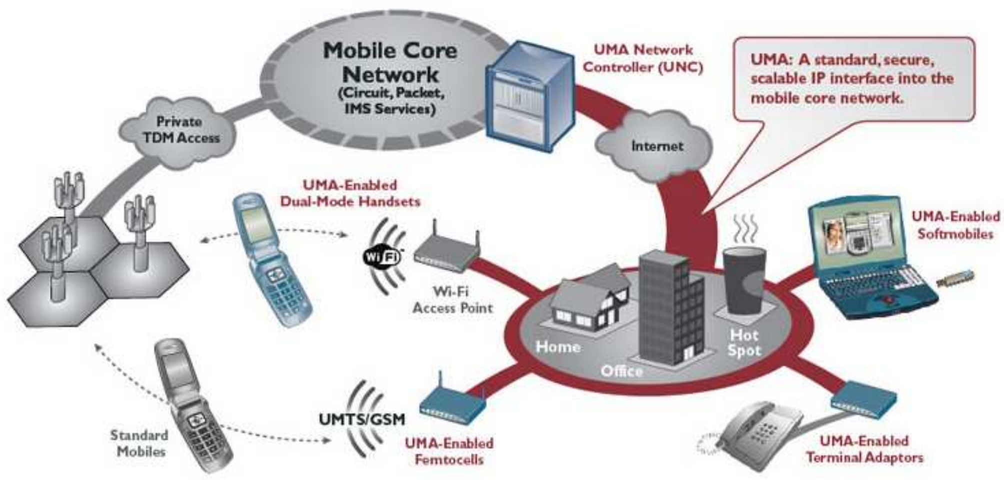

Figure 2.3 Overview of UMA architecture [10]

In addition to Wi-Fi indoor access points, there are also other indoor access solutions such as femtocell access points (Figure 2.4). “Femtocells are low-power wireless access points that operate in the licensed spectrum to connect standard mobile devices to a mobile operator’s network using residential DSL or cable broadband connections”[11]. They provide better quality voice and data services for indoor located users with lower cost than outdoor service (Chambers, 2008).

[10] http://www.umatoday.com/umaOverview.php [Accessed 10.08.2008]
[11] http://www.femtoforum.org/femto/index.php?id=46 [Accessed 10.08.2009]

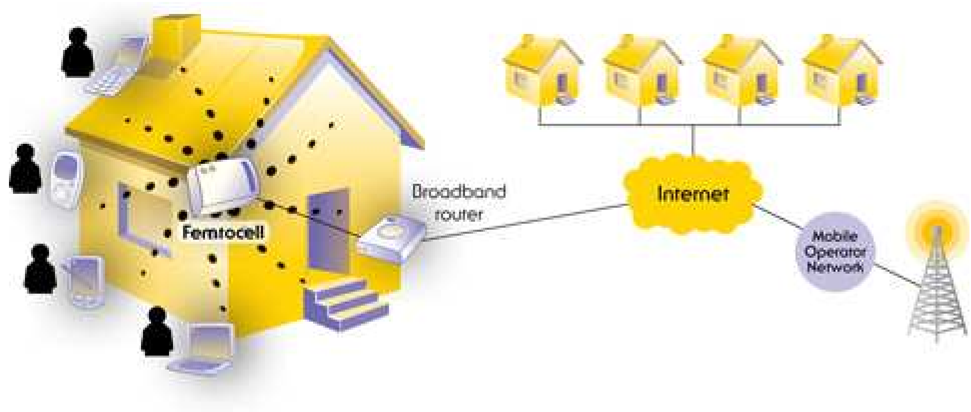

Figure 2.4 Overview of femtocell architecture[11]

Femtocell access points operate in a similar manner to 2G or 3G base stations. Though, broadband Internet is used as interface between femtocell access points and the mobile core network while the radio interface, called the lub interface, is used in case of 2G or 3G base stations. The rapid growth of wide area network traffic and the poor coverage of mobile services are likely to be the major market drivers for femtocell technology in the near feature. By 2011, worldwide, the number of femtocell product users and access points is expected to reach 102 million and 32 million[11], respectively.

2.3 Mobile services

Services are "activities or benefits offered for sale that are essentially intangible and do not result in the ownership of anything" (Kotler and Armstrong, 1996). In economics and marketing, services are generally referred to as the non-material equivalent of a good. There are two types of services; *core services* and *support services*. A core service is a service provider's main business, where as a support service makes the provision of core service more feasible and competitive. For instance, the core service of *Facebook*, the most famous of social networks, is connecting people with friends, families, partners and others while support services are, for instance, providing online games, advertising among other things.

A *mobile service* is defined in this thesis as the service that an end-user with a mobile device receives from the network operator or a 3rd party service provider. In this context, a mobile device means any handheld computing device that end-users employ for the purpose of data or voice communications. Some examples of mobile devices are basic phones, PDAs, portable media players, laptops and smartphones. Examples of mobile services include voice/video calls, SMS and MMS messages, access to content on web, e-mail, etc.

In order to deliver mobile services effectively, mobile phones require running sets of software referred to as *applications*. Verkasalo (2009) defined applications as "either network or handset-based pieces of software that run services". The common examples of mobile applications are Music Players, Logs, Calendars, Contacts and Handset Clocks. Contacts and Logs are used to browse phonebooks and to review logs about recent calls, call durations and packet data. In this thesis, sometimes the terms service and application are used interchangeably, for example, when we refer to voice/video calls. The reader may notice this in Sections 3 and 4.

2.4 Business models and value networks in the mobile industry

Before delving in to the business models and value networks in the mobile industry, various definitions of business model and value network are discussed.

Business model

Currently, a commonly accepted definition for a *business model* is inexistent. A wide diversity of understandings and usages of business model exist among people, especially between business-oriented and technology-oriented individuals. Osterwalder et al (2005) introduced business model as a conceptual tool containing the set of objects, concepts and their relationships with the objective to express the business logic of a specific firm. Another definition from Amit and Zott (2001) states it as a depiction of the content, structure, and governance of transactions designed so as to create value through the exploitation of business opportunities. Chesbrough and Rosenbloom (2002) propose that a business model is the method of doing business by which a company can sustain itself. Bouwman et al (2008) propose the following definition; "A business model is a blueprint for a service to be delivered, describing the service definition and the intended value for the target group, the sources of revenue, and providing an architecture for the service delivery, including a description of the resources required, and the organizational and financial arrangements between the involved business actors, including a description of their roles and the division of costs and revenues over the business actors". There is one similarity among all the four definitions, which is, emphasizing the description of a method which generates revenue (Heikkinen and Luukkainen, 2008). According to Sainio (2007), there are six common elements in the definition of business models, namely, source of revenues, strategy, activities, assets/resources, and value/benefit and value network. Table 2.1 summarizes the definitions of a business model by including its constituent elements.

Table 2.1 Elements included in the definition of business model (Sainio, 2007)

Definitions of business model:	Elements included in the definition: Source of revenues	Strategy	Activities	Assets/ resources	Value/ benefit	Value network
EXTERNAL PERSPECTIVE: "General vision or strategy" (Dickinson 2000)		x				
"Spells out how a company makes money" (Rappa 2000)	x					
"How inputs to an organization are transformed into value-adding outputs" (Betz 2002)		x				
"Wireless approach: the nature of interaction and the complexity of the value offering" (Lopperi 2002)					x	
INTERNAL PERSPECTIVE: "Unique combinations and proportions of a company's asset portfolio" (Boulton et al. 2000)				x	x	
"Organization of product, service and information flows, and the sources of revenue and benefits for customers" (Timmers 2000)	x		x		x	
"Unique combination of value stream, revenue stream and logistical stream" (Mahadevan 2000)	x		x		x	x
"Customer interface, core strategy, strategic resources and value network. (Hamel 2000)	x	x		x	x	x
"Entire system of delivering utility to customers and earning a profit" (Slywotzky 1996)	x	x	x	x	x	x

Value network

A value network can be defined as "relationships that generate economic value and other benefits through complex dynamic exchanges between two or more individuals, groups, or organizations"[12]. Organizations or stakeholders have their own roles. The

[12] http://www.vernaallee.com/value_networks/Understanding_Value_Networks.html [Accessed 12.08.2009]

traditional set of relationships which is mainly characterized by linear sequential dependencies is referred to as a *value chain*. In contrast to a value chain, the relationships in a value network are built in the form of parallel and interlinked tracks of different chains and systems. That means the value chain is based on the industrial age production line, and a value network can be considered as a set of value chains. For instance, let us consider the local access value network and perceive how the relationships are established.

The major stakeholders who are interested in indoor wireless access (local access) are end-users, device vendors, application service providers, service operators, network operators, network equipments vendors, regulators and policy-makers and site owners (Smura and Sorri, 2009). The role of each of these stakeholders is presented in Figure 2.5 (represented by ellipses). One stakeholder can take multiple roles or activities.

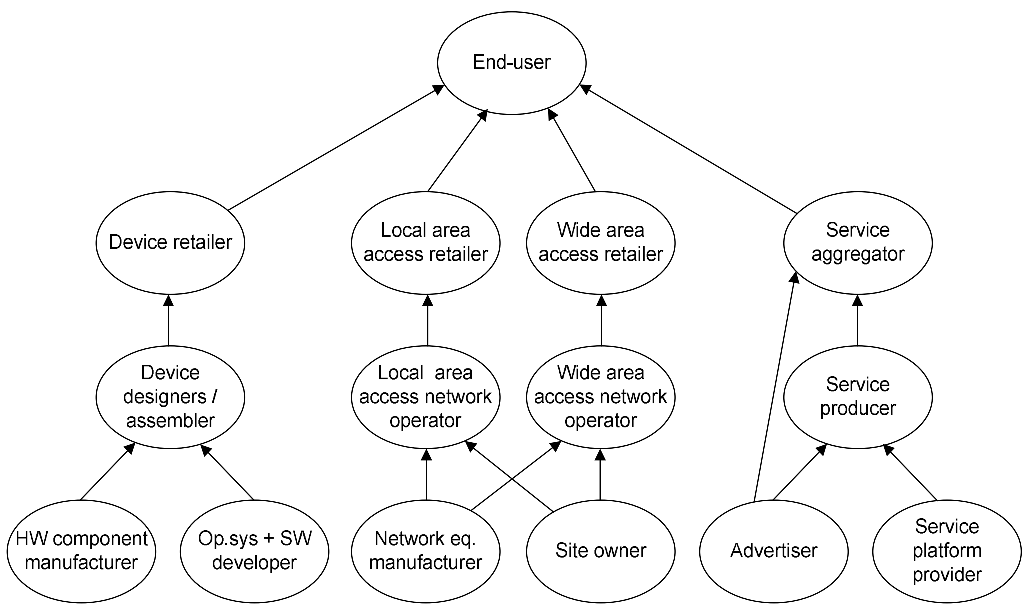

Figure 2.5 Major stakeholder in local access value network (Smura and Sorri, 2009)

The value network in Figure 2.5 consists of three distinct value chains, namely *device value chain, access provision value chain* and *service provisioning value chain* and each of them comprises a number of essential roles. Beginning with the device value chain, there are four identified essential roles: device retailers, device designers/assemblers, hardware (HW) component manufacturers, and operating system and software (SW) developers while there are six in the access provisioning value chain: local area access retailer, wide area access retailer, local area access network operator, wide area access network operator, network equipment manufacturers and site owners. And the last value chain includes service aggregators, service producers, service platform providers, and advertisers. Table 2.2 lists some examples of stakeholders and their roles.

Table 2.2 Examples of stakeholders and their roles

Stakeholder	**Example roles**	**Example of stakeholder**
Mobile operator	Wide area access network operator and access retailer, device retailer, service retailer	
Device vender	Device designer/assembler, operating system + SW developer, service aggregator and service provider	
Application service and content provider	Device operating systems and software(Google Android, Google mobile services)	

2.4.1 Current wide-area centric business model

Here the word *wide-area centric* simply refers to wide area mobile networks, such as 3G. According to the Yankee Group (2000), a mobile value network is consisting of five major, value chains. These are network transport, applications operation, content provisioning, payment processing and providing device solutions (Figure 2.6). The figure also presents the key stakeholders in each value chain (Ballon, 2004). In the figure, the arrows represent the relationships between the value chains.

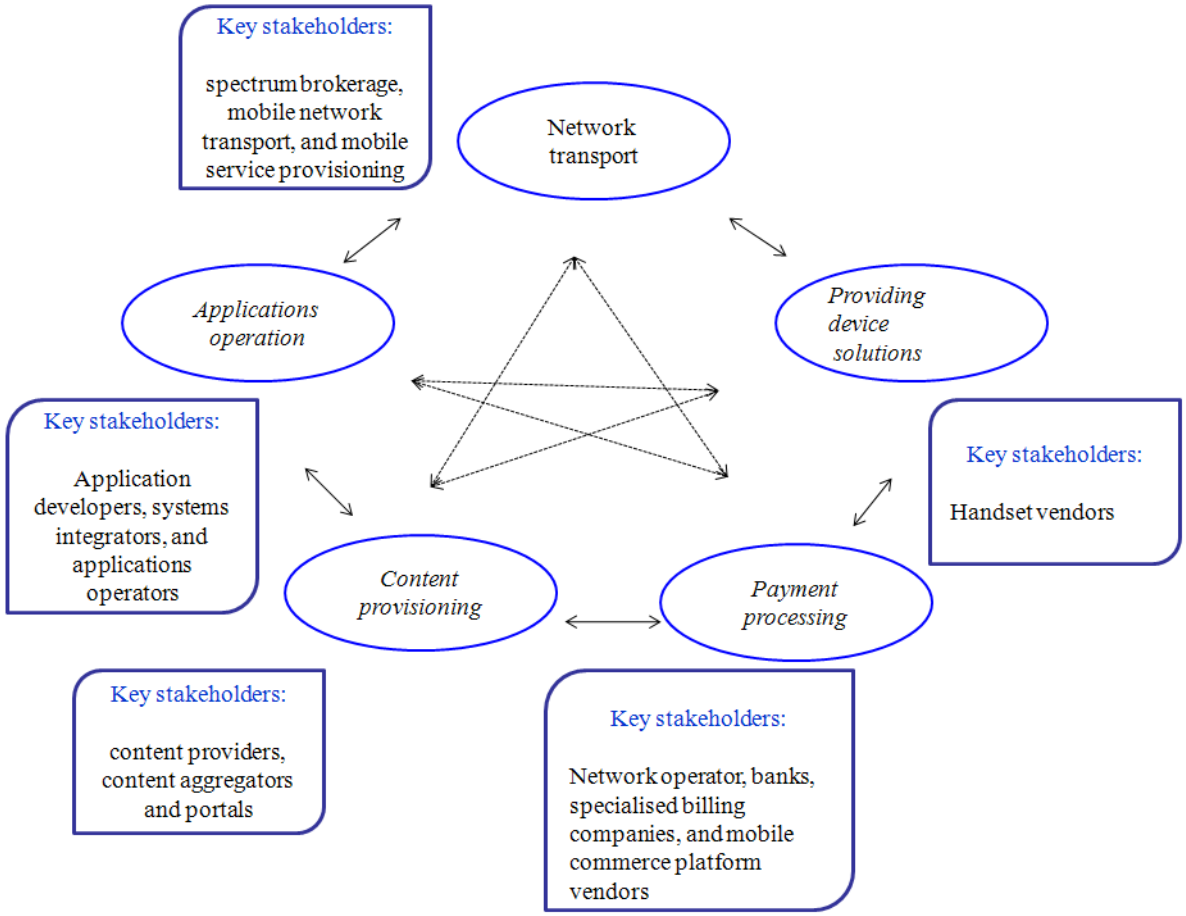

Figure 2.6 The five value chains with key stakeholders in the mobile value network

For 3G, three potential generic business models have been promoted by the UMTS Forum (2000), namely *network operator centric service provider*, *content aggregator/m-portal centric service provider* and *content provider centric service provider*. Each of these business models have different role which acts as the main service provider (Ballon, 2004).

In the first model, *network operator centric service provider*, there is a direct relationship between the customer and the network operator. The network operator has a role of setting the prices of services along with handling the payments. Content is offered by content providers or by the network operator itself. In many cases, services are bundled and sold as packages to end-customers. This business model helps network operators to improve ARPU and to keep customers.

In case of the *content aggregator/m-portal centric service provider* business model, the customer has a direct relationship with the content aggregator. The network operators may also have a relationship with the customer, though. In many cases, content charges might be separated from access charges.

The last business model, *content provider centric service provider,* is similar to the second model, except that "the content provider has a considerable portfolio of its own and wants to align itself with a network operator, and thus take up the content aggregator role" (Ballon, 2004). The customer has various options for receiving content. In this model, there is high level competition between services.

2.4.2 Local area business models

Smura and Sorri (2009) have put forward four potential business models for local area access provisioning. These business models are labelled as follows (Figure 2.7):

- *Pick-n-mix – Internet rules:* In this model, access and services are offered separately and various players provide different service components. Thus there is higher level of competition between services. Local access is separated from wide area access provisioning, and the number of local access operators and technologies is high, which introduces a higher level of competition between access technologies and networks. In this case, end-customers have many choices of both access and services.
- *Complete bundles – operator rules:* This model is the opposite of *Pick-n-mix – Internet rules.* End-customers buy bundled access and services, and local area access is provided by indigenous mobile (WA) operators. In this case, there are a low number of access technologies, and end-customers choose only between similar service bundles from established players.
- *Operators as bitpipes:* This model is similar to *Pick-n-mix – Internet rules,* except that established operators control the local access markets.
- *Internet giants:* This model is similar to *Complete bundles – operator rules,* except that access is bundled to service offerings in this case.

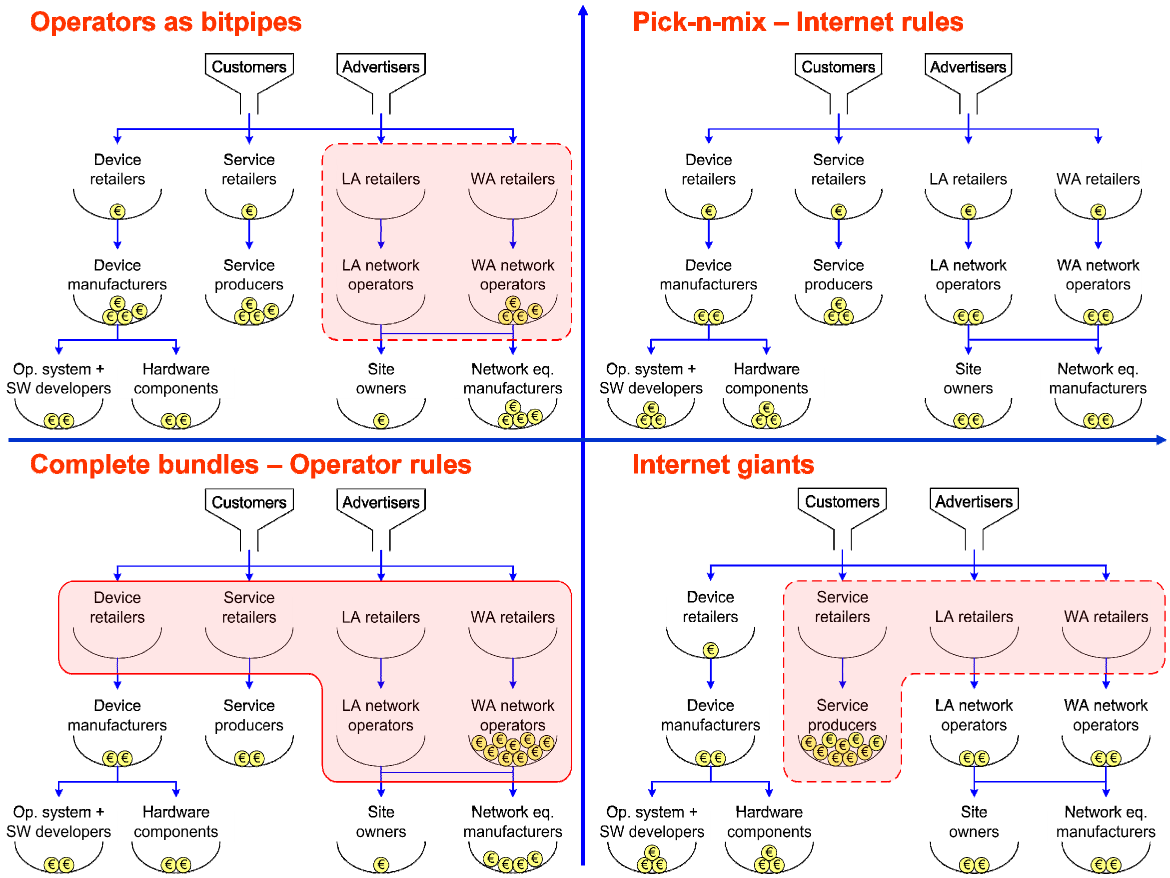

Figure 2.7 Local area business models (Smura and Sorri, 2009)

3 Research methods and tools

In this chapter, we briefly introduce the research methods used in the thesis. First the handset-based measurement method (used in the mobile service usage analysis) is introduced. After that an introduction to system dynamics is presented together with the modeling process and other elements used in the model construction for the future of the local area access provisioning. Finally, the brainstorming session is introduced which was held as a part of the model construction process.

3.1 Handset-based mobile service usage measurement

3.1.1 Method description

The data, used in the thesis, was collected from a panel of Finnish smartphone users during October – December 2008.

A handset-based measurement platform (developed for Nokia S60 class of mobile devices) was used to collect the data. The platform consists of a Symbian application monitoring software client which is installed in the mobile devices. The software client has two functions. First, it records all actions done by a user with the phone. Second, it writes them to a log file and sends automatically the data log to a centralized server (based in Finland) for analysis. The reader can find more details about the measurement platform and process in Verkasalo (2009).

The measurement client records many things such as "the *active usage time* for every application launched and used by the panelists". The active usage time is defined as " the time that elapses while the application is topmost and visible on the screen of the device " (Smura, 2008). However, the measured time does not necessarily reflect the actual usage time for some applications such as FM-radio or MP3 players since the applications run in the background without the user's active interaction. The measured time reflects the actual usage time only if there is active interaction between the user and the applications (e.g. phone calls, messaging, web browsing, or video playback).

In addition to the active usage time, "the measurement client also collects data about all the packet data sessions launched by the device, together with the used bearer (GPRS/EDGE, WCDMA, WLAN) and the amount of data sent in uplink and downlink directions. By mapping this network usage data with the application usage data it is possible to analyze the usage of each application with each bearer separately" (Smura, 2008).

Regarding the panelists, 223 panelists (having an age of over 18 and owning a Nokia S60 smartphone) were included in the focal dataset and they all successfully installed the software client on their devices. Out of them, 153 fulfilled the requirement that they "had been in the panel for at least three active usage weeks or 21 active usage days. The day or week being active means that the subscriber has used his handset at least once during the period of time (i.e. day or week), by e.g. launching an application or placing a call" (Verkasalo and Hämmäinen, 2007). Out of 153 panelists, two were excluded because they were only testing the software client and two of them used unclear foreign language settings. Therefore, 149 panelists[13] were included in the final dataset.

3.1.2 Classification of applications

In this thesis, we use the framework developed by Smura et al (2009) for classifying device applications. There are two key classification criteria in the framework:

- The nature of interactivity that the application provides (person-to-person communications, content retrieval, content viewing/playback, synchronization, or standalone).

[13] "Compared to the Finnish population in general, the sample of panelists was biased towards young men. The panelists can also be expected to be relatively advanced in using mobile devices, as they were willing and capable to install the measurement software to their devices themselves, by following instructions on a web page" (Smura, 2008).

- The type of content handled by the application (real-time video/voice, non-real-time voice/video/text/image, client-specific data, Generic HTML/WAP pages etc).

The two classification criteria results in ten mobile device application classes/categories: 1) calling, 2) messaging, 3) browsers, 4) infotainment clients, 5) servers and file sharing,6) multimedia, 7) games, 8) business / productivity, 9) system / utilities, and 10) other applications (as presented in **Table 3.1**).

Table 3.1 Application classes/categories (Smura et al, 2009)

Class	**Classification criteria**		**Examples**
	Nature of interactivity	**Type of content**	
Calling	Person-to-person communication	Real-time voice / video	Applications for circuit- and packet-switched voice calls, video calls, Push-to-Talk over Cellular, and “rich calls”
Messaging	Person-to-person communication	Non-real-time voice / video / text / images	Software clients for SMS, MMS, Bluetooth, instant messaging, and e-mail
Browsers	Content retrieval	Generic HTML / WAP pages	Clients providing an access to HTML / WAP pages
Infotainment clients	Content retrieval	Client-specific data	Specialized clients to information or entertainment content, e.g. weather, navigation, RSS clients, widgets
Servers and file sharing	Content retrieval and sharing	Various	Web servers, Bittorrent, FTP, media servers
Multimedia	Content creation, editing, and playback	Music / video / image files or streams	Offline or online/streaming multimedia players, image viewers, recording/capturing and editing software
Games	Offline / data synchronization	Game data	Offline and network games
Business / productivity	Offline / server access	Office documents	Calendars, personal information management, word processors, spreadsheet and presentation applications, enterprise systems
System / utilities	Offline	Local data / files	File managers, configuration, security, system updates, compression
Other applications	Various	Various	Uncategorized applications

3.2 System dynamics

System dynamics is "a method for studying the world around us. It deals with understanding how *complex systems*[14] change over time. Internal feedback loops within the structure of the system influence the entire system behavior."[15] Bayless (2004) defined system dynamics as "a methodology for using computer models and simulations to better understand the impact of strategies on the performance of *complex systems* over time." Karikoski (2009) also defined system dynamics as follows: "system dynamics is a systems engineering method for enhancing learning in a complex system. The basis lies in systems thinking i.e. being able to see the world as a *complex system* where everything is connected to everything and one cannot assume that a change in one variable would not affect anything else." In short, system dynamics is a method for understanding the dynamic behavior of *complex systems* and the interrelationship of various elements in the system.

System dynamics was originally developed in the 1950s by Professor Jay Forrester of the Massachusetts Institute of Technology in order to help corporate managers gain a better understanding of industrial processes. Currently, both public and private sectors are using system dynamics for the purpose of policy analysis and design[16].

3.2.1 Concepts

There are three basic concepts related to system dynamics: 1) feedback loop also referred to as causal loop, 2) stock and flow, and 3) Time delay. The feedback loop (Figure 3.1) is used to model different forces/actors and their interrelationship. In the example in Figure 3.1 an increase in the fractional birth rate means the birth rate will increase, and births add to the population. An increase in the population accelerates the birth rate. The feedback

[14] Herbert Simon (an American economist and psychologist) defined a complex system as a system that can be analyzed into many components having relatively many relations among them, so that the behavior of each component depends on the behavior of others.

[15] http://sysdyn.clexchange.org/ [Accessed 04.08.2009]

[16] http://www.systemdynamics.org/DL-IntroSysDyn/start. htm [Accessed 04.08.2009]

loop between the birth rate and the population is referred to as the reinforcing loop. In the same example, an increase in the average lifetime of the population means the death rate will fall, and a decrease in the number of deaths means the population will increase and balance the death rate. The feedback loop between the death rate and the population is referred to as the balancing loop.

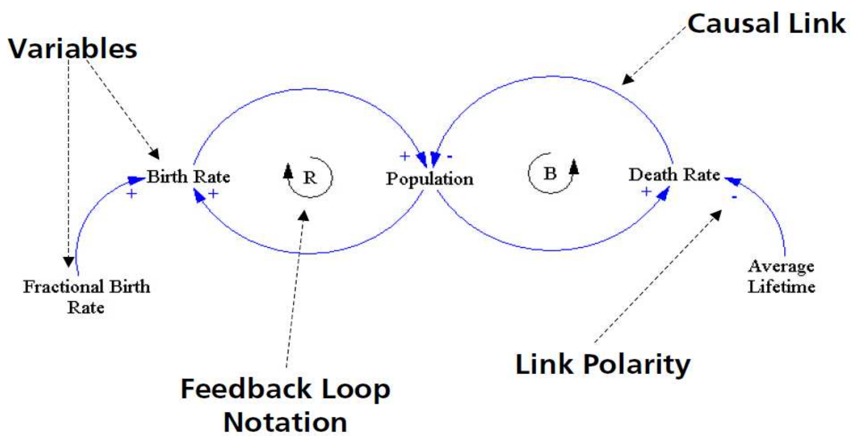

Figure 3.1 Causal loop diagram (Bayless, 2004)

The second concept in system dynamics is represented in Figure 3.2. Stock refers to a container holding an accumulation of units and flow simply refers to a pipe through which units move. For example, in Figure 3.1, the variable Population and Birth Rate can be considered as a stock and a flow, respectively.

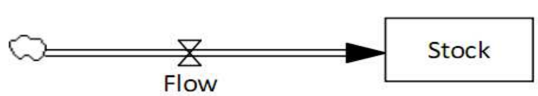

Figure 3.2 Stock and Flow diagram

A delay refers to a situation that the output lags the input. “In system dynamics modeling, identifying delays is an important step in the modeling process because they often alter a system's behavior in significant ways. The longer the delay between cause and effect, the more likely it is that a decision maker will not perceive a connection between the two.” [17]

[17] http://www.systemdynamics.org/DL-IntroSysDyn/stock.htm [Accessed 04.08.2009]

3.2.2 Modes of dynamic behavior

In system dynamics, there are four modes of dynamics behavior, namely exponential growth, goal seeking, s-shaped and oscillation (Figure 3.3 a-d). Each of these is generated by a feedback structure.

Exponential growth (Figure 3.3a) arises when there is a positive feedback. A typical example of this is the growth of savings with compounding interest. An increase in interest leads to an increase in savings, which in turn makes the interest growth since interest earnings are proportional to the level of savings (Kirkwood, 1998). With goal seeking behavior (Figure 3.3b), the quantity of interest starts either above or below a goal level and over time moves toward the goal. Figure 3.3b shows two possible cases, one where the initial value of the quantity is above the goal, and one where the initial value is below the goal. In the case of s-shaped behavior (Figure 3.3c), the value of a variable in the system first grows exponentially then follows goal seeking behavior. Oscillation (Figure 3.3d) arises when there is a negative feedback with time delays in the loop (Sterman, 2000).

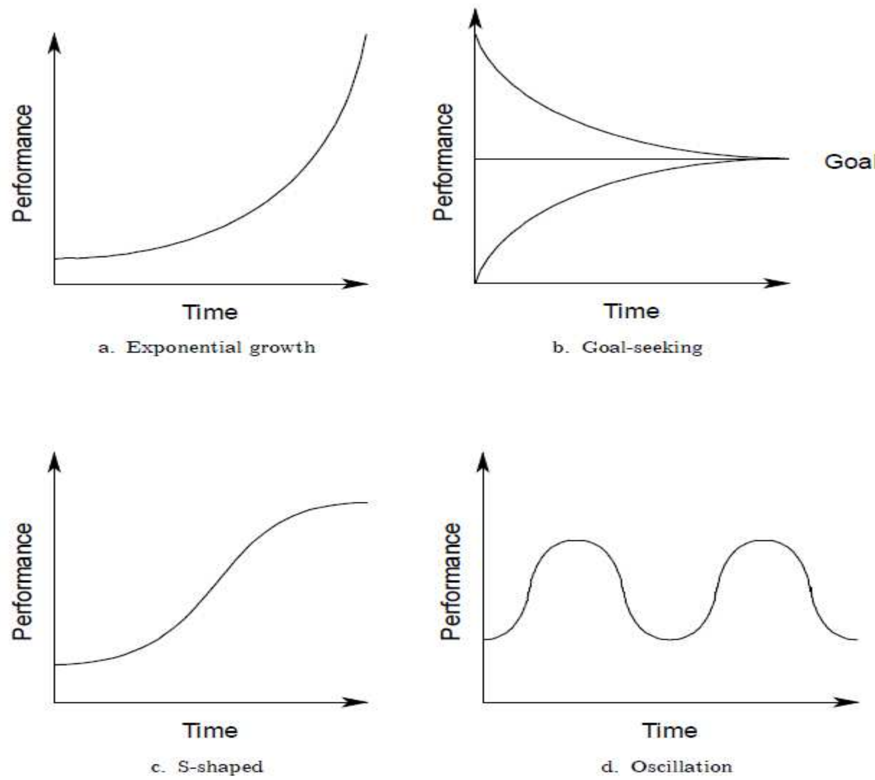

Figure 3.3 Characteristic patterns of system behavior (Kirkwood, 1998)

3.2.3 Modeling process

Following a disciplined modeling process is vital to develop and use good quality system dynamics models. The modeling process that we use in this thesis has been introduced by Sterman (2000). There are five fundamental steps in the process and presented in Figure 3.4. The modeling process is iterative and iteration can occur from any step to any other step (indicated by the arrows in the right side of the figure).

The first step in modeling is problem articulation. It clearly answers the question, “what is the purpose of the model?” and clarifies the key variables and concepts in the model. The time horizon and *reference modes*[18] will also be defined in this step. Having a clear

[18] Vensim (2003) stated a reference mode as a pattern of behavior over time. Reference modes are drawn as graphs over time for key variables, but are not necessarily graphs of observed behavior.

problem in mind always plays a great role in developing an effective model (Vensim, 2003).

In the second step, a theory, called a dynamic hypothesis, is developed. The dynamic hypothesis is all about understanding the problem stated in step one. The hypothesis is dynamic because it gives explanation of the dynamic behavior of the problem. Either a causal loop diagram or stock and flow diagram can be used to state a dynamic hypothesis. Most importantly, the hypothesis is used to determine what will be kept in models, and what will be excluded using tools such as a model boundary chart.

In the third step, the dynamic hypothesis, model boundary and conceptual model are tested by formulating a simulation model. A simulation model includes an explicit set of mathematical relationships and generates behavior through simulation. Developing a simulation model is an iterative and flexible process. During the process, a modeler will gain understanding that can change the initial conditions of variables, parameters and equations in the model.

Once the simulation model is developed, testing begins by comparing the simulated behavior of the model to the actual behavior of the system. In this step, the behavior of the model is also tested under extreme conditions. The model should behave realistically when stressed by extreme conditions.

The last phase of the modeling process is designing and evaluating polices for improvement. The results from the model are put into use and their practical implications are examined.

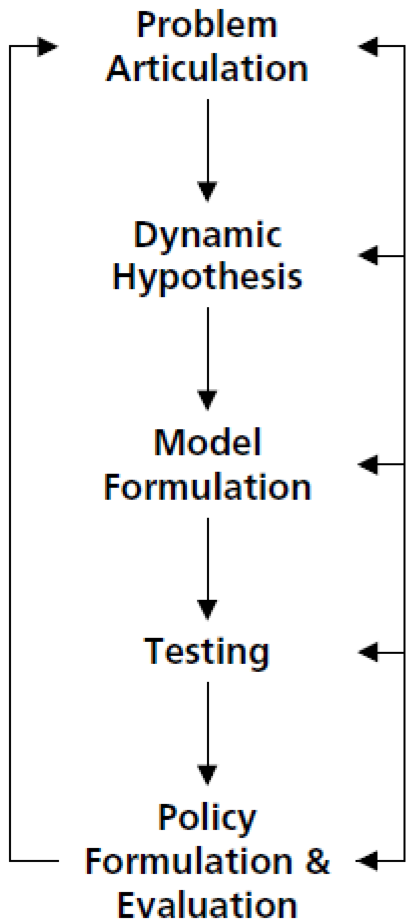

Figure 3.4 The modeling process (Bayless, 2004)

3.3 Brainstorming session

As part of model developing process, a brainstorming session was conducted with a group of experts from Nokia Research Center (NRC) on 14th of May 2009. The purpose of the session was to model the interactions of main forces related to local area access provisioning and to understand spectrum regulation interactions with local area ecosystem.

4 Results from handset-based measurement analysis

In this chapter, we identify the similarities and differences in mobile service usage between local area networks (e.g. WLAN) and wide area networks (e.g. WCDMA, EDGE and GPRS) based on the data collected at a panel attended by Finnish smartphone users during October - December 2008. This is the extension of work reported in Smura (2008), which used the data collected from panel of 2007.

4.1 Usage of different applications

Analyzing applications which are widely used by mobile users at different times of day is one of the interesting topics in application usage studies. Figure 4.1 shows the active usage time divided between different application categories and hours of day.

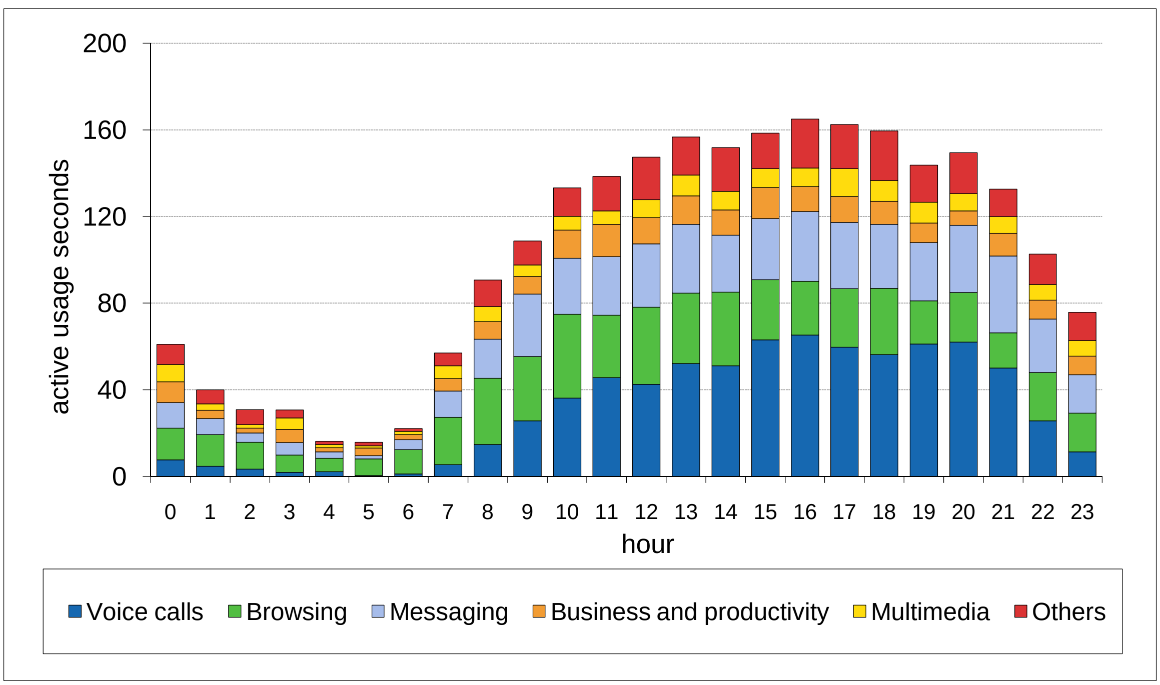

Figure 4.1 Distribution of active smartphone usage time between application categories and hours of day, averaged over Monday-Sunday throughout the panel period (N=149)

The figure shows the dominance of voice calls on average over the entire day followed by browsing, messaging, business and productivity, multimedia and other applications. In the panel of 2007, messaging was ahead of browsing (Smura, 2008). As one can observe from the figure, Browsing was the second largest application category in the panel of 2008, which indicates rapid growth in data services. Voice calls accounted for 30.7% of the total average daily active usage seconds per panelist in 2008. The next-largest application categories, browsing, messaging and business and productivity accounted for 21.9%, 20.1% and 8.5%, respectively while multimedia accounted for 6.5%.

The active smartphone usage time distributions for the four most important application categories can be found in Appendix A: Figure A.0.1 a-d. For voice calls (Figure A.0.1a), the active usage seconds rises almost continuously after 6am, peaking at around 66 seconds of active use per panelist between 4pm and 5pm and then starts to decline after 8pm. The active usage amounts for browsing (Figure A.0.1b) increase steadily after 4am, peaking at around 39 seconds between 10am and 11pm, at which time browsing actually overtakes voice calls as the top application category by active usage amounts. Otherwise, the active usage time varies in a non-uniform manner. Figure A.0.1c shows messaging applications are used more actively between 9am and 10pm even if the peak hour is unclear. For business and productivity (Figure A.0.1d), the active usage seconds are relatively small compared to other application categories but as the figure shows business and productivity applications are used actively between 10am and 6pm.

Table 4.1 lists the most actively used applications under different application categories. The table demonstrates that web, text message, music player and calendar are the most widely used applications under their category.

Table 4.1 Actively used mobile applications under different application categories (N=149)

Application categories	Application names	Average usage_seconds/day/panelist
Browsing	Web	405.53
	Services	36.36
	Opera Mini	89.3
Messaging	Text message	272.82
	MMS	7.21
Multimedia	Music player	55.61
	Gallery	26.28
	Camera	34.27
Business and productivity	Calendar	57.36
	Contacts	39.9
	Log	29.84

4.2 Usage of different access networks

WCDMA, GPRS, EDGE and WLAN are the four bearer technologies (access networks) that we consider for the analysis of access networks usage. Figure 4.2 and Figure 4.3 show the distribution of daily data usage in kB and active usage time in seconds between bearers and hours of day, respectively.

From Figure 4.2, it can be seen that on average the daily data usage in kB for WCDMA is higher than other bearer technologies. The active usage (in seconds) for WCDMA is also greater than other bearer technologies on average as reflected by Figure 4.3. In general, the two figures show that WCDMA is the most widely used bearer technology.

Figure B.0.2 a-d in Appendix B and Figure C.0.3 a-d in Appendix C show the daily data usage in kB and the active usage time in seconds separately for the four bearer technologies, respectively.

For WCDMA (Figure B.0.2a), the daily data usage amounts vary in a non-uniform manner, peaking at around 40kB of daily data usage per panelist between 11am and 12 noon.

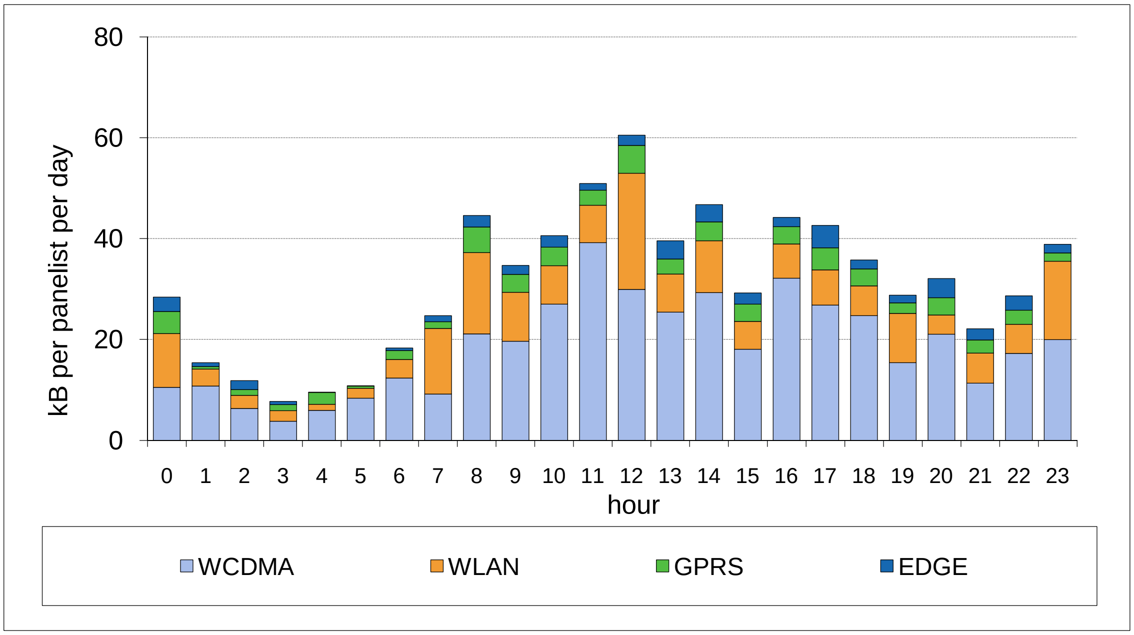

Figure 4.2 Distribution of daily data usage between bearers and hours of day, averaged over Monday-Sunday (N=130)

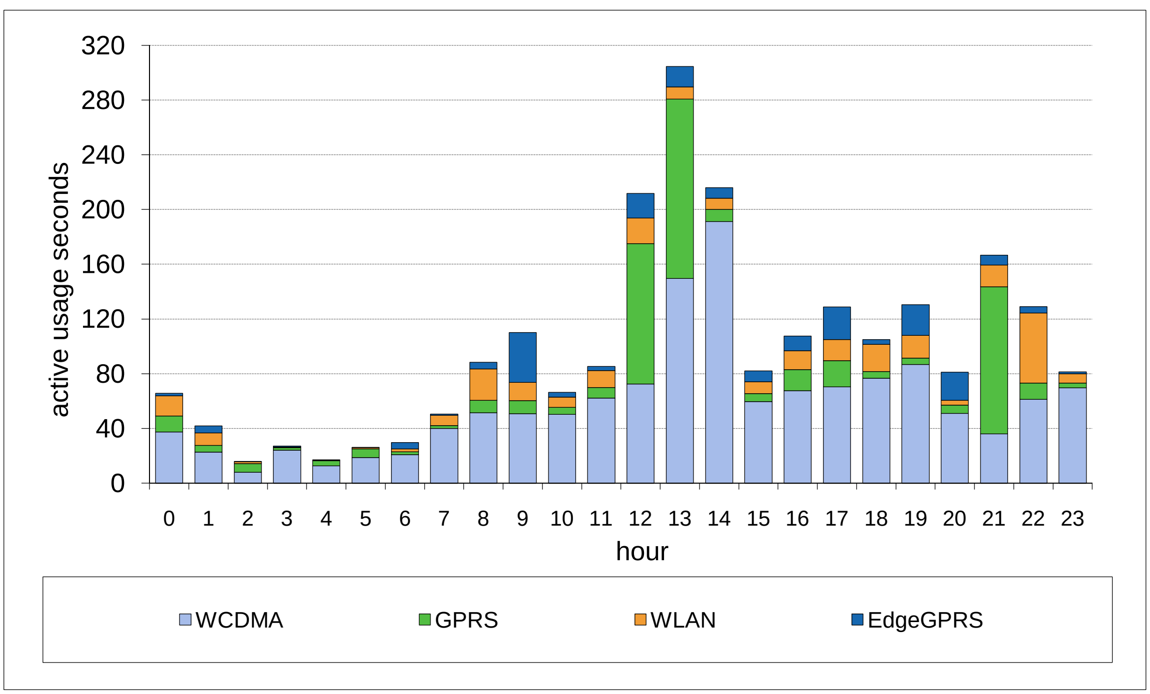

Figure 4.3 Distribution of active usage time in seconds between bearers and hours of day, averaged over Monday-Sunday (N=130)

Similarly to WCDMA, for WLAN (Figure B.0.2b), the daily data usage amounts vary in a non-uniform way, peaking around 22kB between 12 noon and 1pm. For EDGE (Figure B.0.2c) and GPRS (Figure B.0.2d), the daily data usage amounts are less than 6kB per user all the time.

In terms of active usage time, for WCDMA (Figure C.0.3a), the active usage amounts increase continuously after 5am, peaking at around 191 seconds of active use per user between 2pm and 3pm. For GPRS (Figure C.0.3b), the active usage amounts are significant only between 12 noon and 2pm and between 9pm and 10pm.The active usage amounts for WLAN (Figure C.0.3c) increase between 3pm and 10pm while for EDGE (Figure C.0.3d), the active usage amounts vary significantly between 12 noon and 8pm.

The user’s choice between access networks while launching various applications is also one of the key points in mobile service usage analysis. Table 4.2 shows that there were more users for browsing applications than for messaging and multimedia in all types of access networks. For multimedia applications, the number of sessions per user during the panel was lower than other application categories. However, the amount of data transmitted during one session was significantly higher during WCDMA, WLAN and GPRS connections.

For browsing and messaging applications, the average amount of data per session (kB) during WLAN connection was higher than during WCDMA, GPRS and EDGE connections, i.e. a smartphone data session during WLAN connections was higher in terms of data volumes than during wide area network connections. More than 85% of WLAN users used WLAN connections for web browsing, while 32% used it for communications services such as messaging and 15% for streaming multimedia content, as shown in Table 4.2.

Table 4.2 Usage of application categories during WCDMA, WLAN, GPRS and EDGE connections (N=130)

Access networks	Active users	Application categories	Applications users	Share of users	No of sessions per user during the panel	Average data per session (kB)
		Browsing	102	90%	20.36	481.46
WCDMA	113	Messaging	71	63%	10.30	109.12
		Multimedia	27	24%	0.85	2474.26
		Browsing	46	87%	3.72	1420.92
WLAN	53	Messaging	17	32%	0.58	654.63
		Multimedia	8	15%	0.15	1437.50
		Browsing	60	74%	4.12	416.32
GPRS	81	Messaging	46	57%	1.54	78.45
		Multimedia	8	10%	0.10	735.25
		Browsing	57	77%	2.87	429.81
EDGE	74	Messaging	31	42%	3.13	28.64
		Multimedia	6	8%	0.05	194.82

4.3 Comparing daily data usage of WLAN and non WLAN users

In general, usage of WLAN correlated clearly with usage of data services as described in Table 4.2. Figure 4.4 presents the average daily data usage for both WLAN and non-WLAN users, divided between different bearers. As can be seen from the figure, the daily data usage of WLAN users was higher than that of non-WLAN users in all types of bearer technologies, and usage of WCDMA was significantly higher than that of other access technologies.

Among WLAN users, the share of WLAN access increased from 12% of total network data traffic in 2007 (Smura, 2008) to 39% in 2008 which could indicate that there is a rapid growth in WLAN APs deployment in the mobile market.

The share of WCDMA access went down from 79% among non-WLAN users to 50% among WLAN users. This shows that WLAN can be considered as a potential complement and/or substitute to 3G networks for usage of data services.

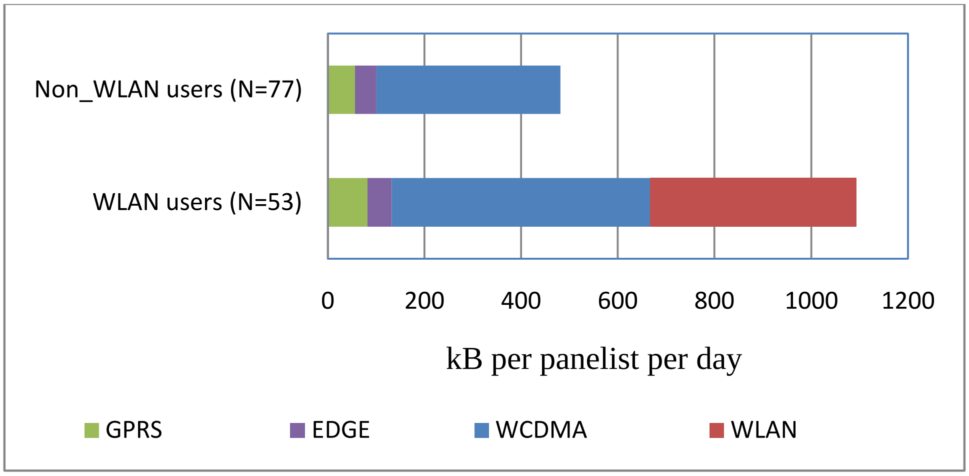

Figure 4.4 Daily data usage per bearer for panelists either using or not using WLAN during the panel (N=130)

4.4 The user's choice between alternative access methods

So far, application category and time-of-day are the only dimensions in our analysis. The user's choice between the alternative access methods is another dimension added to the application usage studies. We focused more on WLAN usage because of its role as a potential alternative to 3G networks in many use cases. The use cases can be found in Smura (2008, Appendix D).

Out of the total 253 panelists, 130 initiated a data session at least once during the panel. Out of these, 53 were WLAN users – panelists who used WLAN connections at least once for data access services. Figure 4.5 presents the distribution of WLAN usage events between users and access points. On average, for each user, 80% of WLAN connections were made to the first access point, 12% to a second one, and 8% to other access points.

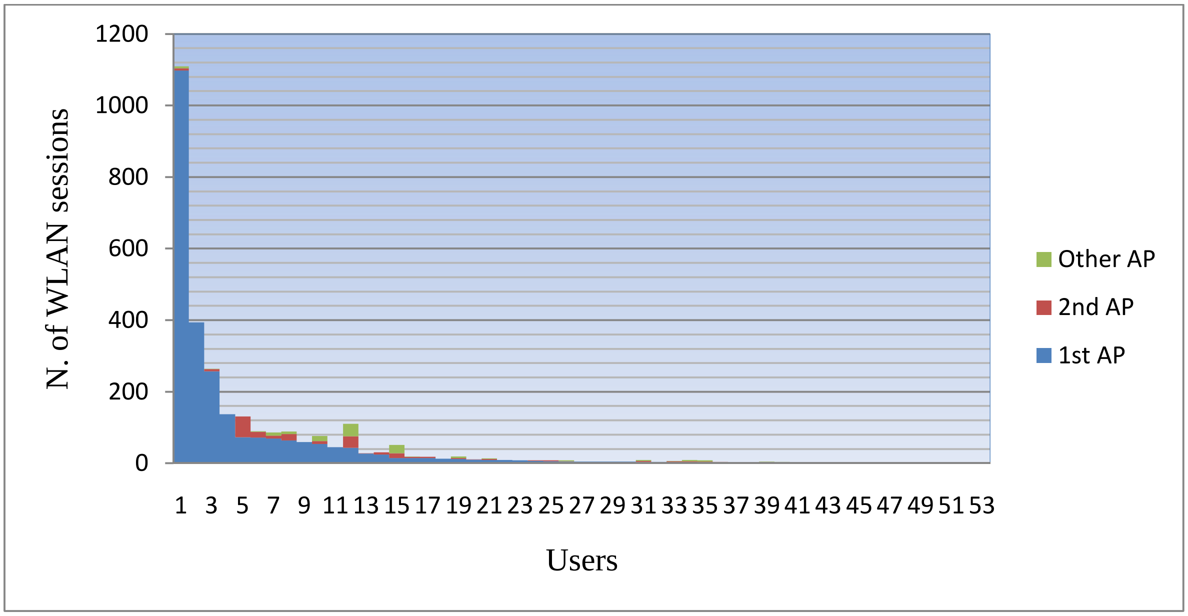

Figure 4.5 Distribution of WLAN usage events between users and access points[19] (N=53)

We considered two methods to identify an access point as either private or public. Checking the list of WLAN access point names was the first method. For example, access points having names such as "Reval Hotels", "TOT_HotSpot","alto" and "homerun" can be considered as public. The second method was checking the security mode of access points. The data (collected from the panel) contained four types of security modes - Open, WEP (Wired Equivalent Privacy), WPA (Wi-Fi Protected Access) and WPA-PSK (WPA - Pre - Shared key). We grouped access points which asked for security keys before connections as private.

Using those two methods, we found that 91% of all WLAN connections were made from private access points while the rest were made from public ones. That means most of WLAN connections are made from private access points located at home or office.

[19] The reader may ask why "User 1" in Figure 4.5 had so many sessions (more than 1000 sessions from the first access point) during the panel. This was because the user configured his mobile device to initiate WLAN session automatically every 30 minutes.

4.5 Summary and limitations

In general, we tried to illustrate how people use mobile devices with different access technologies by analyzing the data collected from 253 Finnish panelists owning a Nokia phone based on the S60 platform, which is currently amongst the leading smartphone platforms in the world. The panelist installed a measurement client in their device voluntarily. As Smura (2008) mentioned in his paper, the results of this type of analysis cannot be simply generalized to all mobile users in Finland due to the limited number of panelists in addition to including only the advanced users of mobile devices in the study. In general, however, the results can describe some of the trends taking place in the mobile industry in the near future.

WLAN continues its role as a potential complement and/or substitute to 3G networks. The number of WLAN capable mobile devices is growing rapidly, rising from 5% of the Finnish mobile handset base in 2007 (Smura, 2008) to 10% in 2008 (Kivi, 2009).

In Section 4.4 we have seen that many of the WLAN connections are made at home and mainly used for the purpose of web browsing (Table 4.2). Table 4.2 demonstrates that the average amount of data per session (kB) during WLAN connection for the purpose of browsing and messaging applications is higher than during WCDMA, GPRS and EDGE connections, i.e. WLAN is mainly used by those users who in general use large amounts of data services.

3G networks were the most widely used access technologies among all the panelists including WLAN users. This can be because they provide higher data rates than GPRS/EDGE with better geographical coverage and penetration than WLA among mobile users. In our panel, nearly 60% of the total network traffic was generated from WCDMA connections.

There were two limitations in this handset-based measurement analysis. The first one was that the whereabouts of panelists were not known which made it difficult to identify which applications and access technologies were used at home, office and other locations. The other limitation was that only NOKIA S60-based smartphones were monitored with a rather small number of panelists.

5 System dynamics modeling for local area access value networks

In this chapter, we develop a system dynamics model for network connectivity to indoor located devices based on the scenarios constructed by Smura and Sorri (2009). Firstly, we discuss the background of the model. Secondly, the conceptual and quantitative models are developed, and, finally, the results and limitations of the model are discussed.

The main objective of developing our system dynamics model is to study the dynamics of forces that influence the structure and the development of network connectivity to indoor located devices over the next 6 years (2009-2015).

In terms of the quantitative model, the idea is not to find and simulate the exact numerical values, but to gain a broad level of understanding about the dynamics of forces that affect the future of local area access provisioning. The motivation for this is the fact that, while examining the entire system behavior, it is more important to understand behavioral patterns than to find absolute numerical values. For example, it will be interesting to know how, say, the growth curve of Wi-Fi access points might behave due to changes in some parameters.

5.1 Background for modeling

5.1.1 Time frame and scope

As mentioned above, the time frame for our system dynamics model is 2009-2015 and the scope is limited to indoor provisioning in the Finnish mobile industry and markets. All indoor located devices that need connectivity are included in the model but our primary focus is on handsets and laptops since they are the key drivers of rapid growth in network traffic. We focus on data traffic and, circuit switched voice is not included in the model since mobile data traffic is growing more dynamically than voice traffic (Cisco, 2009).

5.1.2 Key trends and uncertainties

Trend means “the general movement over time of a statistically detectable change”[20]. Hubbard (2007) defines uncertainty as the lack of certainty, a state of having limited knowledge where it is impossible to exactly describe the existing state or future outcome, more than one possible outcome. Having clearly identified key trends and uncertainties in the topic area is helpful in developing a system dynamics model[21].

Smura and Sorri (2009) indentified seven key trends (Table 5.1) and six uncertainties (Table 5.2) which have an effect on the future of local area access provisioning by applying Shoemaker’s scenario planning method. The reader can find details about the trends and the uncertainties as well as the method from Smura and Sorri (2009) if interested.

Table 5.1 Seven key trends (adapted from Smura and Sorri, 2009)

Id	Trend
T1	Devices’ capabilities and performance improve
T2	Wireless traffic will increase
T3	Number of base stations / access points increases
T4	Importance of indoor wireless access increases
T5	Role of developing countries increasing
T6	Operational costs will dominate over hardware costs
T7	Wireless emissions scare people

Table 5.2 Six key uncertainties (adapted from Smura and Sorri, 2009)

Id	Key uncertainty	Possible outcomes
U1	Industry structure	1) Vertical 2) Horizontal
U2	Competition between technology substitutes	1) Remain low 2) Increase strongly
U3	Spectrum policy and regulation	1) Harmonized 2) Liberalized
U4	Role of unlicensed spectrum	1) Limited 2) Significant
U5	Number of connected devices	1) Grow modestly 2) Explode
U6	Role of emerging markets in affecting technology choices	1) Minimal 2) Significant locally 3) Significant world-wide

[20] http://www.merriam-webster.com/dictionary/trend [Accessed 13.07.2009]
[21] In our system dynamics model, in general, we refer trends and uncertainties as forces.

5.1.3 Scenario matrix

After identifying the key trends and uncertainties, Smura and Sorri (2009) constructed a scenario matrix (Figure 5.1) by selecting U1 and a combination of U2, U3, and U4 as the two dimensions. The four scenarios (Pick-n-mix –Internet rules, Complete bundles – Operator rules, Operators as bitpipes and Internet giants) in the scenario matrix are the local area business models that we discussed in Subsection 2.4.2.

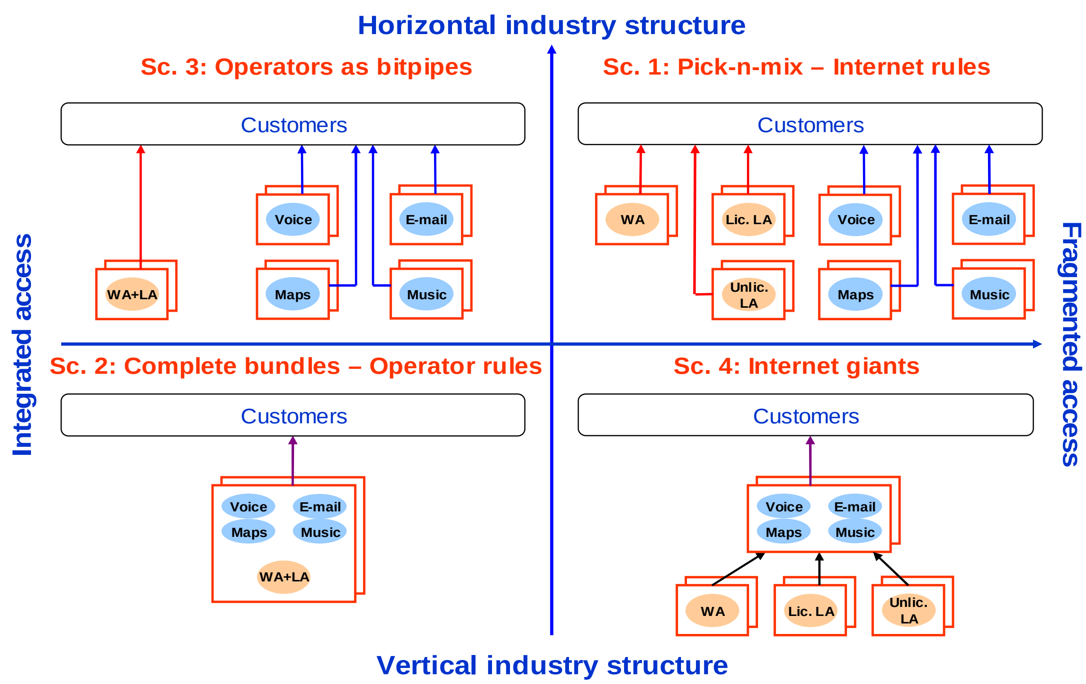

Figure 5.1 Scenario matrix (Smura and Sorri, 2009)

The y-axis of the scenario matrix defines the industry structure. In the vertical industry structure, end users buy bundled packages of access (e.g. WA, LA in Figure 5.1) and services (e.g. voice, e-mail, maps, and music in Figure 5.1), and there is a lower level of competition between services. In the case of horizontal industry structure, end users can get services which are not bundled with access, and since there are a number of players who are interested in providing different service components, there is a higher level of competition between services.

The x-axis of the scenario matrix is labeled as the level of technological fragmentation in the access market – referred to as integrated access and fragmented access. In the case of integrated access, wide area and local area access are offered as bundles, and incumbent operators have significant control over local area networks. In this case, the level of competition between access technologies is low.

In the fragmented access case, local area access and wide area access are offered separately, and usage of licensed spectrum becomes more flexible. As a result, the level of competition between access technologies and networks is high.

As mentioned earlier, the x-axis of the scenario matrix is the combination of three uncertainties (U2, U3 and U4) and the y-axis is defined in terms of one uncertainty (U1). More external elements are needed to model the y-axis than the x-axis. In order to keep the scope of our system dynamics model reasonable, we only model the x-axis - the level of technological integration in the access market.

Regarding the uncertainties and trends in our model, due to limitations in time and difficulties of modeling abstract variables, it is a very challenging task to include all the key trends and uncertainties in the model. Therefore, we selected three uncertainties and trends, which we believe are most important and easy to model quantitatively. The selected trends are T1, T2 and T3 while U2, U3 and U5 are the selected uncertainties.

T1: Productivity, data rates, efficiency, processing power, memory sizes, connectivity options and new features of mobile and portable devices continue to improve from time to time, thus resulting in the devices becoming more intelligent and cognitive. However, these improvements are limited by various factors such as energy consumption and battery life.

For modeling purposes, we split *T1: Devices' capabilities and performance improve*[22] up into *T11: device access selection capabilities and T12: AP self optimizing capability.*

[22] A naming rule (*ID: Name of trends/uncertainties*) is used to refer to the trends and uncertainties, and we use italics in the text to highlight the elements and the feedback loops that are used in the model.

T2, T3: The volume of wireless traffic grows rapidly as the number of wireless device users increases. Consequently, more base stations and access points are required to meet the wireless traffic demand.

T3 is divided into *T31: Num of non-3GPP LA APs*, *T32: Number of 3GPP LA APs and T33: Number of 3GPP WA BSs.* The Quantitative Model section discusses these sub forces.

U2: The number of competing access technologies may either remain relatively low or increase strongly. We consider three different types of radio access technologies: non-3GPP LA (Wi-Fi), 3GPP LA (femtocell) and 3GPP WA (3G/4G). 3GPP LA and 3GPP WA belong to the same technology family, though. *U2: Competition between technology substitutes* is split into three sub forces (groups), namely *U21: share of 3GPP LA out of all LA, U22: share of LA out of all indoor traffic* and *U23: market share of 3GPP operator of all indoor traffic*. The sub forces compare 3GPP LA (femtocell) with all local area access technologies (Wi-Fi and femtocell); all local area access technologies (Wi-Fi and femtocell) with all indoor access technologies (Wi-Fi, femtocell and 3G/4G); and 3GPP technologies (femtocell and 3G/4G) with all indoor access technologies, respectively.

In our system dynamics model we define the market share of the three technologies in terms of traffic volumes (volumes of bits) from access points/base stations (Figure 5.2).

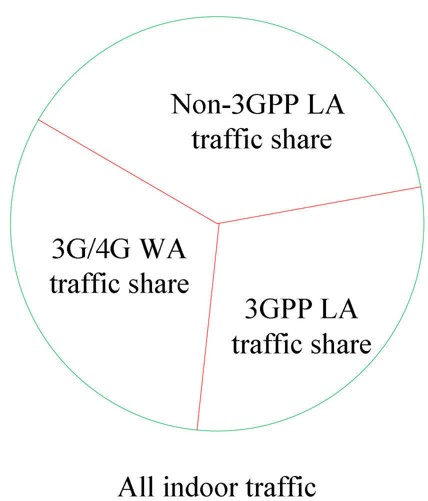

Figure 5.2 Market share of the three technologies

U21: represents the ratio of Wi-Fi traffic to the sum of Wi-Fi and femtocell traffic.

U22: represents the ratio of data traffic from Wi-Fi and femtocell access points to all indoor traffic.

U23: represents the ratio of data traffic from femtocell and 3G/4G base stations to all indoor traffic. U23 can be seen as the combination of U2 and U4 and represents the x-axis of the scenario matrix.

U3: The possible outcomes of Spectrum policy and regulation are: liberalized and harmonized. The first case refers to technology neutrality and a larger degree of liberalization, while the second one refers to geographical and technological harmonization.

U5: The number of wireless devices may explode (10s to 100s of devices per user) or grow modestly (lower than 10s of devices per user).

5.2 Conceptual model

The conceptual model for the future of the local area access provisioning is shown in Figure 5.3. It only sketches the direct causal connections between the variables. The indirect influences are not usually shown in the conceptual model.

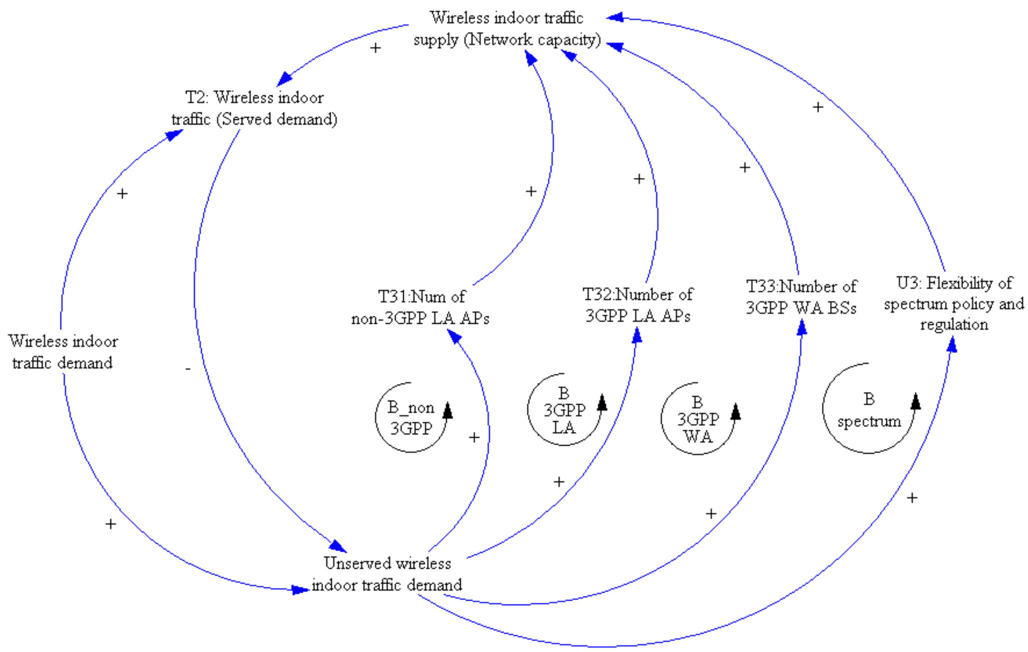

Figure 5.3 Conceptual Model

The aim of the conceptual model is to explain the fundamental idea behind our proposed system dynamics model. In Figure 5.3, the main background assumption is that *Unserved wireless indoor traffic demand*, which is the difference between *Wireless indoor traffic demand* and *T2: Wireless indoor traffic (Served demand)*, drives wireless indoor traffic supply i.e. the larger the *Unserved wireless indoor traffic demand*, the more base stations/access points and flexibility of spectrum policy and regulation is needed. Our conceptual model is a goal seeking system (shown in Figure 3.3b), i.e. the increasing demand is met by more supply. Table 5.3 lists and describes the elements and feedback loops used in the conceptual model.

Table 5.3 Elements and Feedback loops in the conceptual model

Elements	**Descriptions**
Wireless indoor traffic demand	Reflects the sum of the subscribers and the sum of the demanded data traffic (usage).
Wireless indoor traffic supply (Network capacity)	Traffic supply from Non-3GPP LA, 3GPP LA and 3GPP WA networks.
T2:Wireless indoor traffic (Served demand)	The traffic demand that is served by wireless networks. It is the minimum of *Wireless indoor traffic demand* and *Wireless indoor traffic supply (Network capacity).*
Unserved wireless indoor traffic demand	The difference between *Wireless indoor traffic demand* and *T2: Wireless indoor traffic (Served demand)*.
T31: Num of non-3GPP LA APs	The number of non-3GPP local area access points (Wi-Fi) per km^2 area.
T32: Number of 3GPP LA APs	The number of 3GPP local area access points (Femtocell) per km^2 area.
T33: Number of 3GPP WA BSs	The number of 3GPP wide area base stations per km^2 area.
Feedback loops	
B_non_3GPP	This is a balancing feedback loop. As *Unserved wireless indoor traffic demand* increases, the more non_3GPP_LA access points (*T31: Num of non-3GPP LA APs*) will be required which improves *Wireless indoor traffic supply (Network capacity)* which in turn increases *T2: Wireless indoor traffic (Served demand*) which finally reduces *Unserved wireless indoor traffic demand*.
B_3GPP_LA	Similar to *B_non_3GPP*, except femtocell technology is implemented.
B_3GPP_WA	Similar to B*_3GPP_LA*, except 3G/4G technology is implemented.
B_spectrum	The larger *Unserved wireless indoor traffic demand,* the higher *U3: Flexibility of spectrum policy and regulation* is required which improves the *Wireless indoor traffic supply (Network capacity).* An increase in the supply means the *T2: Wireless indoor traffic (Served demand*) increases, and the *Unserved wireless indoor traffic demand* decreases.

5.3 Quantitative model

As mentioned at the beginning of this chapter, the main objective of developing our system dynamics model is not to find and simulate exact numerical values but to get an overall understanding about the dynamics of forces that affect the future of local area access provisioning. The quantitative model is constructed based on assumptions, available data and the conceptual model. All the parameters and equations that are used in the quantitative model can be found in Appendix E: Parameters and Equations.

There are multiple tools to implement the quantitative model which is developed based on the conceptual model (depicted in Figure 5.3), although only a few of them have established their base in business and research. Sterman (2000) suggests three main tools - Vensim, iThink (or Stella) and Powersim. All of these tools offer the same basic functionalities that system dynamics require. For our modeling purposes, we picked Vensim which we found easy and provides the essential features to complete the thesis.

5.3.1 Data and Assumptions

Data gathering about the volume of traffic indoor located devices generate on Wi-Fi, femtocell and 3G networks was one of the major challenges in the thesis. The input data to our system dynamics model was collected from a workshop attended by the experts from Nokia Research Center, from literature (Uusitalo, 2006; Smura and Saksela, 2006) , from handset-based measurement analysis (discussed in Chapter 4) as well as from analyst reports (Informa, 2008a; Informa, 2009; Cisco, 2009).

There are two key background assumptions in our system dynamics model. The first assumption is that the capacity of wired backhaul network is sufficient to support high speed femtocell and Wi-Fi access points, and radio interface is the bottleneck in local area access provisioning. The backhaul network refers to the portion of the network located between the access point and the core network.

For the purpose of modeling, we consider a 100Mbps backhaul data rate. The assumption is that a significant part of the traffic stays within the local area network (local traffic such as video streaming between terminals) and does not go to the backhaul.

The second background assumption is that wireless indoor traffic demand drives the supply i.e. network service providers have to increase the capacity and data rates of their networks in response to the growth of mobile data traffic demand mainly from video applications (Cisco,2009).

5.3.2 Domains

The larger a model is, the more difficult it is to understand the model. When developing a model diagram, if everything appears in one place, things can quickly become overwhelming. The solution to this is to break the model up into a number of more manageable pieces[23] (Vensim, 2007).

In order to get a clear view of the dynamic behavior of our system dynamics model, we break the model into four interrelated domains; *User (Demand) domain, Infrastructure (Supply) domain*, *Spectrum Regulation and Technology (Supply) domain and Market Share* domain (Figure 5.4). The domains focus on end-user dynamics, infrastructure dynamics, spectrum regulation and technology dynamics and market share dynamics, respectively.

[23] We refer a manageable piece of a model as domain in our system dynamics model.

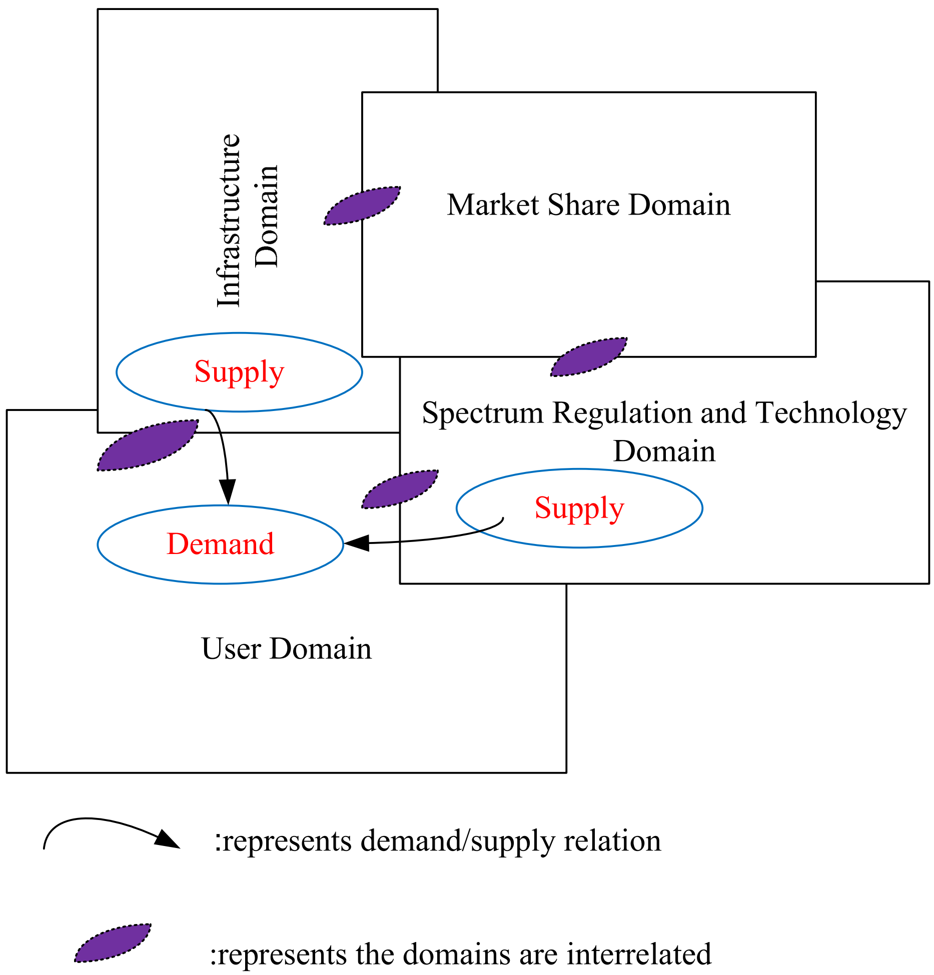

Figure 5.4 The four domains in our system-dynamics model

5.3.2.1 User (Demand)

The first piece of our system dynamics model is referred to as the *User (Demand) domain* (presented in Figure 5.5), which is the source of *wireless indoor traffic demand*. The base of the domain consists of one flow – the flow of mobile devices in the system – and one stock variable *U5: Number of mobile devices* – the number of mobile devices per km^2 area.

The number of mobile devices grows as the devices' access selection capabilities improve and the role of access points (i.e. Wi-Fi and femtocell) rises in the future of local area access provisioning. However, the growth is limited by *T7: fear of wireless emissions*. The mobile devices are categorized into two groups: primary devices and secondary devices.

Primary devices include handsets, laptops, PDAs, etc. On the other hand, secondary devices consist of game consoles, televisions and other home appliances that may embed a communications chip (and possibly a SIM-card) in the future. The *number of primary devices* in the model is based on the *number of users* and the average number of primary devices per person.

The *wireless indoor traffic demand* grows as traffic demand from both primary and secondary devices increases. Typically, the data traffic volumes from primary devices are much larger than from secondary devices, and in the model it is based on the *number of users* and *data traffic from primary devices (video) per person*.

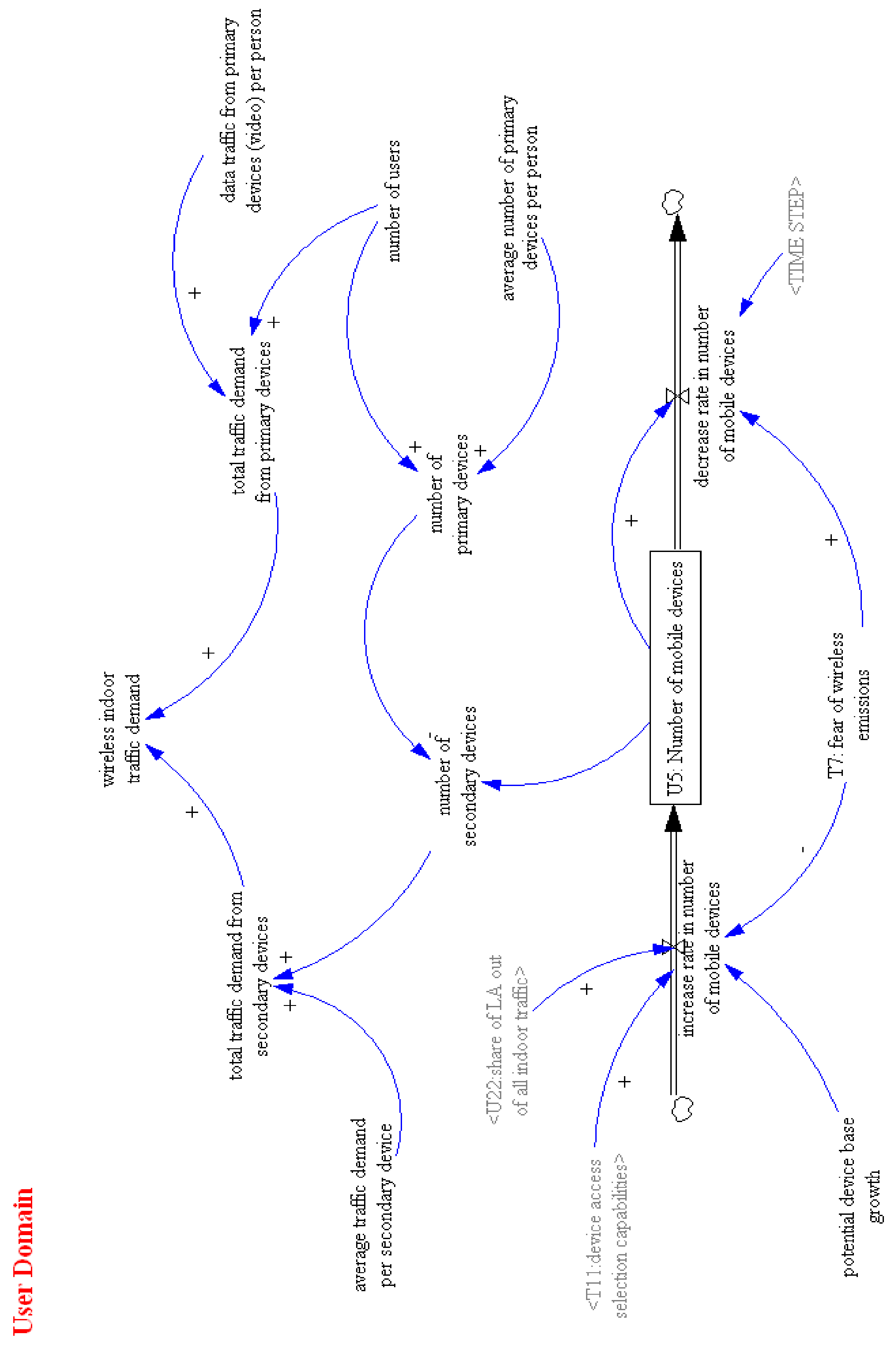

Figure 5.5 User (Demand) domain

5.3.2.2 Infrastructure (Supply)

The traffic demand from the user domain is served by the *Infrastructure (Supply) domain* (depicted in Figure 5.6). The domain consists of three radio access technologies, namely non-3GPP LA (Wi-Fi), 3GPP LA (femtocell) and 3GPP WA (3G/4G).

The base of the model shown in Figure 5.6 consists of three flows – the first one depicting the flow of non-3GPP LA access points, the second one depicting the flow of 3GPP LA access points and the last one depicting the flow of 3GPP WA base stations - and three stock variables - *T31: Num of non-3GPP LA APs*, *T32 Number of 3GPP LA APs* and *T33: Number of 3GPP WA BSs.*

As one should recall from the conceptual model, the larger the *unserved wireless indoor traffic demand* is (which is the difference between *wireless indoor traffic demand* and *T2: wireless indoor traffic*), the more base stations/access points there are.

The number of non-3GPP LA APs (Wi-Fi) grows as *unserved wireless indoor traffic demand*, *T11: device access selection capabilities* and *market share of non-3GPP LA* increase. The *market share of non-3GPP LA* reflects the current market positions and economies of scale effects in the growth. *T7: fear of wireless emissions* and *non-3GPP LA APs yearly traffic volume supply* negatively affect the growth (Equation 27 in Appendix E: Parameters and Equations).

Similarly, the number of 3GPP LA APs (femtocell) grows as *unserved wireless indoor traffic demand,* and *market share of 3GPP LA* increase. The growth is also positively affected by self optimizing capabilities of access points (which mainly reduces OPEX costs) and willingness of operators to subsidize femtocells. *T7: fear of wireless emissions* and *3GPP LA APs yearly traffic volume supply* negatively affect the growth (Equation 25 in Appendix E: Parameters and Equations).

The number of 3GPP WA base stations grows when the *unserved wireless indoor traffic demand* and *market share of 3GPP WA* increase. The growth is negatively affected by

3GPP WA BSs yearly traffic volume supply and *potential WA BS density* (Equation 26 in Appendix E: Parameters and Equations).

Table 5.4 presents the four balancing feedback loops *B_non_3GPP_LA*, *B_3GPP_LA*, *B_3GPP_WA and B_OPEX* in the *Infrastructure (Supply) domain*.

Table 5.4 Feedback loops in the infrastructure domain

Feedback loops	**Descriptions**
B_non_3GPP,*B_3GPP_LA*, *B_3GPP_WA*	The more *unserved wireless indoor traffic demand*, the more non_3GPP_LA APs, 3GPP_LA_APs and 3GPP WA BSs there will be required which results in a higher volume of *T2: wireless indoor traffic* which in turn reduces unserved *wireless indoor traffic demand*. The growth of access points and base stations is influenced by various factors e.g. *T11: device access selection capabilities*, *T12: AP self optimizing capability*, *T7: fear of wireless emissions*, interference issues, willingness of operators to subsidize non-3GPP LA APs (femtocell), the current market shares and economies of scale effects.
B_OPEX	A high number of femtocell access points results in high OPEX costs that limit the growth rate of femtocell access points in the future. However, the OPEX costs can be reduced by improving access points’ self optimizing capabilities.

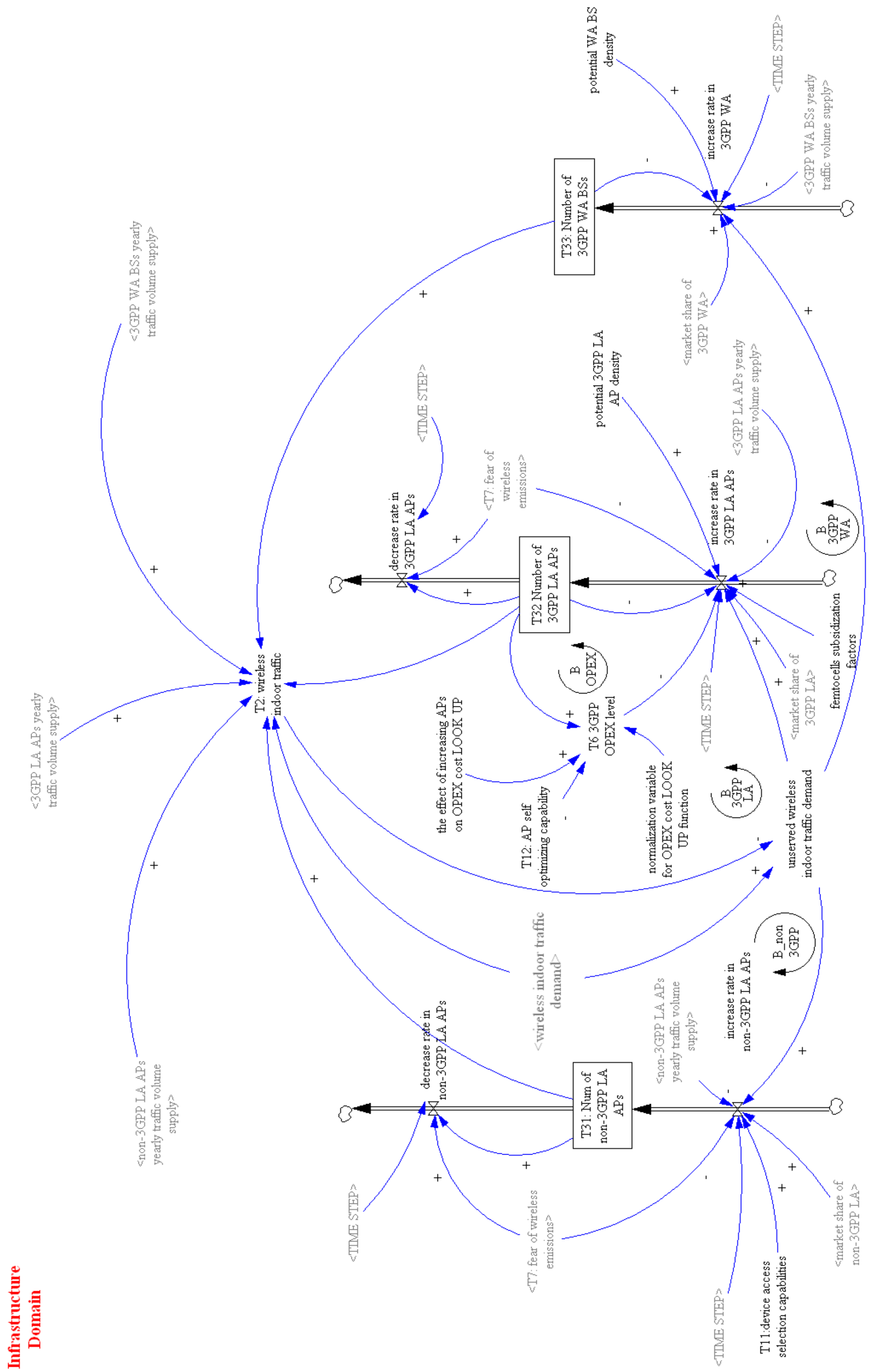

Figure 5.6 Infrastructure domain

5.3.2.3 Spectrum Regulation and Technology (Supply)

If the traffic supply from the *Infrastructure (Supply) domain* fails to reach the level of traffic demand from the *User (Demand) domain*, additional spectrum will be required to achieve higher data rates, thus resulting in the higher inherent network capacity.

In our system dynamics model, the *Spectrum Regulation and Technology (Supply) domain* (depicted in **Figure 5.7**) offers additional spectrum in a flexible way. The base of the model consists of one balancing feedback loop *B_spect_request*.

As the demand for unserved wireless indoor traffic increases, network service providers will request a regulator for the new spectrum. However, the regulator does receive the request quite quickly, but is slow to react due to heavy bureaucracy etc. The delays related to frequency regulation becoming more flexible are modeled with the variables *DELAYED SPECTRUM DEMAND* and *DELAYED ADDITIONAL SPECTRUM*.

Flexible frequency regulation (*U3: spectrum policy and regulation flexibility*) includes allowing e.g. technology neutral spectrum allocation (e.g. in Finland the 900 MHz band originally allocated for GSM can now also be used for WCDMA), spectrum trading/leasing, and opportunistic access in addition to the unlicensed spectrum. The additional spectrum enhances the throughput of non-3GPP LA and 3GPP LA access points as well as 3GPP WA base stations which all in turn increase yearly traffic volume supply. As the yearly traffic volume supply increases, *T2: wireless indoor traffic* grows which in turn reduces *unserved wireless indoor traffic demand*.

The throughput of non-3GPP local area access points is also affected by factors such as the availability of new IEEE 802.11x technologies, the utilization of unused allocated unlicensed bands such as the 5 GHz band and the interference issue.

Similarly, the throughput of 3GPP local area access points as well as 3GPP wide area base stations are affected by the availability of new 3GPP technologies and the utilization of the unused licensed IMT-2000 band.

In addition to the throughput of the local area access point (or wide area base station), the yearly traffic volume supply of a single access point (or base station) is influenced by *active yearly usage time per LA AP (or WA BS)*. The *active yearly usage time per LA AP* is the same for both non-3GPP and 3GPP local area access points (even though their capacity is different) and it remains constant throughout the simulation period of the model.

Normally, the *active yearly usage time per LA AP* (or *WA BS*) should decrease as the capacity (throughput) of an access point or (base station) improves, i.e., a shorter time is required to download movies if one has access to a high speed access point (or base station). Therefore, the active yearly usage time of an access point should not be constant, and rather should decrease as a function of throughput[24]. This is a weakness the reader may notice in our model. However, it can also be thought that supply for more throughput increases the demand (i.e. active usage time especially if full buffer TCP based applications like torrents are in question) which would offset the decrease in active usage time. This can be well observed in Section 4.2 which showed that WLAN is mainly used by those users who in general use large amounts of data services, i.e., WLAN traffic volumes are higher than for WCDMA because of high data rates of LA AP (e.g. Wi-Fi with 54 Mbps).

[24] This was a simplification that we had to make to keep the amount of modeling work reasonable.

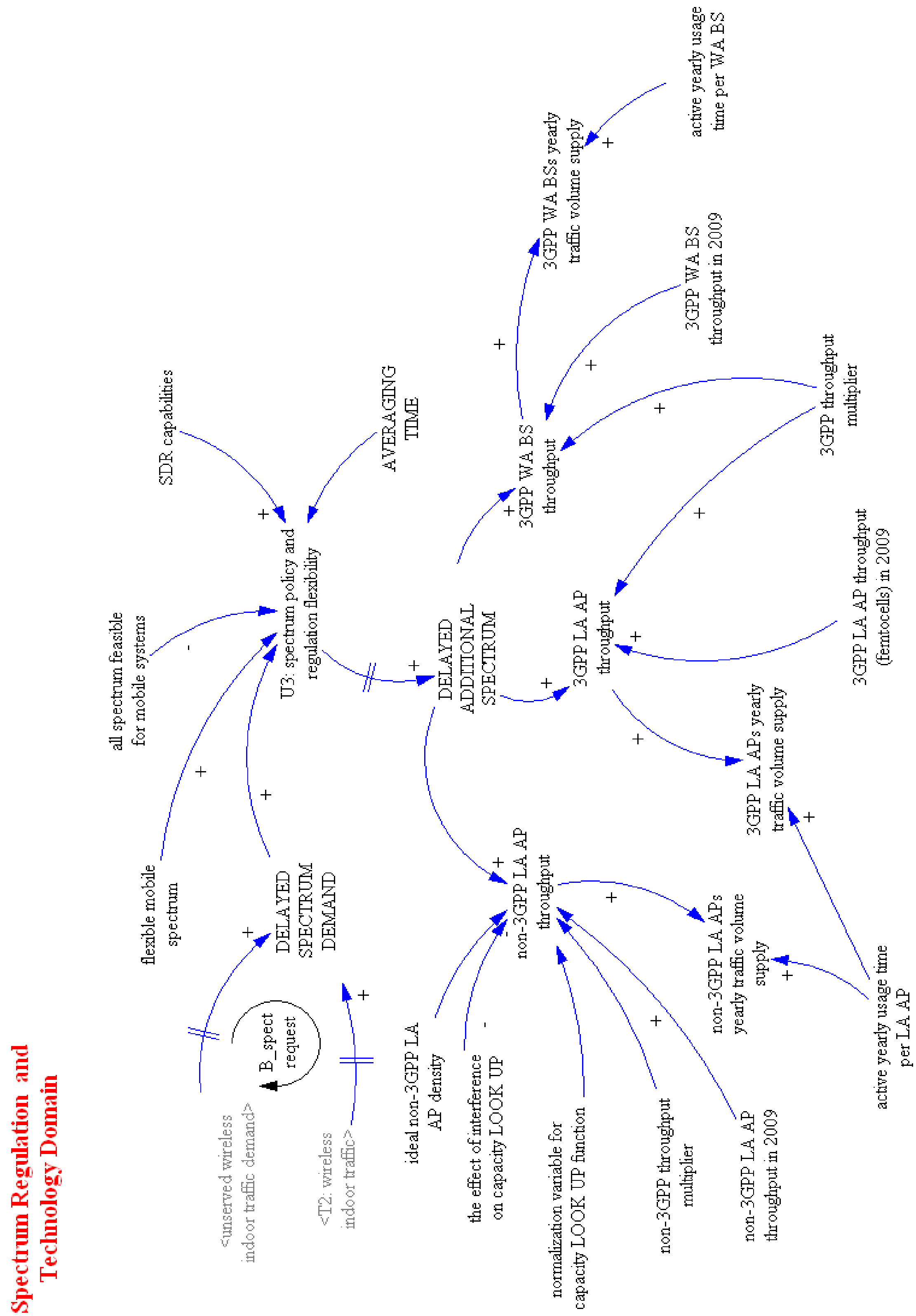

Figure 5.7 Spectrum Regulation and Technology domain

5.3.2.4 Market Share

The *Market Share domain* is mainly defined as an output of our system dynamics model and it is depicted in **Figure 5.9**.The base of the domain consists of three key variables *U21: share of 3GPP LA out of all LA indoor traffic*, *U22: share of LA out of all indoor traffic* and *U23: market share of 3GPP operator of all indoor traffic*. The variables compare 3GPP LA (femtocell) with all local area access technologies (Wi-Fi and femtocell), all local area access technologies (Wi-Fi and femtocell) with all indoor access technologies (Wi-Fi, femtocell and 3G/4G) and 3GPP technologies (femtocell and 3G/4G) with all indoor access technologies in terms of traffic volumes, respectively (discussed in Subsection 5.1.3).

The Market Share[25] domain also includes three elements that are used as input to the Infrastructure (Supply) domain - *market share of non-3GPP LA, market share of 3GPP LA* and *market share of 3GPP WA* – which represent the ratio of Wi-Fi traffic volumes to all indoor traffic volumes (the sum of Wi-Fi, femtocell and 3G/4G base station traffic volumes), the ratio of femtocell traffic volumes to all indoor traffic volumes and the ratio of 3G/4G base station traffic volumes to all indoor traffic volumes, respectively.

As mentioned in Section 5.1.3 concerning the Scenario matrix, the x-axis of the scenario matrix is labeled as the level of technological fragmentation in the access market (integrated access and fragmented access) , and it is represented by U23*: market share of 3GPP operator of all indoor traffic* (ranges between zero and one) in our system dynamics model. The value of U23 goes from zero to one means the type of access provisioning is moving from fragmented access to integrated access (Figure 5.8)

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[25] Currently, in our model, the market share is calculated based on supply. Yet, the supply does not necessarily reflect the realized traffic (if demand is lower than supply). This is one of the limitations in our model. However, traffic demand is lower than supply only for a short period of time throughout the simulation period.

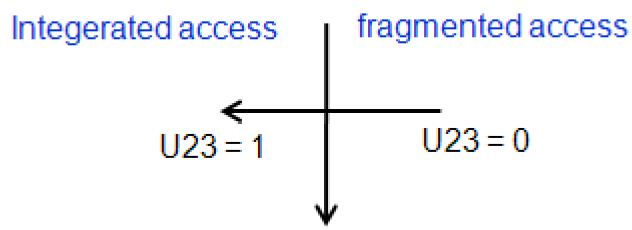


Figure 5.8 The level of technological fragmentation in the access market

In the case of the integrated access, the level of competition between access technologies is relatively small, and few operators dominate access provisioning in indoor locations, i.e. 3GPP operators captures the highest market share in local area access provisioning (U23 goes to 1).

In contrast to the integrated access, U23 is considerably small in the fragmented access case (U23 goes to 0), i.e. most of the indoor data traffic goes through Wi-Fi access points instead of femtocells or WA base stations.

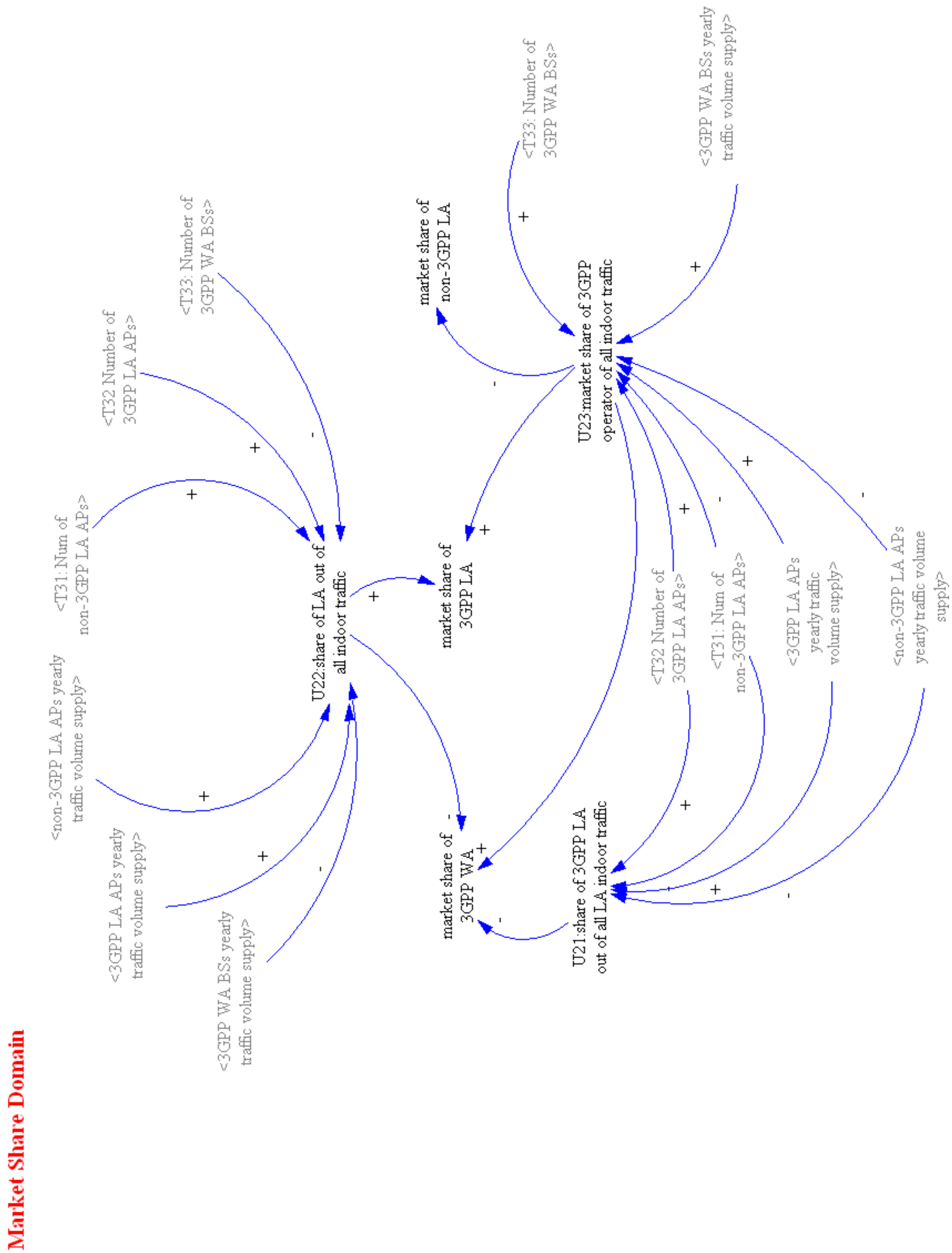


Figure 5.9 Market Share domain

5.4 Results

5.4.1 Base case results

In the thesis, the Base case simply refers to our system dynamics model simulated with initial values. The most relevant initial values for the Base case in the model are[26]:

- Typical Finnish suburban area with 2300 users/km²
- Indoor access provisioning is fragmented (U23 ≈ 0.02)
- T31: Num of non-3GPP LA APs (WiFis) = 300 APs/km²
- T32: Number of 3GPP LA APs (Femtocells) = 10 APs/km²
- T33: Number of 3GPP WA BSs = 10 sectors/km²

When simulating the model with the initial values, the demand versus supply for wireless indoor traffic (Figure 5.10) grows exponentially.

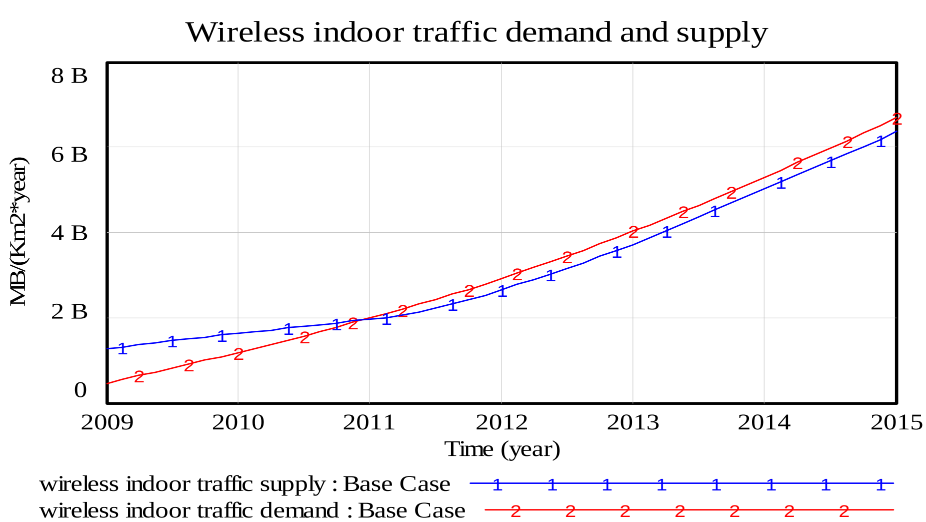


Figure 5.10 The amount of wireless indoor traffic demand and supply simulated with initial values

[26] The rest of the parameters and the initial values (and the equations used) in the model can be found in Appendix E: Parameters and Equations.

The increase in the amount of unserved wireless indoor traffic demand is zero until the end of 2010 (Figure 5.11). This is because of the fact that the increasing mobile data traffic is supported by the already deployed access points and base stations. Therefore, the supply is greater than the demand during this period of time as shown in Figure 5.10. The unserved wireless indoor traffic demand declines through 2014 and again increases through 2015.

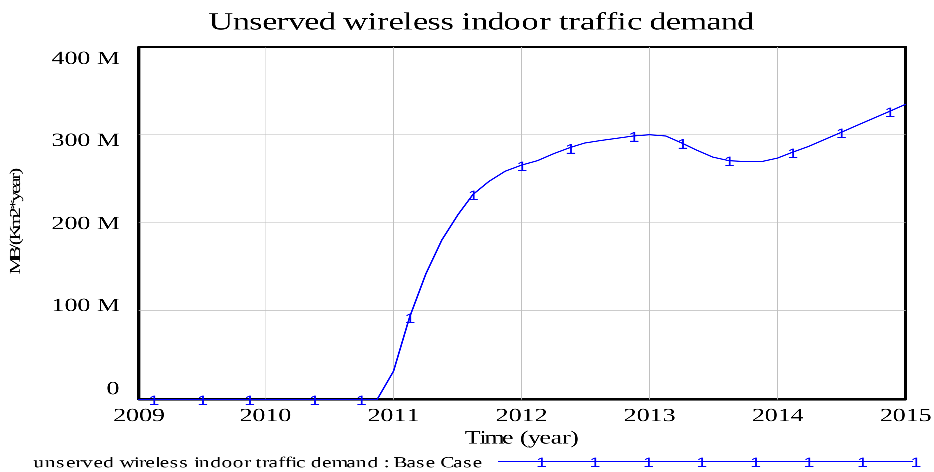


Figure 5.11 The amount of unserved wireless indoor traffic simulated with initial values

Until 2011 (when the growth of the traffic demand exceeds the growth of the traffic supply), served traffic demand (*T2: wireless indoor traffic*) is the same as the wireless indoor traffic demand (Figure 5.12), i.e. the traffic supply meets the level of demand.

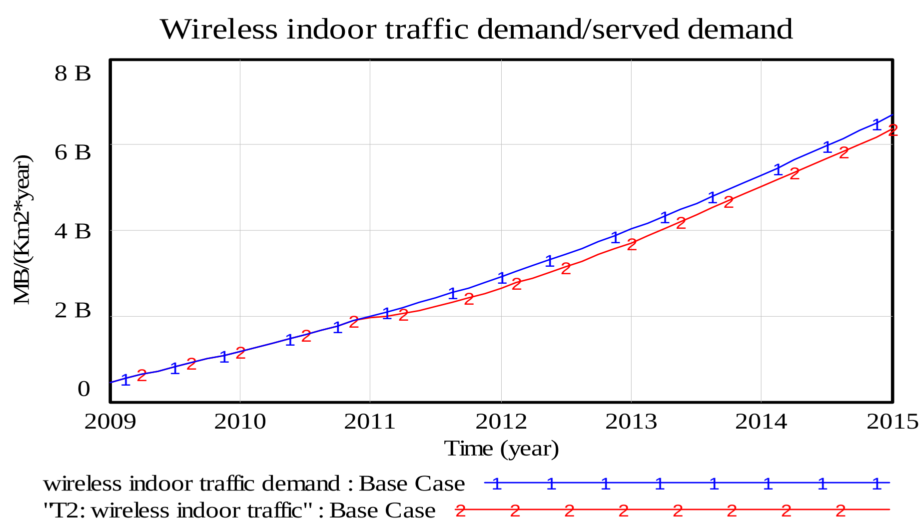
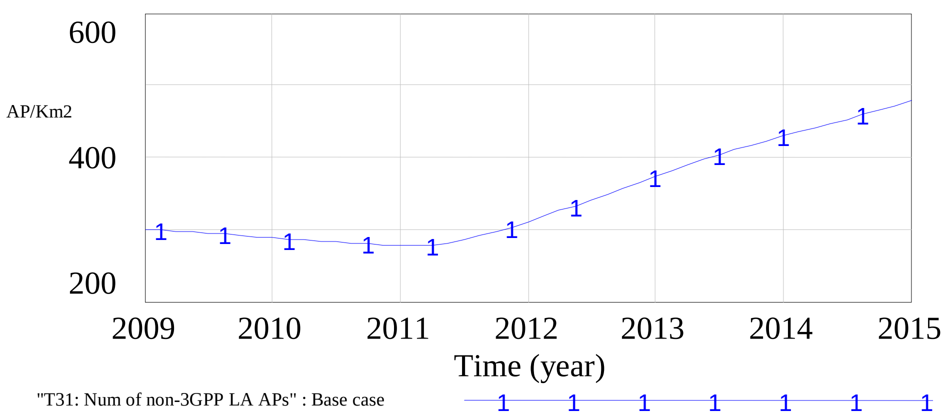


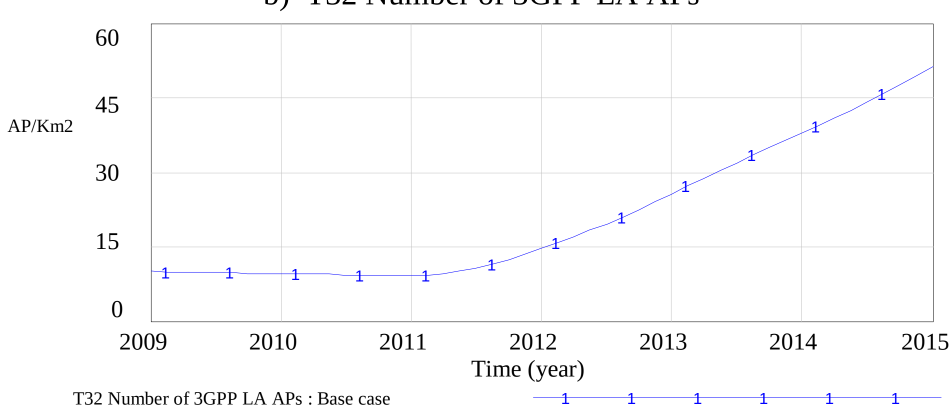
Figure 5.12 The amount of wireless indoor traffic demand and served demand simulated with initial values

As the growth of the traffic demand exceeds the growth of the traffic supply, the number of non-3GPP LA (Wi-Fi) and 3GPP LA (femtocell) access points as well as 3GPP wide area base stations increases (Figure 5.13 a-c). Comparing to the general rule stating "more demand, more supply", our model seems to behave accordingly. The number of non-3GPP LA access points (Figure 5.13a) declines slightly until 2011 due to fear of wireless emissions. Then it starts to increase, and in 2015 the growth is nearly 150%. The number of femtocell access points per km^2 area (Figure 5.13b) is quite insignificant from 2009 to 2011 since femtocell is a new technology. However, as shown in the figure, femtocells are on a positive growth path (500% growth during the study period). The number of 3G/4G base stations per km^2 area reaches the maximum allowable number (in order to minimize adjacent channel interference) in the beginning of 2012 (Figure 5.13c).

a) T31: Num of non-3GPP LA APs



b) T32 Number of 3GPP LA APs



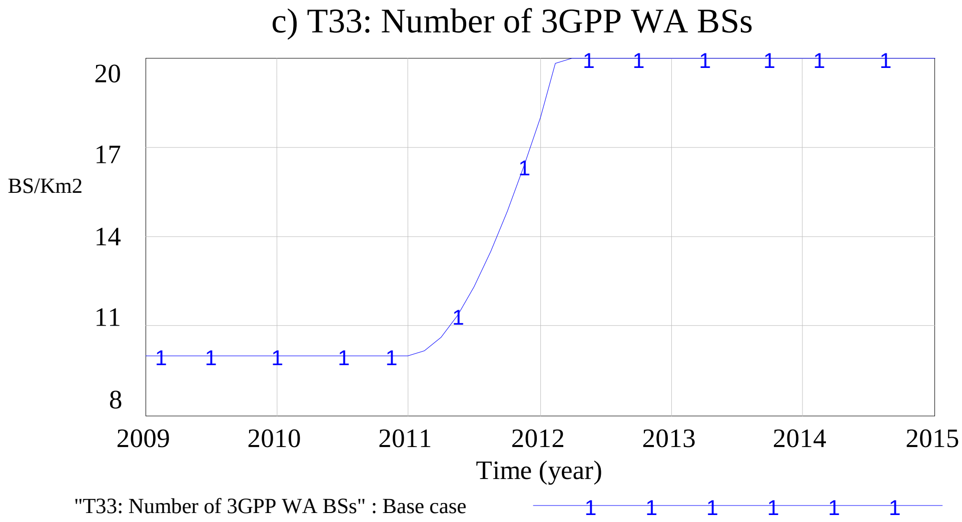


Figure 5.13 Number of non-3GPP LA APs (a), number of 3GPP LA APs (b) and number of 3GPP WA BSs (c) simulated with initial values

Spectrum policy and regulation flexibility also grows fast once the traffic demand exceeds the supply (Figure 5.14). There is a delay before additional spectrum is in use as discussed earlier.

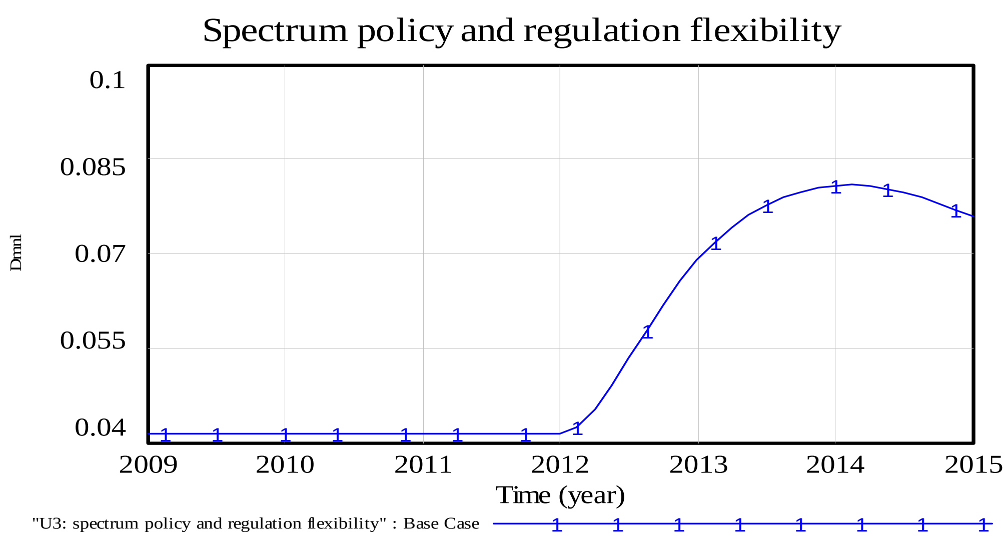


Figure 5.14 Spectrum policy and regulation flexibility simulated with initial values

As mentioned earlier, we have defined the market share of the three technologies - non-3GPP LA (Wi-Fi), 3GPP LA (femtocell) and 3GPP WA (3G/4G) – in terms of the data traffic volumes and the level of technological fragmentation in access provisioning in terms of *U23: market share of 3GPP operator of all indoor traffic*. Figure 5.15 shows that the value of U23 is near to zero which reflects fragmented access in the local area access provisioning. This is mainly because the volumes of traffic indoor located devices generate on Wi-Fi access points is larger than femtocells and 3G/4G base stations since there are a large number of high speed Wi-Fi access points that have been already deployed in the model.

In general, the simulation of the model with initial values seems to lead to Scenarios 1 and 4 (Subsection 5.1.3) in the future of the local area access provisioning (Figure 5.16). Next we will present the sensitivity analysis.

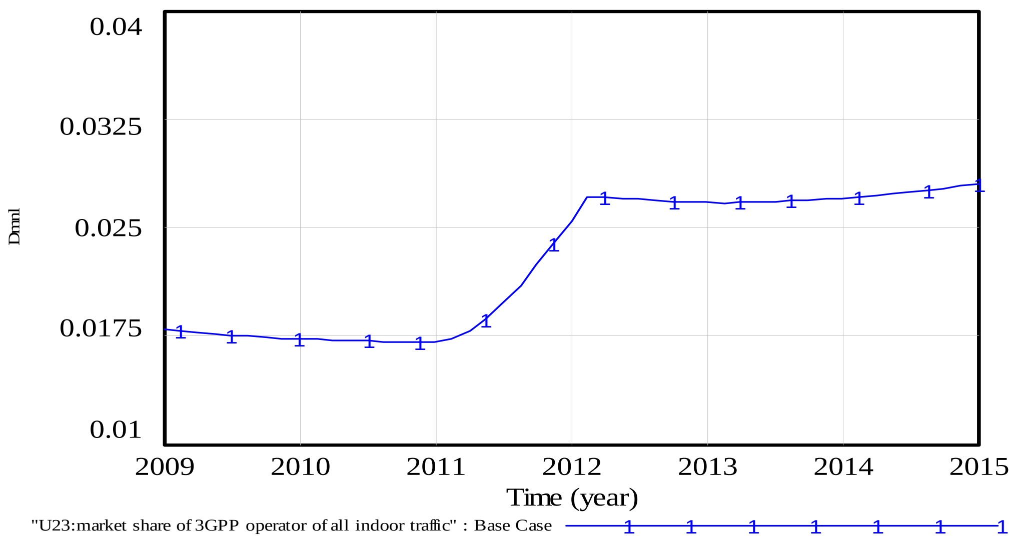


Figure 5.15 The market share of 3GPP operator of all indoor traffic simulated with initial values

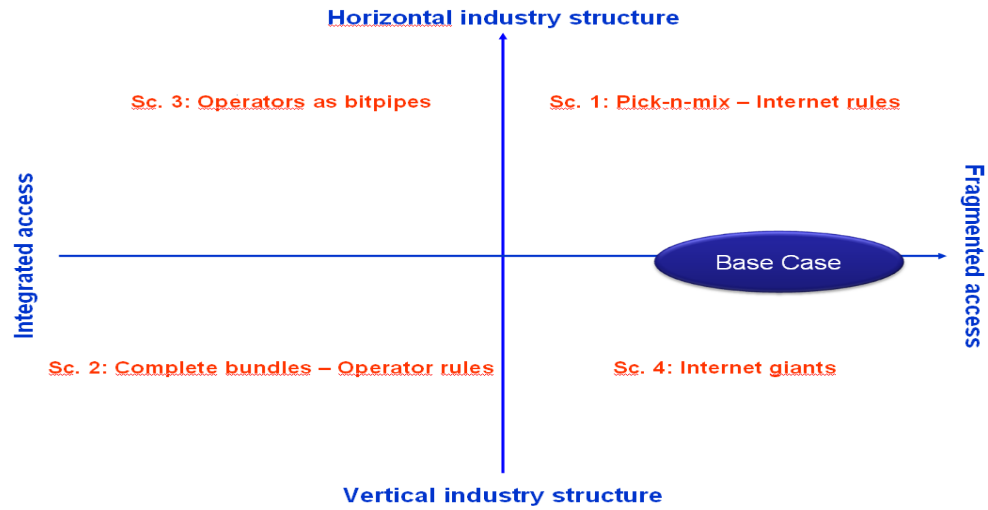


Figure 5.16 The position of the result of the Base case in the scenario matrix (adapted from Smura and Sorri (2009)

5.4.2 Sensitivity case results

A sensitivity analysis refers to the process of changing the assumptions on the value of constants in a (system dynamics) model and analyzing the resulting output. It involves changing the value of a constant and running a simulation, then changing the value of the constant again and simulating again, and repeating this action many times to get a spread of output values for the analysis (Vensim, 2007). The aim is to identify the impact of changes on key trends and uncertainties in a system dynamics model.

In our system dynamics model, we use the model simulated with the initial values (Base case) as a reference model and define five cases for sensitivity analysis. In each of these five cases, the value of some elements/variables in the model changes from the original/initial value. The aim is to identify the impact of the changes on key forces affecting the future of the local area access provisioning.

Case 1: High device access selection capabilities

The device access selection capabilities (ranges between zero and one) in this case grow more rapidly than in the Base case (Figure 5.17).

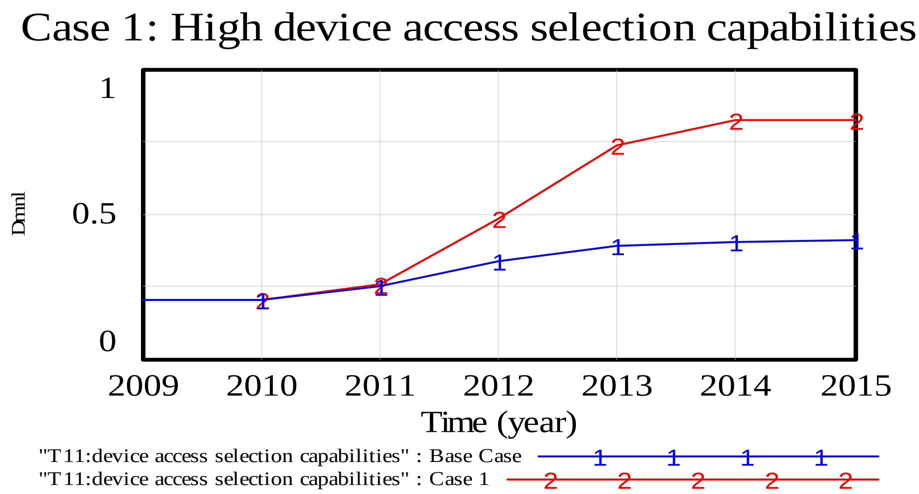


Figure 5.17 Device access selection capacities under the Base case and Case 1

As device capabilities such as ease of mobility management, network prioritization and selection and authentication improve, more users are able to utilize different access technologies and networks of different operators. This increases the number of mobile devices and favors the growth of non-3GPP local area access points which finally reduces unserved wireless indoor traffic demand (difference between *wireless indoor traffic demand* and *T2: wireless indoor traffic*) (Figure 5.18).

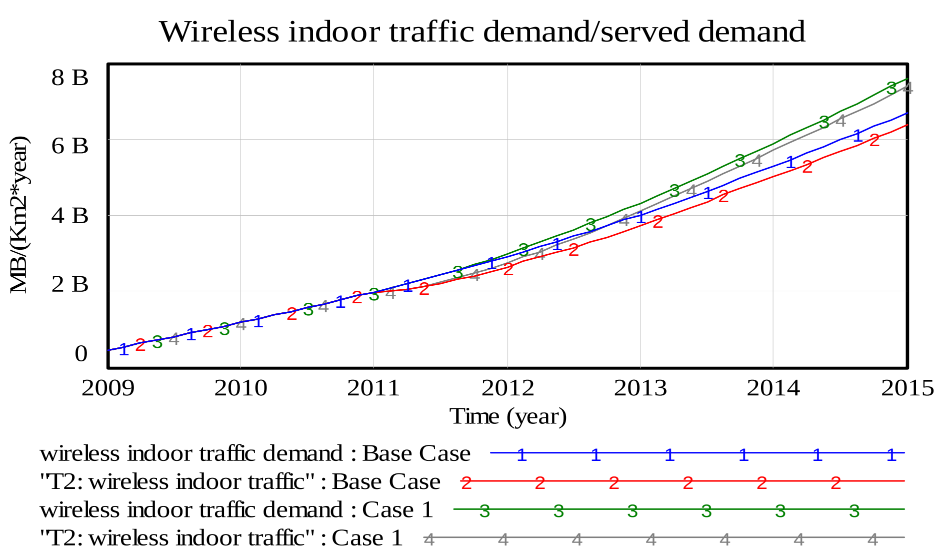


Figure 5.18 The amount of wireless indoor traffic demand/served demand under the Base case and Case 1

As one can observe from Figure 5.18, the gap between the lines marked with 3 and 4 (unserved wireless indoor traffic demand) is narrower than 1 and 2 in response to high values of device access selection capabilities. That means, the better the device access selection capabilities, the lesser is the unserved wireless indoor traffic, which in turn reduces the need for a new spectrum (Figure 5.19).

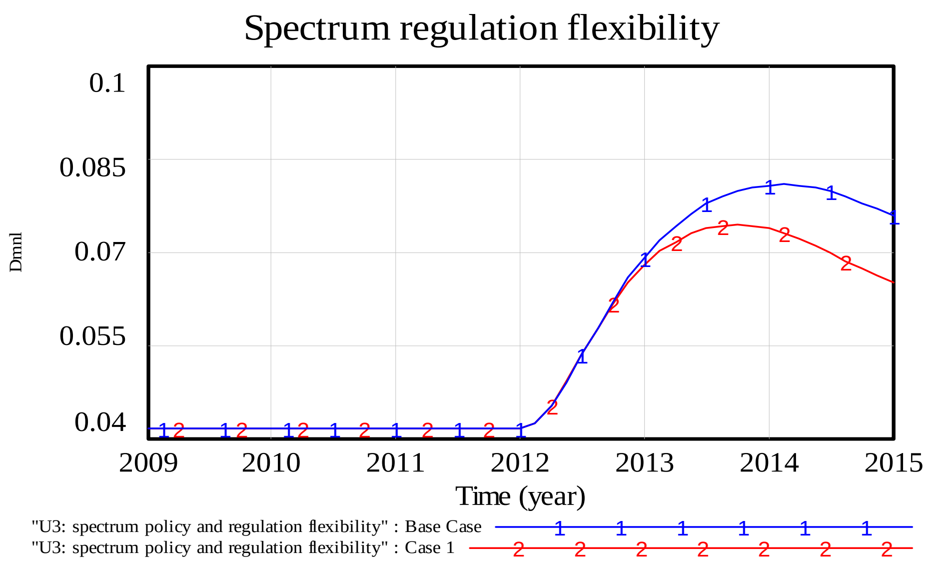


Figure 5.19 Spectrum regulation flexibility under the Base case and Case 1

Case 2: High AP self optimizing capability and high willingness of operators to subsidize femtocells

The better the AP self optimizing capabilities are and the more willing operators are to subsidize femtocell access points by means such as by paying for the equipment (Figure 5.20), the better chance femtocell technology will get off the ground (line marked with “5” in Figure 5.21). Thus the market share of 3GPP operators grows which reflects the possible evolution path towards integrated access in the local area access provisioning (line marked with “5” in Figure 5.22).

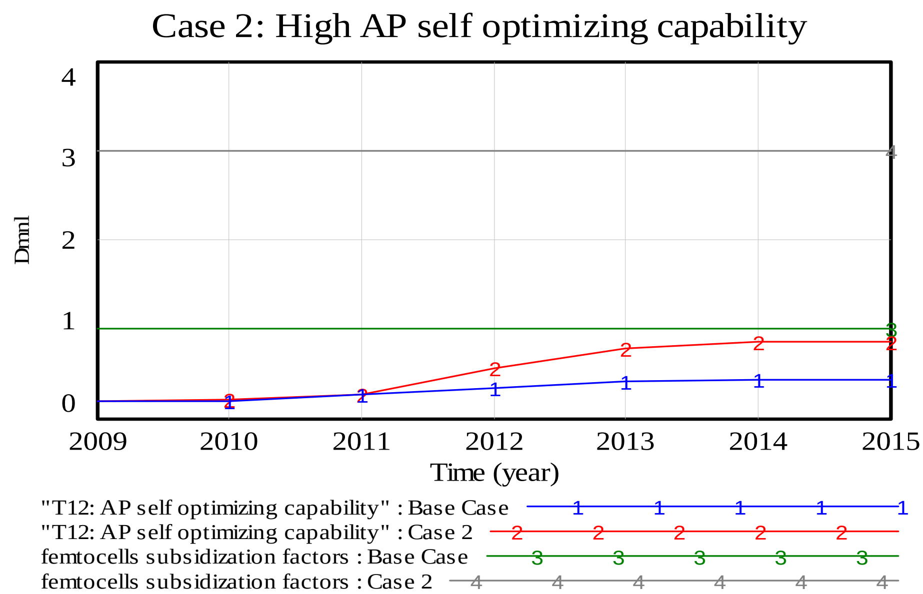


Figure 5.20 AP self optimizing capability and femtocells subsidization factors under the Base case and Case 2

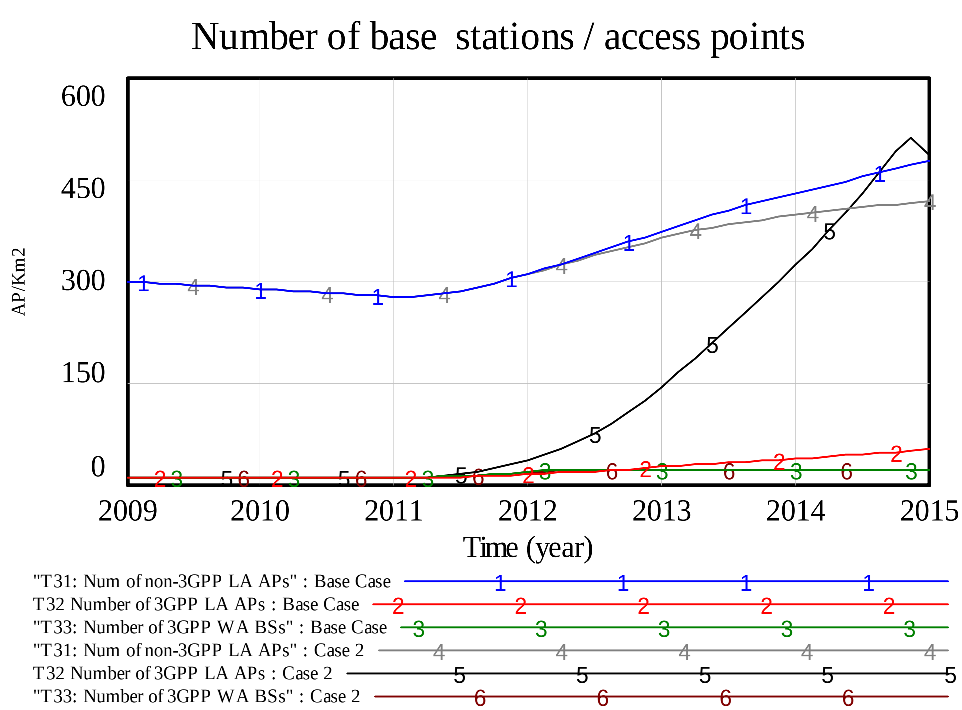


Figure 5.21 Number of base stations/access points under the Base case and Case 2

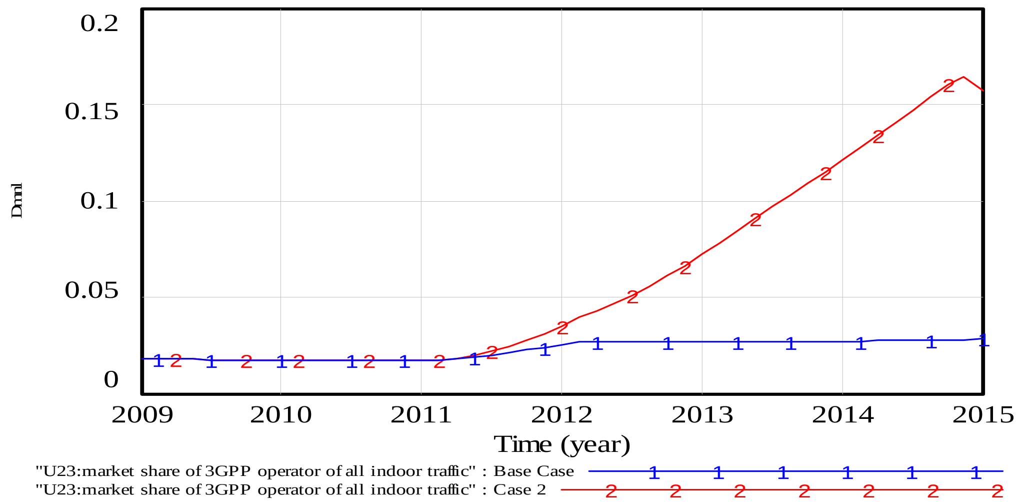


Figure 5.22 The market share of 3GPP operator of all indoor traffic under the Base case and Case 2

Case 3: Number of users per km2 rises (suburban to urban areas)

The Base case environment is a typical Finnish suburban area (2300 users per km2). Case 3 addresses the question, "What are the impacts of changing the environment to urban area (3300 users per km2 as shown in Figure 5.23) on key forces in the future of the local area access provisioning?"

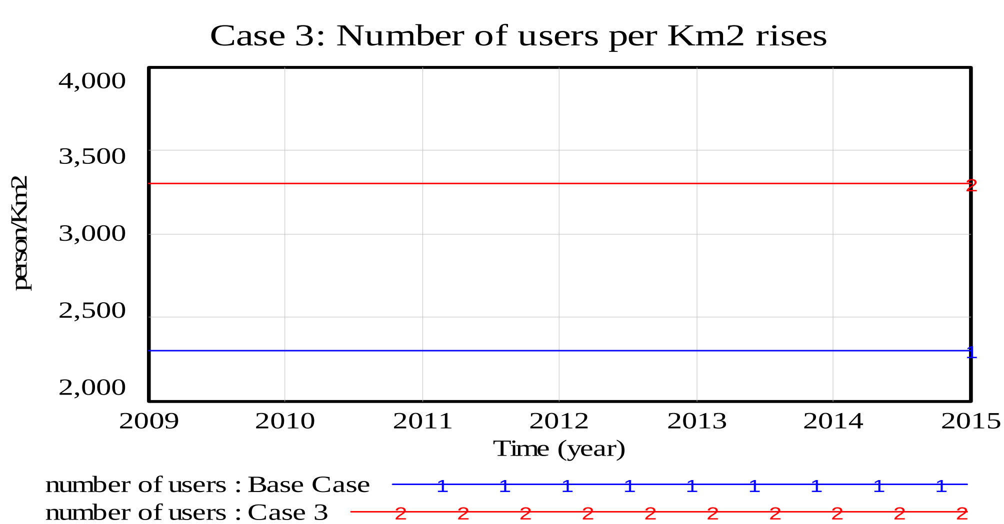


Figure 5.23 Number of users per km2 under the Base case and Case 3

In Case 3, *wireless indoor traffic demand* and *T2:wireless indoor traffic* (served demand) show similar growth patterns with the ones in the Base case except that the demand exceeds the supply already in 2010 (Figure 5.24).

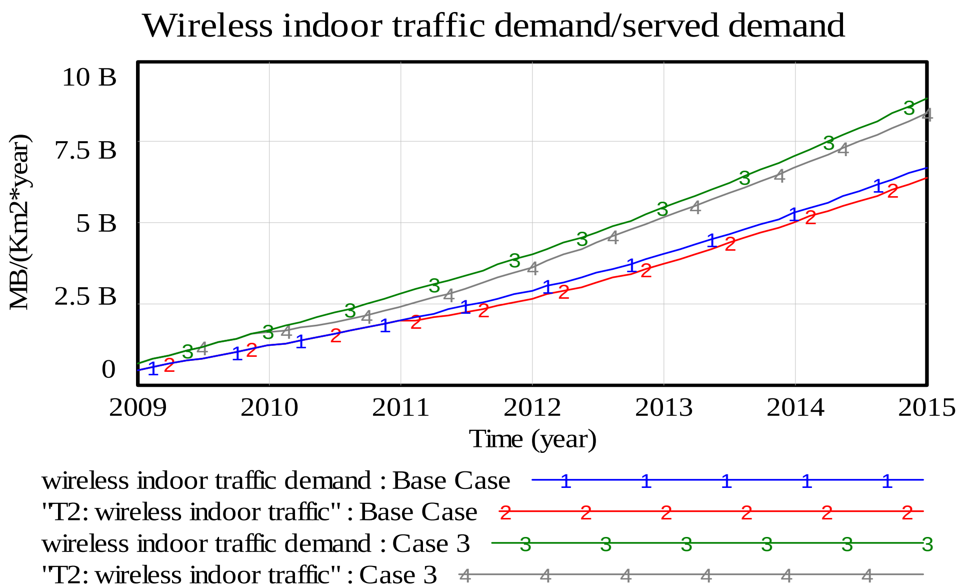


Figure 5.24 The amount of wireless indoor traffic demand/served demand under the Base case and Case 3

The number of access points/bases stations rises in urban areas (Figure 5.25), and the market share of 3GPP operator of all indoor traffic grows slightly (Figure 5.26). However, it is still small due to the large number of already deployed high speed Wi-Fi access points.

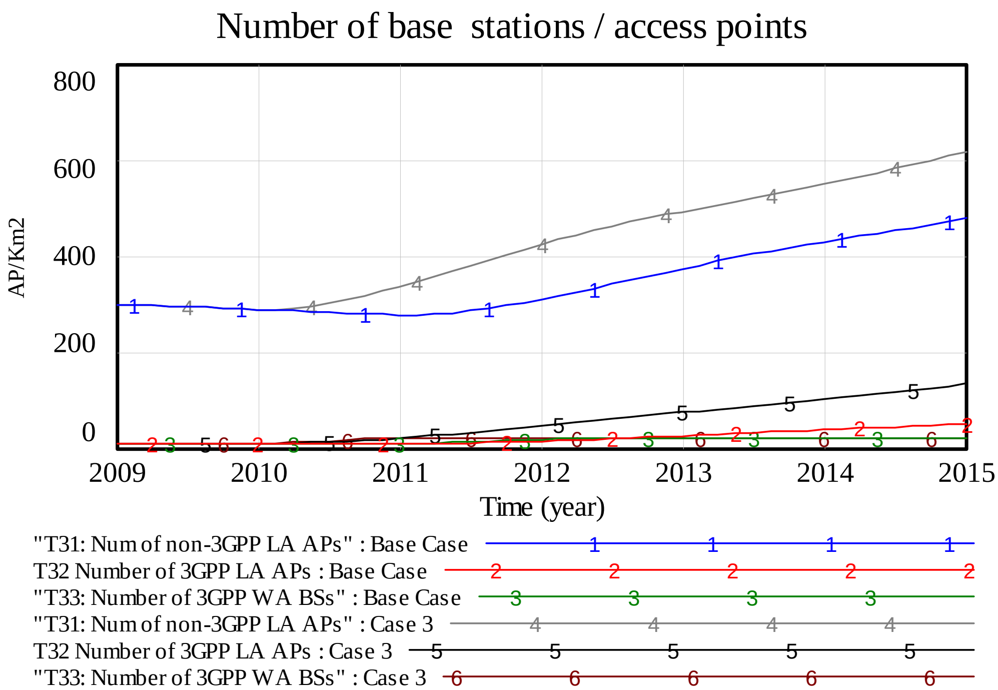


Figure 5.25 The number of access points/base stations under the Base case and Case 3

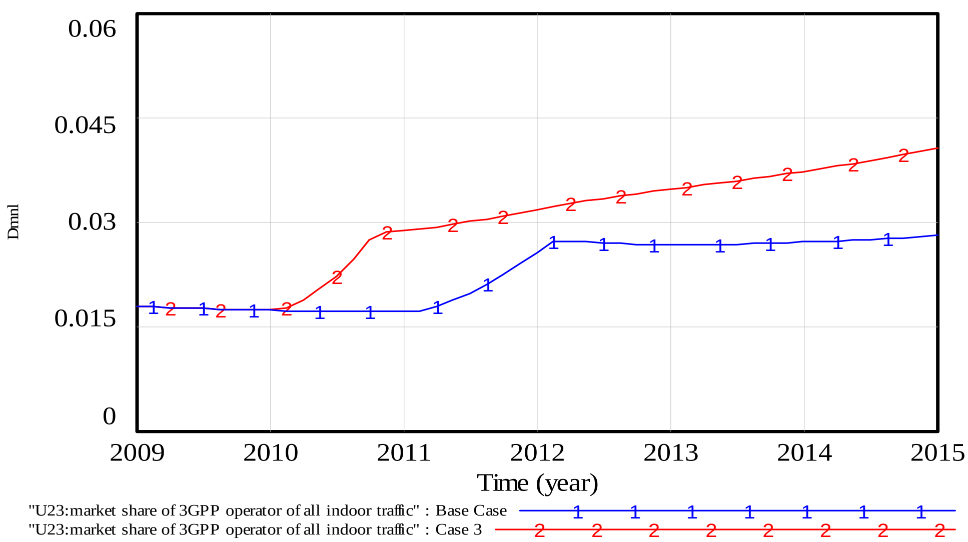


Figure 5.26 The market share of 3GPP operator of all indoor traffic under the Base case and Case 3

Case 4: Fear of wireless emissions rises

As discussed earlier, the fear of wireless emissions is one potential factor which could limit the growth of Wi-Fi and femtocell access points. The growth of the fear of wireless emissions (Figure 5.27) causes the growth of Wi-Fi and femtocell access points to decline, which in turn increases the unserved wireless indoor traffic (Figure 5.28) in the model.

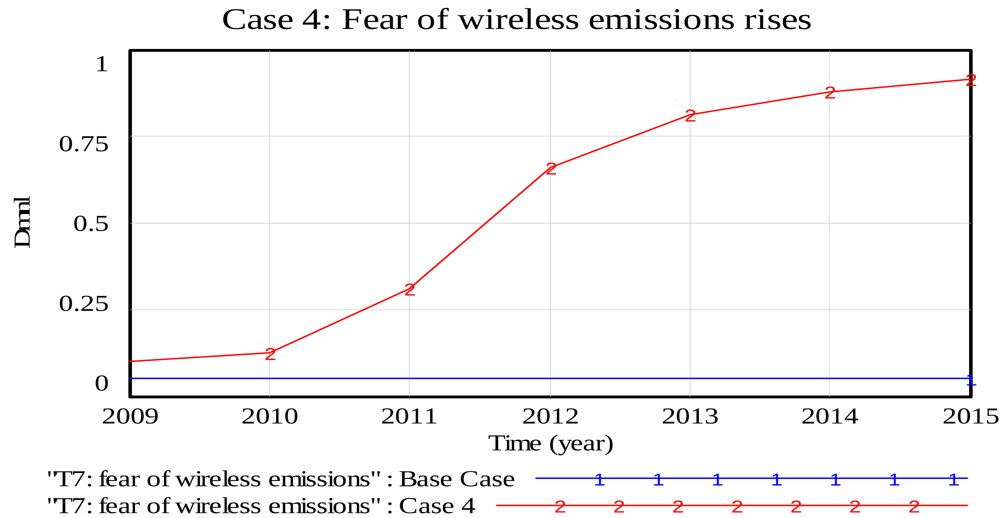


Figure 5.27 Fear of wireless emissions under the Base case and Case 4

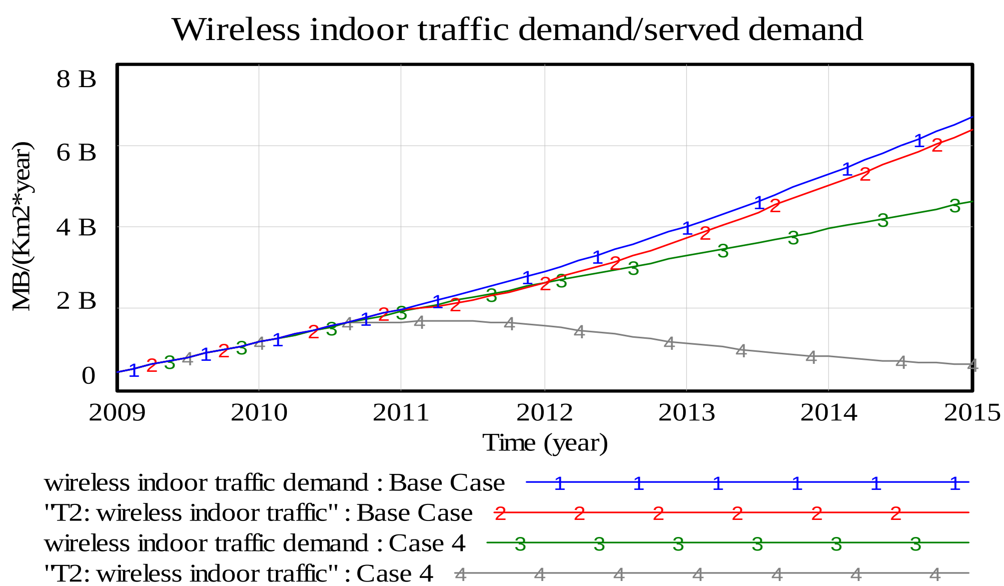


Figure 5.28 The amount of wireless indoor traffic trends under the Base case and Case 4

The higher the traffic demand, the larger number of access points/base stations are required. However, the growth of Wi-Fi and femtocell access points is limited (Figure 5.29) because of the fear of electro-smog from those equipments. This leads to increased pressure for more capacity from the WA network and gives reason for 3G/4G operators to request additional radio spectrum (Figure 5.30). As a result, the market share of 3GPP operators (Figure 5.31) grows which reflects the possible evolution path towards integrated access in the local area access provisioning.

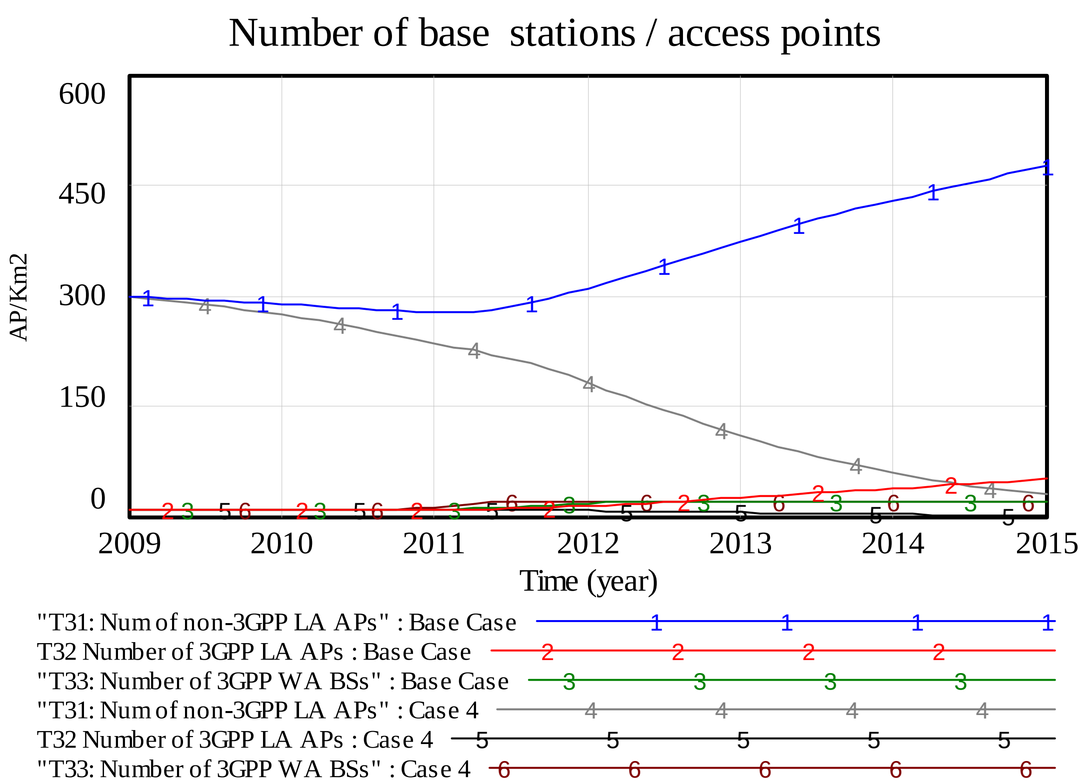


Figure 5.29 The number of base stations/access points under the Base case and Case 4

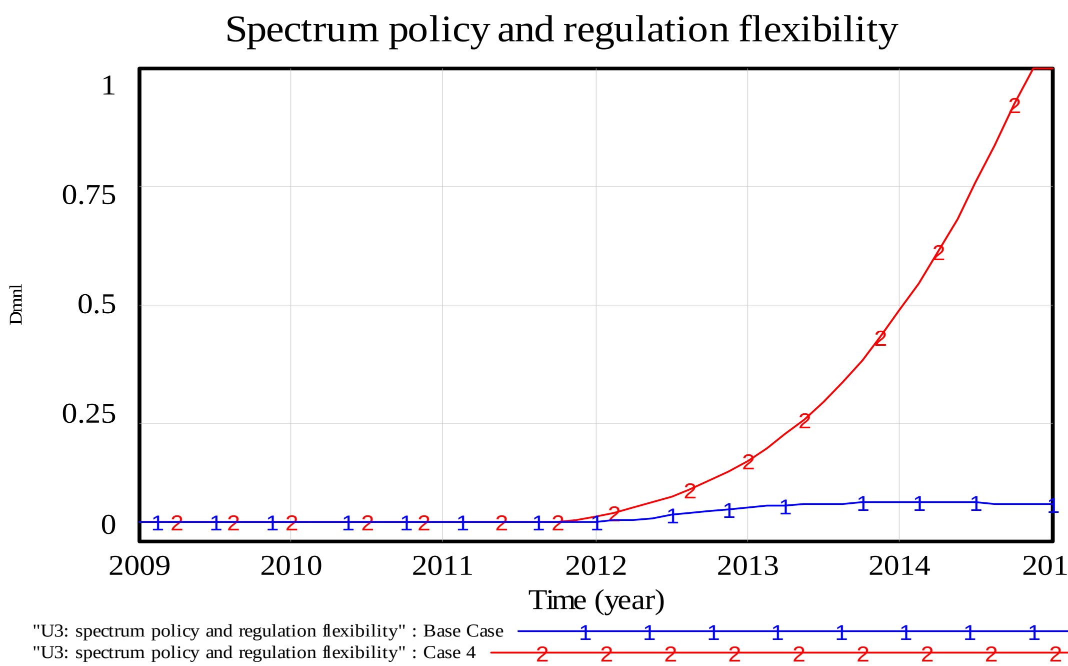


Figure 5.30 Spectrum policy and regulation flexibility under the Base case and Case 4

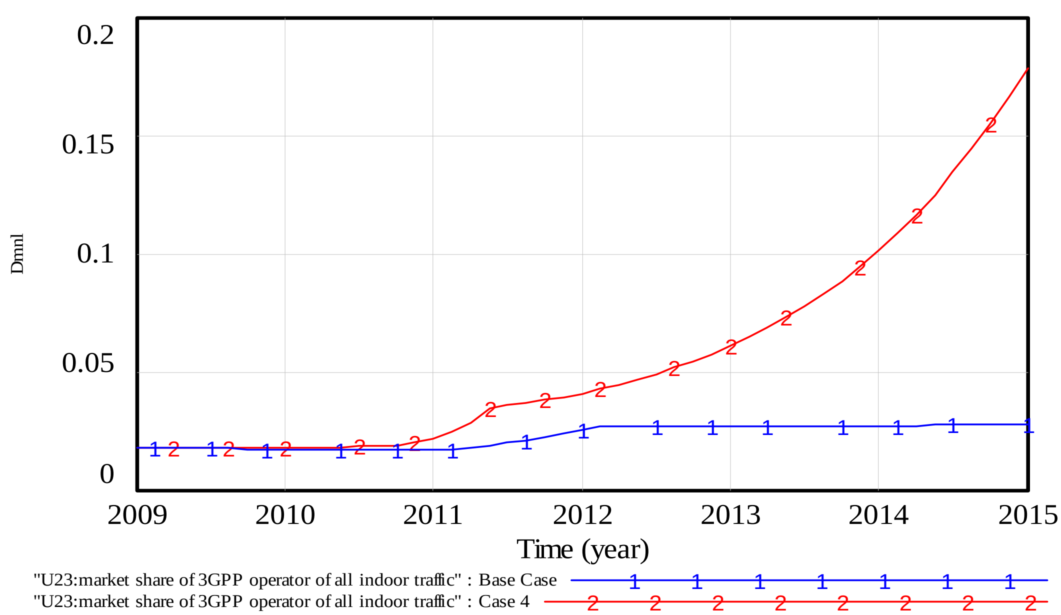


Figure 5.31 The market share of 3GPP operator of all indoor traffic under the Base case and Case 4

Case 5: Backhaul network is a bottleneck

So far, we assume that the capacity of the wired backhaul network is sufficient to support high speed femtocell and Wi-Fi access points, and radio interface is the bottleneck in the model. Here, in Case 5, the idea is to see what happens when the backhaul is the bottleneck. For this case, the model is slightly enhanced (depicted in Appendix D: Figure D.0.4). The changes are that the maximum number of non-3GPP LA and 3GPP LA access points are limited by the speed of domestic broadband connections.

If there are only 2Mbps domestic broadband connections (instead of 100 Mbps in the Base case), high speed Wi-Fi (54Mbps) and femtocell (7.2 Mbps) access points will be of little use. Figure 5.32 shows that the growth of the number of Wi-Fi and femtocell access points is limited since the capacity of wired backhaul network is not sufficient to support high speed femtocell and Wi-Fi access points. As a result, the wireless indoor traffic supply declines which in turn results in an increase in the unserved wireless indoor traffic demand (line marked with "5" in Figure 5.33[27]). Similar to Case 4, this leads to increased pressure for more capacity from the WA network and gives reason for 3G/4G operators to request additional radio spectrum (Figure 5.34) and improve their market share (Figure 5.35) in the future of the local area access provisioning.

In this case, U23 is quite near to one (Figure 5.35) since WA BSs cater to a large part of the indoor traffic, i.e. the access market goes to an integrated access type and the level of technological fragmentation is low.

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[27] Here the reader may notice one deficiency in our model - the *wireless indoor traffic demand* in the figure grows exponentially after 2011. However, in practice, if a user has only 2Mbps domestic broadband, his/her interest of downloading videos or music will decline, and therefore, the traffic demand declines. This can be considered as one of the limitations in our model.

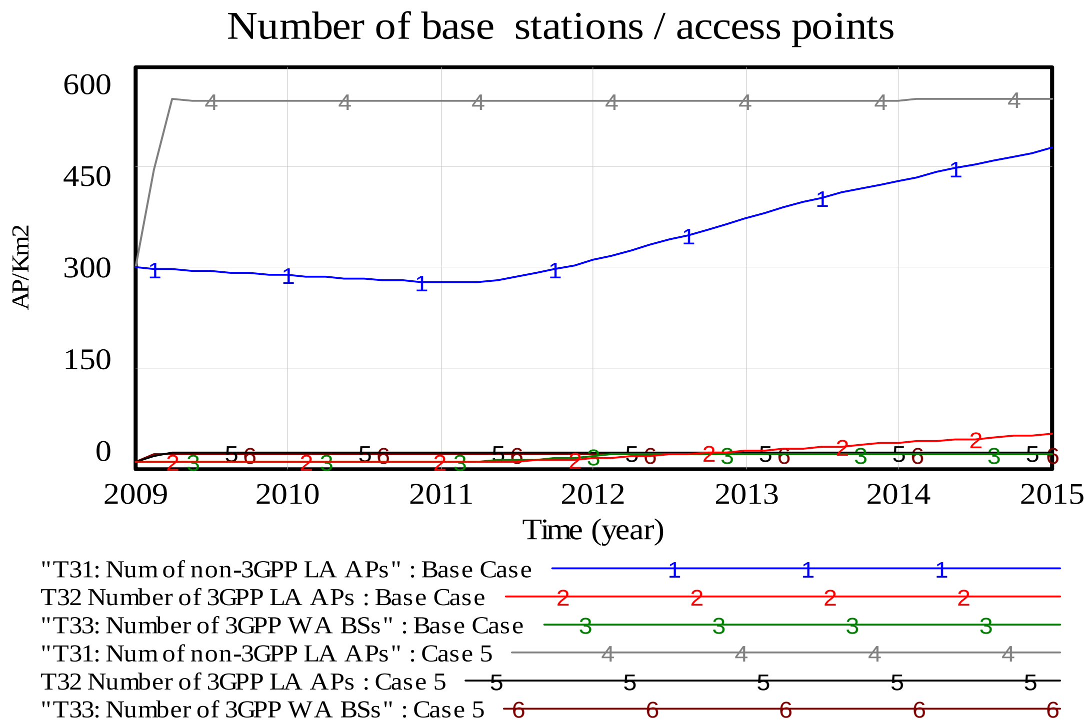

Figure 5.32 The number of base stations/access points under the Base case and Case 5

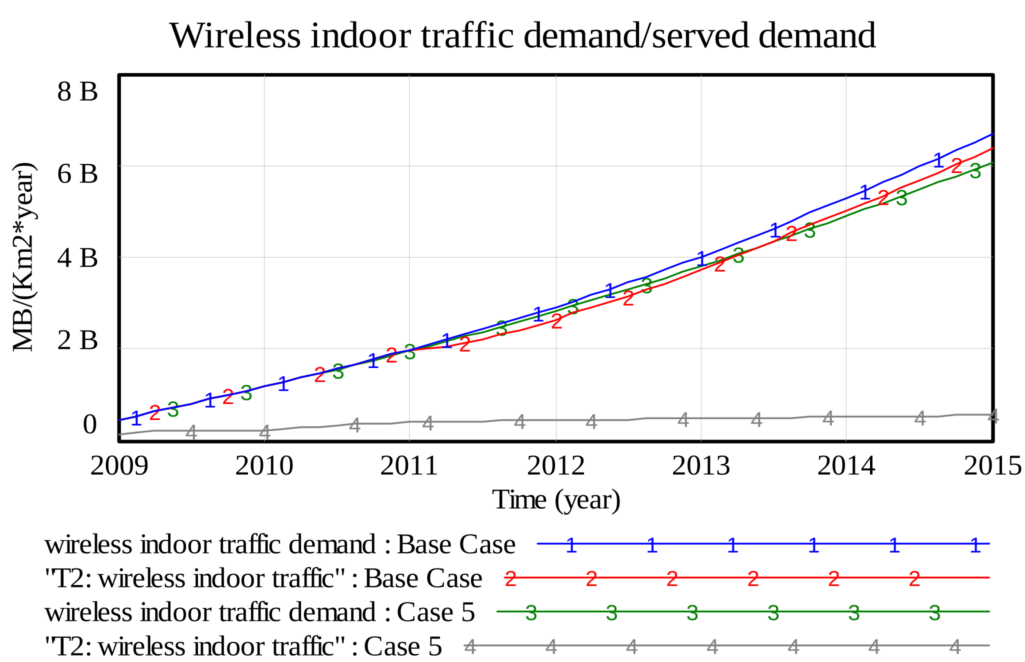

Figure 5.33 The amount of wireless indoor traffic demand/unserved demand under the Base case and Case 5

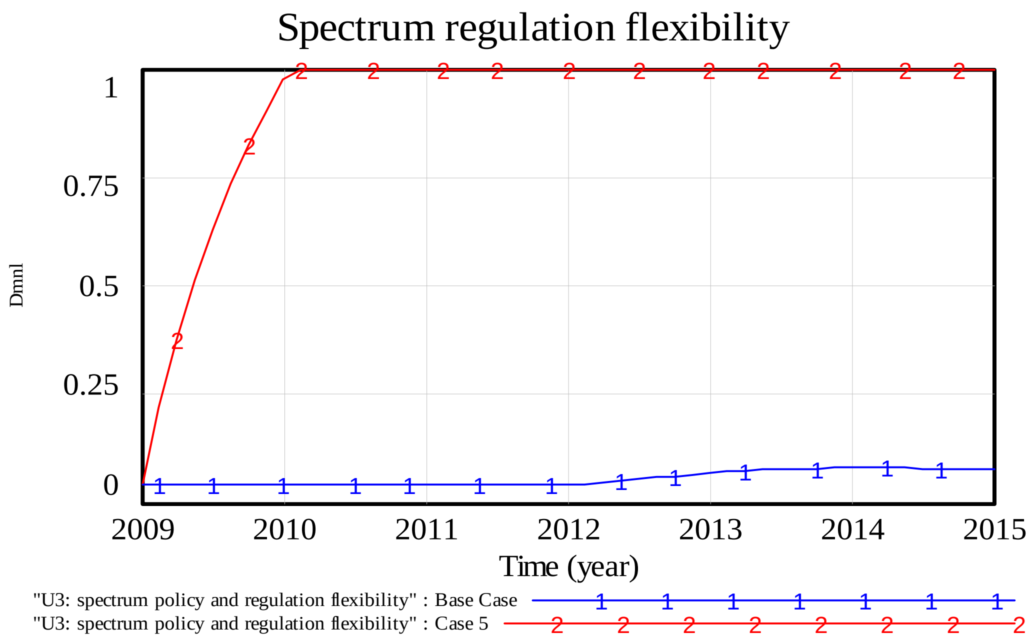

Figure 5.34 Spectrum policy and regulation under the Base case and Case 5

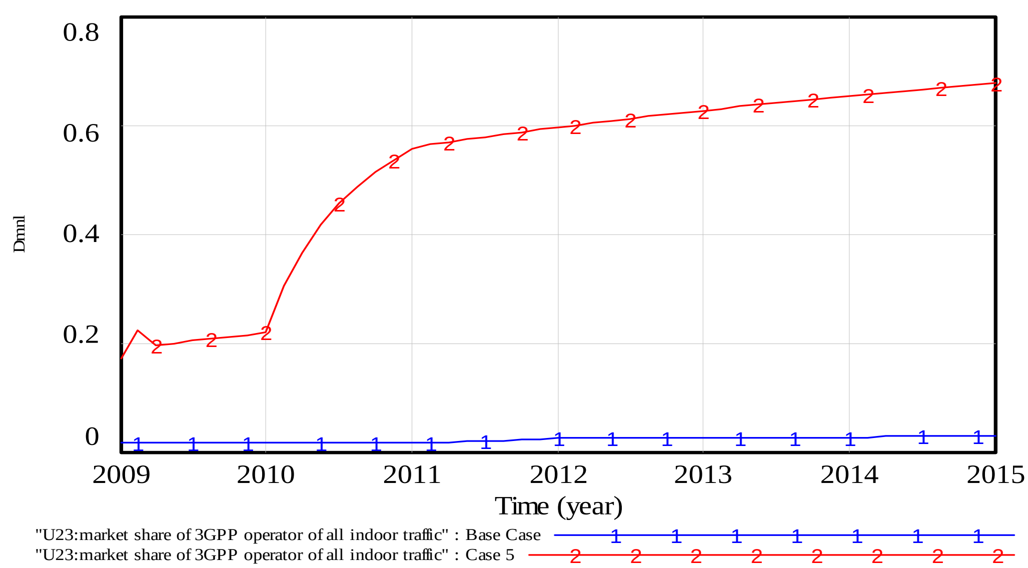

Figure 5.35 The market share of 3GPP operator of all indoor traffic under the Base case and Case 5

5.5 Summary and limitations

In this chapter a conceptual model was first constructed to model the causal connections between different forces regarding the future of the local area access provisioning based on the scenarios constructed by Smura and Sorri (2009). The conceptual model gives an overview of network connectivity to indoor located devices and has no functionality. The quantitative model includes the functionality and models the major forces in the future of the local area access provisioning quantitatively. The main objective of developing this quantitative model was not to find and simulate exact numerical values but to obtain a broad level of understanding about the dynamics of forces that affect the future of local area access provisioning.

The quantitative model consisted of four interrelated domains: *User (Demand) domain, Infrastructure (Supply) domain, Spectrum Regulation and Technology (Supply) domain* and *Market Share domain.* The domains focused on end-user dynamics, infrastructure dynamics, spectrum regulation and technology dynamics as well as market share dynamics, respectively. The last domain was mainly about the output of the model - the level of technological fragmentation in access provisioning.

Section 5.4 showed that most of the simulated evolution paths led to a rather fragmented indoor access provisioning scenario because of the large installed base of Wi-Fi access points (T31: Num of non-3GPP LA APs). Only heavy subsidization and high AP self-optimizing ability (Case 2) led to a significant market share for femtocells within the study period. Femtocells were, however, on a positive growth path (e.g. in the Base case the number of femtocells grew 500 % during the study period. The section also showed that the cases where disturbances were introduced (fear of wireless, backhaul is the bottleneck) led to a large market share for WA BSs. Although the results from the simulation were preliminary, we believe that this model is a valid first step in understanding the dynamic behavior of the future of the local area access provisioning and serves as a good basis for continuing the work.

Nevertheless, the model is a rough and simplified representation of the real world, and it has some limitations. For example the active yearly usage time of an access point should not be constant but should rather decrease as a function of throughput. One other limitation in the model is that end-users' indoor traffic demand is not limited by the speed of their domestic broadband connections (backhaul capacity) at all.

There has not been previous research done in the area of network connectivity to indoor located devices and system dynamics that the author is aware of. We believe that the modeling work in this thesis is the first one. This made the quantitative modeling to be a challenging task. The modeler's skills were also limited since it was the first time for the author to build a system dynamics model. Usually, having experience make using a method as complex as system dynamics simpler. In general, however, we believe our system dynamics model is a useful tool and a valid first step in modeling the dynamic behavior of the future of the local area access provisioning - regardless of the limitations.

Finally the author would like to emphasize that system dynamics modeling is an iterative process and the results presented here should serve as the first iteration round, and one should focus on the usefulness of a model rather than on validation and verification of the exact numerical values.

6 Conclusion

6.1 Results

In the thesis, the first research question was finding how people (end-users) use mobile device with different access technologies. Chapter 4 presented the results (e.g. usage of different applications, usage of different access networks, and daily data usage of WLAN and non-WLAN users) from handset-based measurement analysis.

The thesis work found that, on average over the entire day, people use mobile devices mostly for the purpose of voice calling application followed by browsing, messaging, business and productivity, multimedia and other applications. Among the four access networks (WCDMA, WLAN, GPRS and EDGE), WCDMA was proved to be the most widely used bearer technology by end-users to start a data session, on average over the entire day. The thesis work also investigated the user’s choice between access networks while launching various applications and found that there were more users for browsing applications than for messaging and multimedia in all types of access networks. For browsing and messaging applications, the average amount of data per session (kB) during WLAN connection was higher than during WCDMA, GPRS and EDGE connections, i.e. WLAN is mainly used by those users who in general use large amounts of data services.

Regarding the daily data usage of WLAN and non-WLAN users, the share of WCDMA access dropped from 79% among non-WLAN users to 50% among WLAN users, which can prove the use of WLAN as a potential complement and/or substitute to 3G networks for usage of data services. In the thesis, it was also found that 91% of all WLAN connections was made from private access points while the rest was from public ones, which shows that WLAN connections are mostly made from private access points located at home or office.

The second research question, “how is network connectivity provided to indoor located devices?”, was addressed by constructing a system dynamics model based on the scenarios constructed by Smura and Sorri (2009). The main objective of developing the model was to study the dynamics of forces that influence the structure and development of network connectivity to indoor located devices over the next 6 years (2009-2015). In terms of the quantitative model, the goal was not to find and simulate the exact numerical values, but to gain an overall understanding about the dynamics of forces that affect the future of local area access provisioning and study the possible evolution paths (business models).

Most of the simulated evolution paths in the model led to a rather fragmented indoor access provision scenario in the future of the local area access provisioning i.e. local access is likely to be controlled by other players than established mobile operators and provided both with licensed and unlicensed technologies. However, it is not easy to make too thorough conclusions from the model, since quantitative modeling of some abstract variables and interactions between them and the equations used in the model were based on the modeler's subjective views.

6.2 Future work

Regarding the mobile service usage analysis process used in the thesis, it is recommended to include the whereabouts of panelists in collected data in the future that can play an important role in identifying which applications and access technologies are used at home, office and other locations. In addition to Nokia S60-based smartphones, monitoring other mobile devices such as 2nd Phones and laptops in the study can be helpful in getting a better view on the actual mobile service usage.

In this thesis, one of the biggest challenges in the system dynamics modeling process was the presence of many abstract variables and unavailable data in the topic area. The future of the local area access provisioning is full of uncertainties and thus a more detailed data is required in the future to develop a better quantitative model.

The quantitative modeling, for the future of the local area access provisioning, could be improved by defining the market share differently from now (e.g. based on the number of access points and base stations) and by developing a better traffic model, where currently it is based on static active usage time, and by doing more work on the spectrum and technology domain (e.g. capacity of a technology should be based on spectral efficiency and the available blocks of frequencies).

In the current model only operator femtocell subsidization can be considered as industry structure related modeling and thus better quantitative modeling could be performed in the future, when the y-axis (industry structure) of the scenario matrix (discussed in Section 5.1.3) is modeled. Including dual mode APs (i.e. APs that have both WiFi and femtocells) in the model could also be helpful in getting a better view on the future of the local area access provisioning.

In general, system dynamics modeling is an iterative process and thus a more relevant and reliable quantitative results from the model could be derived in the future by taking the model through constant iteration, continual questioning, testing and refinement. It is also encouraged in the future to use an experienced system dynamics modeler, having good background in the topic area.

References

Amit, R. and Zott, C. (2001), "Value creation in e-business", *Strategic Management J.*, vol. 22, pp. 493-520.

Ballon, P. (2004), "Scenarios and business models for 4G in Europe", *Info: the Journal of Policy, Regulation and Strategy for Telecommunications, Information and Media*, Vol. 6, No. 6. pp. 363-382.

Bayless, D. (2004), "An Introduction to System Dynamics", available at: http://www.pioneerentrepreneurs.net/presentations/An%20Introduction%20to%20System%20Dynamics.html (accessed 10 July 2009).

Bouwman, H., Haaker, T., & De Vos, H. (2008), *Mobile Service Innovation and Business Models*, 1st ed, Springer, New York.

Chambers, D. (2008), *Femtocell Primer*, 1st ed, Lulu.com, United Kingdom

Chesbrough, H. and Rosenbloom, R.S. (2002), "The role of the business model in capturing value from innovation: evidence from Xerox Corporation's technology spin-off companies," *Industrial and Corporate Change*, vol.11, pp. 529-555.

Cisco (2009), "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update", available at: http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.pdf (accessed 20 July 2009).

Gartner (2008), *Glossary of Mobile and Wireless Communications Terminology, 2008*, Gartner, U.S.A.

Gruber, H. (2005), *The Economics of Mobile Telecommunications*, Cambridge University Press, New York.

Heikkinen, M.V.J. and Luukkainen, S. (2009), "Value Analysis of Technology Evolution: Case Mobile Peer-to-Peer Communications", in Proceedings of 8th Wireless Telecommunications Symposium (WTS 2009), Apr 22-24, 2009, Prague, Czech Republic.

Informa (2008), *Global Mobile Forecasts to 2013:8th Edition*, Informa Telecoms & Media, United Kingdom.

Informa (2008a), *Mobile Networks Forecasts: Future Mobile Traffic, Base Stations and Revenues*, Informa Telecoms & Media, United Kingdom.

Informa (2009), *Future Mobile Broadband: SPA & EV-DO to LTE Networks, Devices & Services 3rd Edition*, Informa Telecoms & Media, United Kingdom.

Hubbard, D.W. (2007), *How to Measure Anything: Finding the Value of Intangibles in Business*, John Wiley & Sons, Inc., Hoboken, New Jersey.

Karikoski, J.O.A. (2009), Scenarios and System Dynamics of Mobile Peer-to-Peer Content Distribution, *Department of Communications and Networking, Helsinki University of Technology*, Master's Thesis.

Kirkwood, C.W. (1998), "System Dynamics Methods: A Quick Introduction", available at: http://www.public.asu.edu/~kirkwood/sysdyn/SDIntro/sdintro.zip (accessed 10 July 2009).

Kivi A. (2009), "Mobile Handset Population in Finland 2005-2008, MoMI project report", available at: http://www.netlab.tkk.fi/~jakivi/publications/Kivi_Mobile_Handset_Population_2005-2008.pdf (accessed 02 September 2009).

Kotler, P. & Armstrong, G. (1996), *Principles of marketing*, Pearson Education, Inc., Upper Saddle River, New Jersey.

Lehr, W. and Mcknight, L. W. (2003), "Wireless Internet access: 3G vs. WiFi?" *Telecommunications Policy* In Compeitition in Wireless: Spectrum, Service and Technology Wars, Vol. 27, No. 5-6, pp. 351-370.

Oreskes, N., Shrader-Frechette, K. and Belitz, K. (1994), Verification, validation, and confirmation of numerical models in the earth sciences, Sciences 263 (4Feb), 641-646.

Osterwalder, A., Pigneur, Y. and Tucci, C.L. (2005), "Clarifying business models: origins, present, and future of the concept," *Communications of the Association for Information Systems*, vol. 16, pp. 1-25.

Sainio, L-M. (2007), Tietoliikenne ja liiketoiminta Luento, available at: www.it.lut.fi/kurssit/07-08/CT30A3900/Materiaalit/Lissu%20Tite%20ja%20liiketoiminta.pdf (accessed 8 June 2009).

Sandrasegaran, K. (2002), "Evolution from GSM to 3G", available at: www.ips.gov.au/IPSHosted/NCRS/wars/wars2002/proceedings/comm-c/screen/sandrasegaran_e-abs.pdf (accessed 26 July 2009).

Smura, T. (2008), “Access alternatives to mobile services and content: analysis of handset-based smartphone usage data", in ITS 17th Biennial Conference, Montreal, Canada, June 24-27, 2008.
Smura, T. and Saksela, H. (2006), “Radio Spectrum Policy in Europe”, available at: http://www.tml.tkk.fi/Opinnot/T-109.7510/2006/reports/Policy.doc (accessed 20 June 2009).

Smura, T. and Sorri, A. (2009), **“**Future Scenarios for Local Area Access: Industry Structure and Access Fragmentation”, in Proceedings of the Eighth International Conference on Mobile Business (ICMB 2009), Dalian, China, June 27-28, 2009.

Smura, T., Kivi, A. and Töyli, J. (2009), “A Framework for Analyzing the Usage of Mobile Services”, *INFO - The journal of policy, regulation and strategy for telecommunications, information and media*, vol. 11, no. 4, pp. 53-67.

Sterman, J. D. (2000), *Business Dynamics: Systems Thinking and Modeling for a Complex World, The* McGraw-Hill Companies, Inc.

Uusitalo, M.A. (2006). “Global Vision for the Future Wireless World from the WWRF,” IEEE Vehicular Technology Magazine, Vol. 1, No. 2, pp. 4-8.

Vensim (2003), “Vensim 5 Modeling Guide”, available at: www.engga.uwo.ca/research/iclr/simonovic/ES564/ModelingGuide.pdf (accessed 20 May 2009).

Vensim (2007), “Vensim User Guide”, available at: http://www.vensim.com/ffiles/VensimUsersGuide.zip (accessed 20 May 2009).

Verkasalo, H. (2009), Handset-Based Analysis of Mobile Service Usage, PhD Thesis, *Department of Communications and Networking, TKK Helsinki University of Technology*.

Verkasalo, H. & Hämmäinen, H. (2007), “A Handset-Based Platform for Measuring Mobile Service Usage”, *INFO: The Journal of Policy, Regulation and Strategy*,Vol 9 No 1.

Yankee Group (2000), *The Wireless Access Report*, The Yankee Group, Boston, MA.

Appendix

Appendix A: Usage time distributions (Application categories)

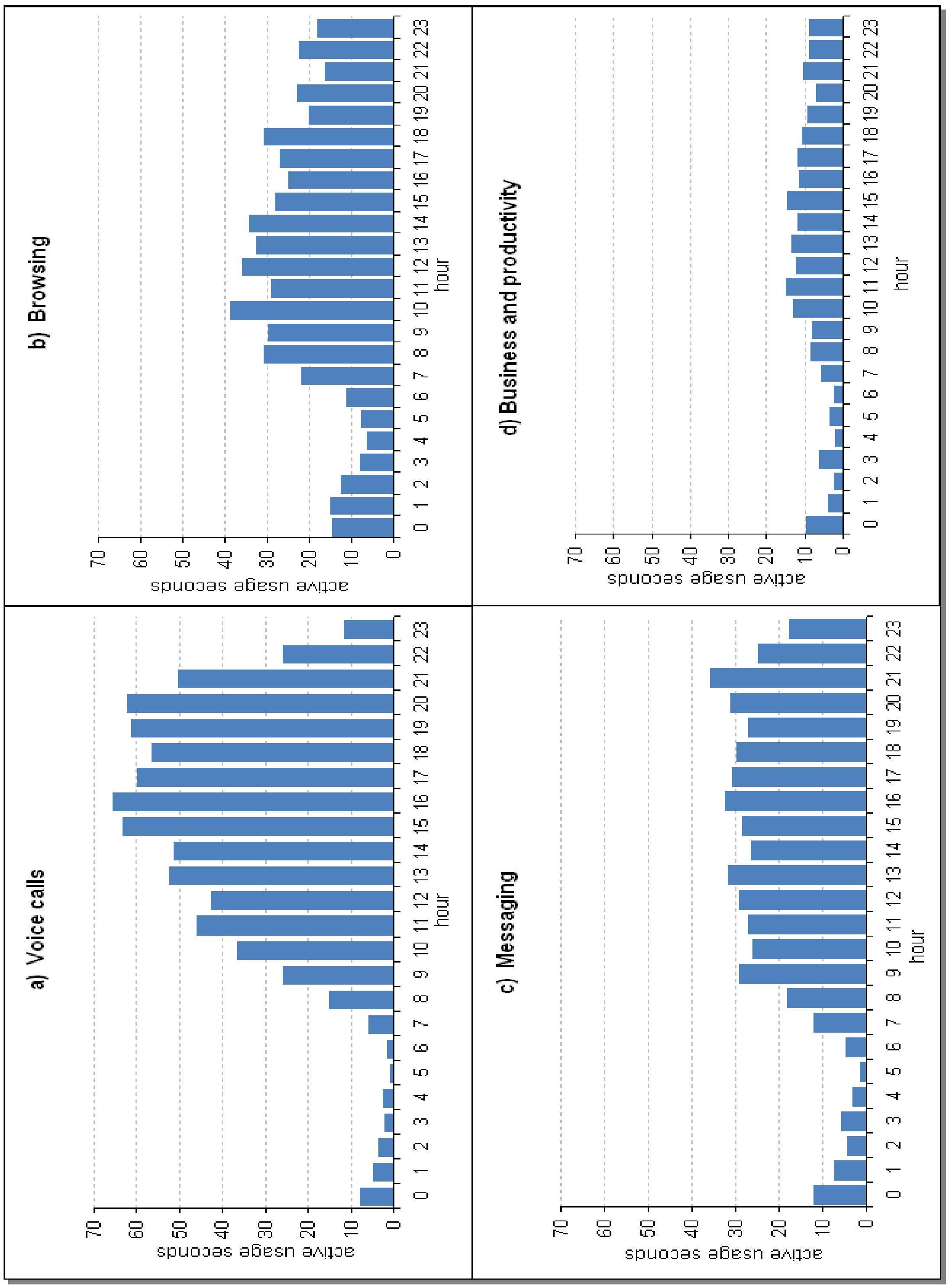

Figure A.0.1 Distribution of active usage time (active seconds per hour per day) for different application categories (N=149)

Appendix B: Daily data usage distribution (access networks)

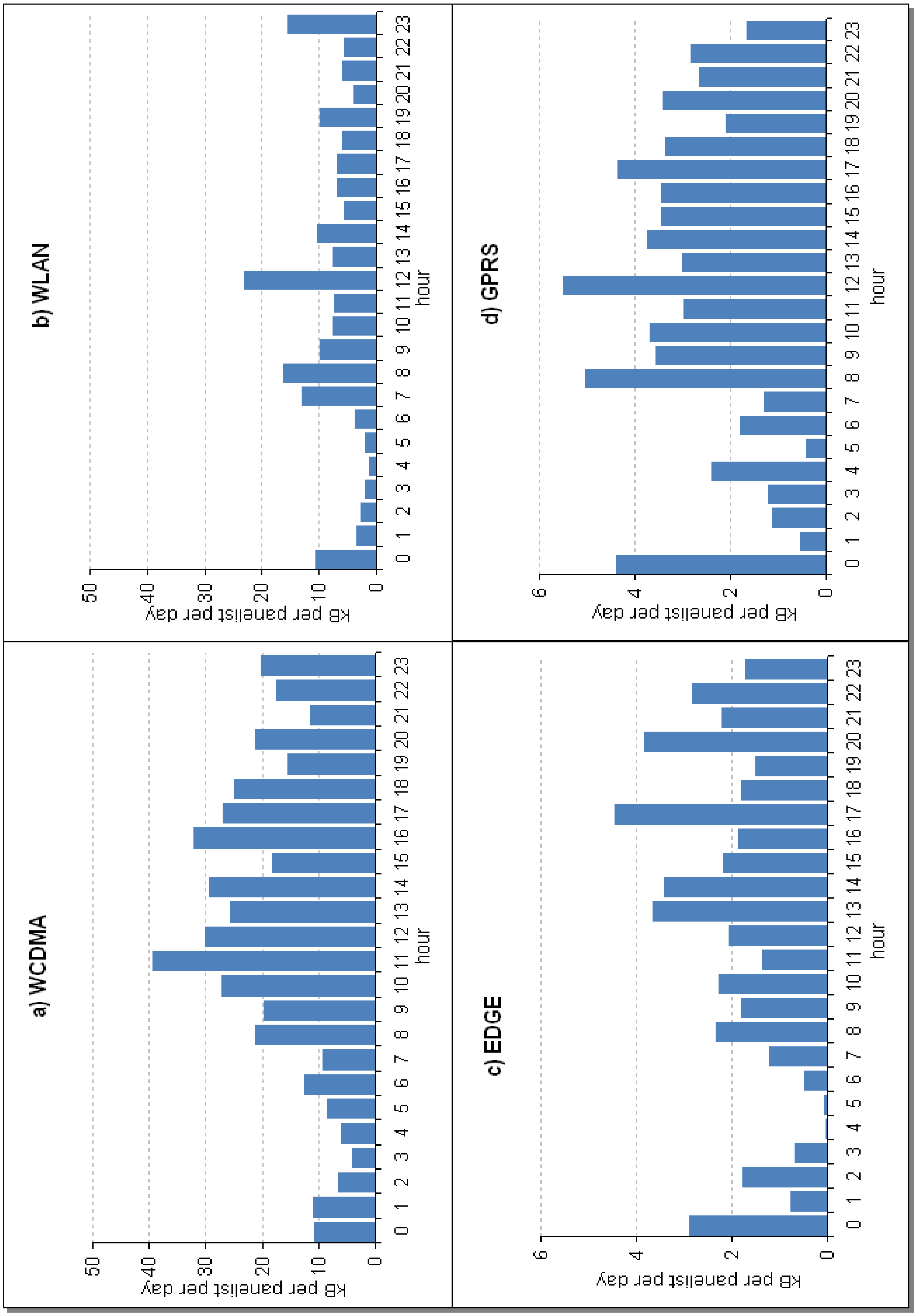

Figure B.0.2 Distribution of daily data usage between hours of day .for different bearer technologies (N=130)

Appendix C: Usage time distributions (access networks)

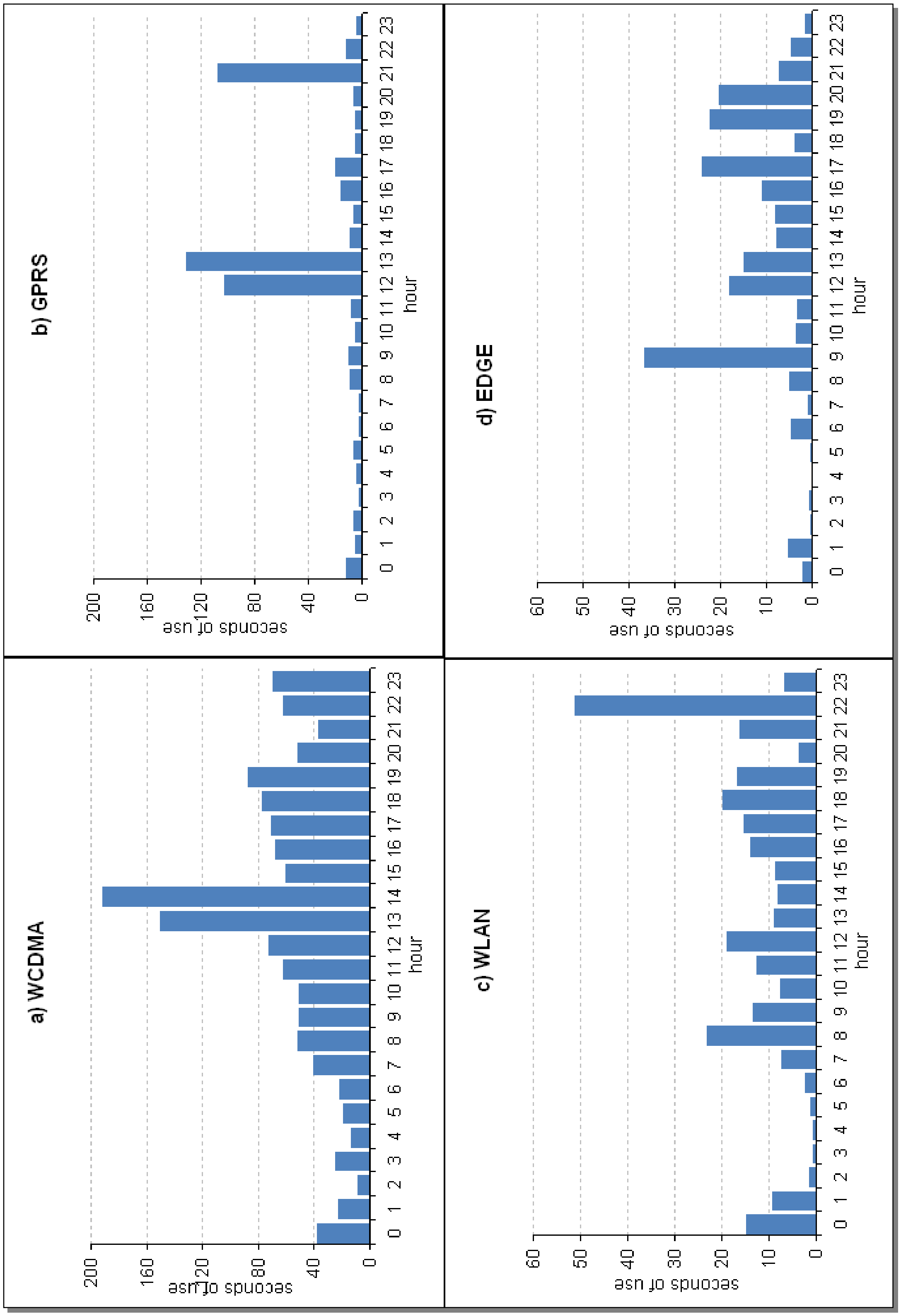

Figure C.0.3 Distribution of active usage time divided between hours of day, for different bearer technologies (N=130)

Appendix D: Modified version of the infrastructure domain

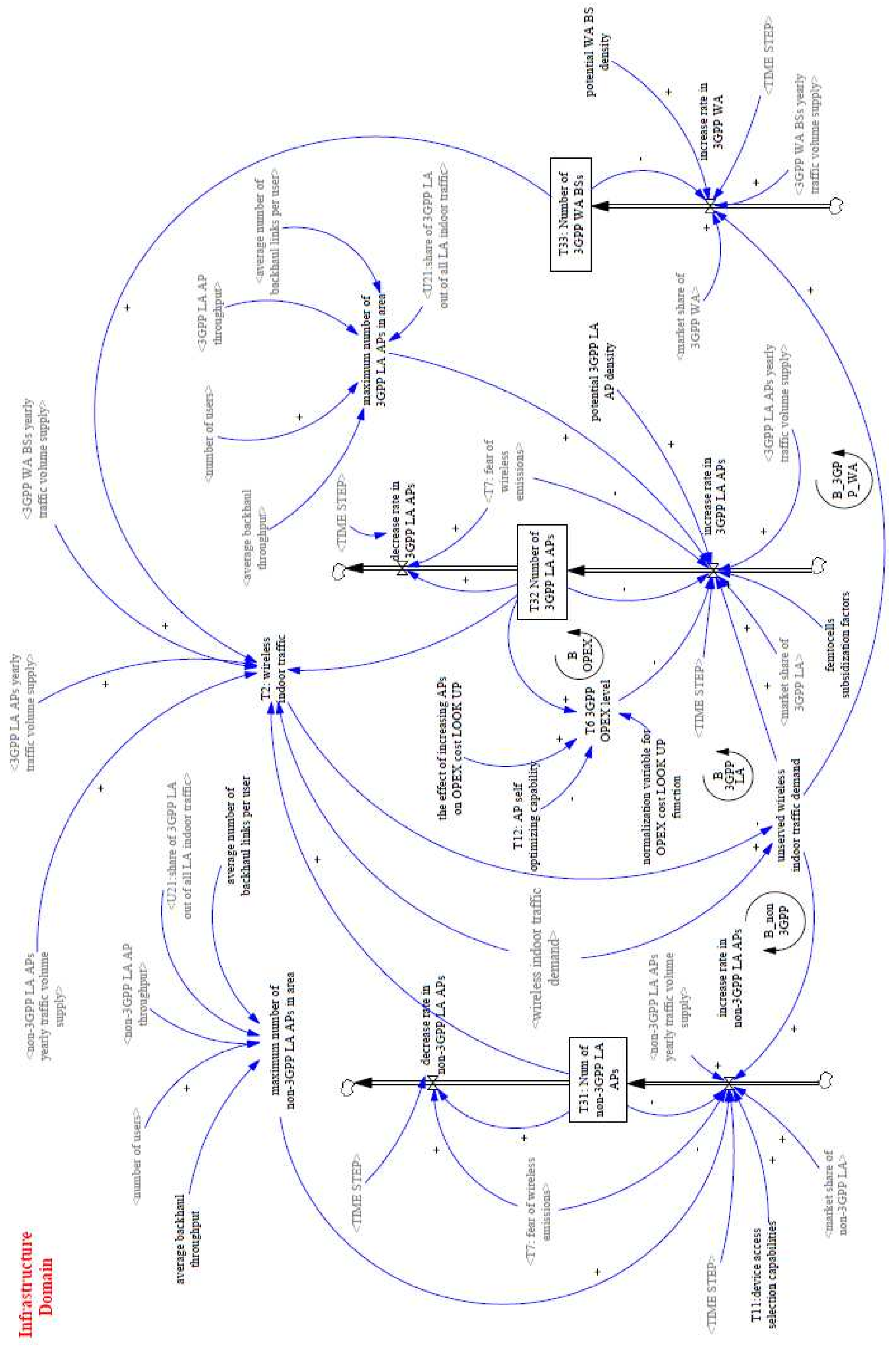

Figure D.0.4 Modified version of infrastructure domain

Appendix E: Parameters and Equations

Parameters

U5: Number of mobile devices (Unit: device/km2): The number of mobile devices per km^2.

Potential device base growth (Unit: device/km2/year): Expected growth rate of devices based on the research which forecasts that there will be 1000 devices per person by 2017 (Uusitalo, 2006).

T11: device access selection capabilities (Unit: dmnl, Ranges: 0 (low) – 1 (high)): As devices' capabilities such as ease of network discovery, mobility management, network prioritization and selection, authentication, and connectivity management improve, more and more users are willing to employ them, which in turn increase the number of mobile devices.

*U22: share of LA out of all indoor traffic (Unit: dmnl, Ranges: 0 - 1)***:** The ratio of data traffic from non-3GPP LA access points (Wi-Fi) and 3GPP LA access points (femtocell) to all indoor traffic (from Wi-Fi and femtocell access points and 3GPP WA base stations).

T7: fear of wireless emissions (Unit: dmnl, Ranges: 0 - 1): Wireless emissions have a negative effect on the growth of the number of access points and active mobile devices. The value zero refers to minimum fear while one indicates maximum fear.

increase rate in number of mobile devices (Unit: device/km2/year): The annual growth rate of mobile devices' number per km2.

decrease rate in number of mobile devices (Unit: device/km2/year): The annual decline rate of mobile devices' number per km2.

*number of users (Unit: person/km2, Initial value: 2300 (*Typical Finnish suburban area*)):* The number of households per km2.

*average number of primary devices per person (Unit: device/person, Initial value: 2***).**

number of primary devices (Unit: device/km2): The number of primary devices per km2.

number of secondary devices (Unit: device/km2): The number of secondary devices per km2.

data traffic from primary devices (video) per person (Unit: MB/year/person): Annual data traffic from primary devices per user. Based on the discussion with experts in the topic area, we assumed that the data traffic grows from 200 GB (2009) to 2000GB (2015).

average traffic demand per secondary device (Unit: MB/device/year, Initial value: 500): Annual data traffic from secondary device. The data traffic from tooth brush or refrigerator in the future isn't that high in contrast to handsets or laptops thus taking the value 500 seems reasonable for our model.

total traffic demand from primary devices (Unit: MB/km2/year): Total annual data traffic from primary devices.

total traffic demand from secondary devices (Unit: MB/km2/year): Total annual data traffic from secondary devices.

wireless indoor traffic demand (Unit: MB/km2/year): Total annual data traffic from both primary and secondary devices.

T31: Num of non-3GPP LA APs (Unit: AP/km2, Initial value: 300): The number of Wi-Fi access points per km^2.

T32 Number of 3GPP LA APs (Unit: AP/km2, Initial value: 10): The number of femtocells per km^2.

T33: Number of 3GPP WA BSs (Unit: BS/km2, Initial value: 10): The number of 3G/4G base stations (sectors) per km^2.

increase rate in non-3GPP LA APs (Unit: AP/km2/year): The annual growth rate of non-3GPP LA APs' number per km^2.

increase rate in 3GPP LA APs (Unit: AP/km2/year): The annual growth rate of 3GPP LA APs' number per km^2.

T12: AP self optimizing capability (Unit: dmnl Ranges: 0 (low) – 1 (high)): Refers to self optimizing capability of femtocells.

femtocells subsidization factors (*Unit: dmnl, Initial value: 1 , Ranges: > = 1*): Refers to willingness of operators to subsidize femtocells.

increase rate in 3GPP WA (Unit: BS/km2/year): The annual growth rate of 3GPP wide area base stations.

T2: wireless indoor traffic (Unit: MB/km2/year): The wireless indoor traffic comes from traffic demand being served by three different radio access technologies: non-3GPP LA, 3GPP LA and 3GPP WA.

potential 3GPP LA AP density (Unit: AP/km2, Initial value: 500): The maximum number of femtocells allowed per km^2.

potential WA BS density (Unit: BS/km2, Initial value: 20): The maximum number of base stations allowed per km^2.

U3: spectrum policy and regulation flexibility (Unit: dmnl, Ranges: 0 - 1): The maximum value (one) refers to larger degree of liberalization and technology neutrality. It is the function of three variables in the model.

- DELAYED SPECTRUM DEMAND

This is the spectrum demand (delayed by some time) from operators when there is a tremendous growth in wireless indoor traffic demand.

- The ratio of flexible mobile spectrum to all spectrums feasible for mobile systems.

The total bandwidth of mobile spectrum allocated in flexible way out of all spectrums feasible for mobile systems. In Finland out the total bandwidth 7545.5MHz, unlicensed spectrums take a share of 538.5MHz (Timo and Henrik, 2006).

- SDR (Software Defined Radio) capabilities

Software Defined Radio is a radio in which some or all of the physical layer functions are software defined. We believe the use of a common radio platform plays a positive role on spectrum policy and regulation flexibility.

ideal non-3GPP LA AP density (Unit: AP/km2): The maximum number of non-3GPP LA APs allowed per km^2.The total capacity of access points will start to decline if their number exceeds the limit because of interference issues.

non-3GPP LA AP throughput (Unit: MB/sec/AP): The capacity of non-3GPP local area access point such as Wi-Fi. Lack of centralized RRM (Radio Resource Management) in Wi-Fi type access points may lead to many problems, e.g. interference between carriers of different Wi-Fi APs.

non-3GPP LA AP throughput in 2009 refers to the practical peak date rate of IEEE 802.11g (e.g. 30% of 54Mbps).

non-3GPP throughput multiplier represents improvement of the throughput of an access point due to new IEEE 802.11x technologies and utilization of the unused allocated unlicensed bands such as the 5 GHz band.

3GPP LA AP throughput: The capacity of femtocell access point.

3GPP throughput multiplier represents effects of new 3GPP technology and utilization of unused licensed IMT-2000 band.

U21: share of 3GPP LA out of all LA indoor traffic (Unit: dmnl, Ranges: 0 - 1): The ratio of data traffic through femtocell access points to all local area indoor traffic (Wi-Fi and femtocell access points).

U22: share of LA out of all indoor traffic (Unit: dmnl, Ranges: 0 - 1): The ratio of data traffic through Wi-Fi and femtocell access points to all indoor traffic from the three access technologies (Wi-Fi, femtocell and 3G/4G).

U23: market share of 3GPP operator of all indoor traffic (Unit: dmnl, Ranges: 0 - 1): The ratio of data traffic through femtocell access points and 3G/4G base stations (sectors) to all indoor traffic.

Equations

(01) "3GPP LA AP throughput (femtocells) in 2009" = 0.3*7.2/8

Units: MB/ (AP*sec)

(02) "3GPP LA AP throughput"= 3GPP LA AP throughput (femtocells) in 2009" * (1+DELAYED ADDITIONAL SPECTRUM)* "3GPP throughput multiplier"

Units: MB/sec/AP

(03) "3GPP LA APs yearly traffic volume supply"= active yearly usage time per LA AP*"3GPP LA AP throughput"

Units: MB/AP/year

(04) "3GPP throughput multiplier"

Units: Dmnl

(05) "3GPP WA BS throughput in 2009"= 3*10/8

Units: MB/sec/BS

(06) "3GPP WA BS throughput"="3GPP WA BS throughput in 2009"*(1+DELAYED ADDITIONAL SPECTRUM)*"3GPP throughput multiplier"

Units: MB/sec/BS

(07) "3GPP WA BSs yearly traffic volume supply"= active yearly usage time per WA BS*"3GPP WA BS throughput"/8

Units: MB/BS/year

(08) active yearly usage time per LA AP= 365*60*60*1

Units: sec/year

(09) active yearly usage time per WA BS= 365*60*60*12

Units: sec/year

(10) all spectrum feasible for mobile systems= 7545.5

Units: MHz

(11) average backhaul throughput= 100/8

Units: MB/(sec*AP)

(12) average number of primary devices per person=2

Units: device/person

(13) average traffic demand per secondary device= 500

Units: MB/device/year

(14) AVERAGING TIME= 1

Units: year

(15) "data traffic from primary devices (video) per person"

Units: MB/year/person

(16) decrease rate in 3GPP LA APs= 0.1*T32 Number of 3GPP LA APs*"T7: fear of wireless emissions"/TIME STEP

Units: AP/(Km2*year)

(17) "decrease rate in non-3GPP LA APs"= 0.1*"T31: Num of non-3GPP LA APs"*"T7: fear of wireless emissions"/TIME STEP

Units: AP/Km2/year

(18) decrease rate in number of mobile devices= 0.1*"U5: Number of mobile devices"*"T7: fear of wireless emissions"/TIME STEP

Units: device/Km2/year

(19) DELAYED ADDITIONAL SPECTRUM= DELAY FIXED("U3: spectrum policy and regulation flexibility", 1, "U3: spectrum policy and regulation flexibility")

Units: Dmnl

(20) DELAYED SPECTRUM DEMAND=DELAY FIXED(unserved wireless indoor traffic demand/"T2: wireless indoor traffic" , 1, unserved wireless indoor traffic demand /"T2: wireless indoor traffic")

Units: Dmnl

(21) femtocells subsidization factors= 1

Units: Dmnl

(22) FINAL TIME = 2015

Units: year

(23) flexible mobile spectrum= 538.5

Units: MHz

(24) "ideal non-3GPP LA AP density"= 500

Units: AP/Km2 [0,999]

(25) increase rate in 3GPP LA APs= (MIN(potential 3GPP LA AP density-T32 Number of 3GPP LA APs,(unserved wireless indoor traffic demand*market share of 3GPP LA)/"3GPP LA APs yearly traffic volume supply")*femtocells subsidization factors*(1-"T7: fear of wireless emissions")^3*MAX(0.2, (1-T6 3GPP OPEX level)))/TIME STEP

Units: AP/(Km2*year)

For modeling purposes we limit the number of femtocell access points, because after a certain density of APs the total capacity won't grow due to interference issues.

(26) increase rate in 3GPP WA=(MIN(potential WA BS density-"T33: Number of 3GPP WA BSs",(unserved wireless indoor traffic demand*market share of 3GPP WA)/"3GPP WA BSs yearly traffic volume supply"))/TIME STEP

Units: BS/Km2/year

Here also, for modeling purposes we limit the number of base stations/sectors since there is a hard limit to the number of sectors due to controlled network planning by mobile operator.

(27) "increase rate in non-3GPP LA APs"=((unserved wireless indoor traffic demand *"market share of non-3GPP LA"/"non-3GPP LA APs yearly traffic volume

supply")*(1-"T7: fear of wireless emissions")^3*MAX(0.1, "T11:device access selection capabilities"))/TIME STEP

Units: AP/(Km2*year)

(28) increase rate in number of mobile devices=potential device base growth* MIN((1-"T7: fear of wireless emissions")^3*(1+"U22:share of LA out of all indoor traffic")*"T11:device access selection capabilities",1)

Units: device/Km2/year

(29) INITIAL TIME = 2009

Units: year

(30) market share of 3GPP LA= ("U23:market share of 3GPP operator of all indoor traffic"+"U22:share of LA out of all indoor traffic") - 1

Units: Dmnl

(31) market share of 3GPP WA= "U23:market share of 3GPP operator of all indoor traffic"- ("U21:share of 3GPP LA out of all LA indoor traffic"*"U22:share of LA out of all indoor traffic")

Units: Dmnl

(32) "market share of non-3GPP LA"=1-"U23:market share of 3GPP operator of all indoor traffic"

Units: Dmnl [0,1]

(33) "non-3GPP LA AP throughput in 2009"=0.3 * 54/8

Units: MB/sec/AP

(34) "non-3GPP LA AP throughput"="non-3GPP LA AP throughput in 2009"*"non-3GPP throughput multiplier"*(1+DELAYED ADDITIONAL SPECTRUM)*the effect of interference on capacity LOOK UP("ideal non-3GPP LA AP density"/normalization variable for capacity LOOK UP function)

Units: MB/sec/AP

(35) "non-3GPP LA APs yearly traffic volume supply"= active yearly usage time per LA AP*"non-3GPP LA AP throughput"

Units: MB/AP/year

(36) "non-3GPP throughput multiplier"

Units: Dmnl

(37) normalization variable for capacity LOOK UP function=1

Units: AP/Km2

(38) normalization variable for OPEX cost LOOK UP function= 1

Units: AP/Km2

(39) number of primary devices= average number of primary devices per person*number of users

Units: device/Km2

(40) number of secondary devices="U5: Number of mobile devices"-number of primary devices

Units: device/Km2

(41) number of users=2300

Units: person/Km2

(42) potential 3GPP LA AP density= 500

Units: AP/Km2

(43) potential device base growth

Units: device/Km2/year

(44) potential WA BS density= 20

Units: BS/Km2

(45) SAVEPER = TIME STEP

Units: year [0,?]

The frequency with which output is stored.

(46) SDR capabilities= 0.1

Units: Dmnl [0,1]

(47) "T11:device access selection capabilities"

Units: Dmnl [0,1]

(48) "T12: AP self optimizing capability"

Units: Dmnl [0,1]

(49) "T2: wireless indoor traffic"= MIN(wireless indoor traffic demand,("3GPP LA APs yearly traffic volume supply" * T32 Number of 3GPP LA APs +"3GPP WA BSs yearly traffic volume supply"*"T33: Number of 3GPP WA BSs"+"non-3GPP LA APs yearly traffic volume supply"* "T31: Num of non-3GPP LA APs"))

Units: MB/Km2/year

(50) "T31: Num of non-3GPP LA APs"= INTEG ("increase rate in non-3GPP LA APs"-"decrease rate in non-3GPP LA APs",300)

Units: AP/Km2

(51) T32 Number of 3GPP LA APs= INTEG (increase rate in 3GPP LA APs-decrease rate in 3GPP LA APs,10)

Units: AP/Km2

(52) "T33: Number of 3GPP WA BSs"= INTEG (increase rate in 3GPP WA, 10)

Units: BS/Km2

(53) T6 3GPP OPEX level=the effect of increasing APs on OPEX cost LOOK UP(T32 Number of 3GPP LA APs/normalization variable for OPEX cost LOOK UP function)*(1-"T12: AP self optimizing capability")

Units: Dmnl [0,1]

(54) "T7: fear of wireless emissions"=0.05

Units: Dmnl [0,1]

(55) the effect of increasing APs on OPEX cost LOOK UP([(0,0)-(2000,1)],(0,0),(500,1),(2000,1))

Units: Dmnl

(56) the effect of interference on capacity LOOK UP([(0,0)-(1000,1)],(0,1),(500,1),(1000,0))

Units: Dmnl

(57) TIME STEP=0.125

Units: year [0,?]

The time step for the simulation.

(58) total traffic demand from primary devices= number of users*"data traffic from primary devices (video) per person"

Units: MB/(Km2*year)

(59) total traffic demand from secondary devices= average traffic demand per secondary device*number of secondary devices

Units: MB/(Km2*year)

(60) "U21: share of 3GPP LA out of all LA indoor traffic"= (T32 Number of 3GPP LA APs*"3GPP LA APs yearly traffic volume supply")/("T31: Num of non-3GPP LA APs"*"non-3GPP LA APs yearly traffic volume supply"+T32 Number of 3GPP LA APs*"3GPP LA APs yearly traffic volume supply")

Units: Dmnl [0,1]

(61) "U22: share of LA out of all indoor traffic"= ("T31: Num of non-3GPP LA APs"*"non-3GPP LA APs yearly traffic volume supply" +T32 Number of 3GPP LA APs*"3GPP LA APs yearly traffic volume supply")/("T31: Num of non-3GPP LA APs"*"non-3GPP LA APs yearly traffic volume supply"+T32 Number of 3GPP LA APs*"3GPP LA APs yearly traffic volume supply"+"T33: Number of 3GPP WA BSs"*"3GPP WA BSs yearly traffic volume supply")

Units: Dmnl [0,1]

(62) "U23:market share of 3GPP operator of all indoor traffic"= (T32 Number of 3GPP LA APs*"3GPP LA APs yearly traffic volume supply"+ "T33: Number of 3GPP WA

BSs"*"3GPP WA BSs yearly traffic volume supply")/("T31: Num of non-3GPP LA APs"*"non-3GPP LA APs yearly traffic volume supply"+T32 Number of 3GPP LA APs*"3GPP LA APs yearly traffic volume supply"+"T33: Number of 3GPP WA BSs"*"3GPP WA BSs yearly traffic volume supply")

Units: Dmnl [0,1]

(63) "U3: spectrum policy and regulation flexibility"= 0.5* SMOOTHI (DELAYED SPECTRUM DEMAND, AVERAGING TIME, 0)+0.2*SDR capabilities + 0.3*(flexible mobile spectrum/all spectrum feasible for mobile systems)

Units: Dmnl [0, 1]

(64) "U5: Number of mobile devices"= INTEG (increase rate in number of mobile devices-decrease rate in number of mobile devices, 1000)

Units: device/Km2

(65) unserved wireless indoor traffic demand= wireless indoor traffic demand - "T2: wireless indoor traffic"

Units: MB/Km2/year [0,?]

(66) wireless indoor traffic demand= total traffic demand from primary devices + total traffic demand from secondary devices

Units: MB/Km2/year