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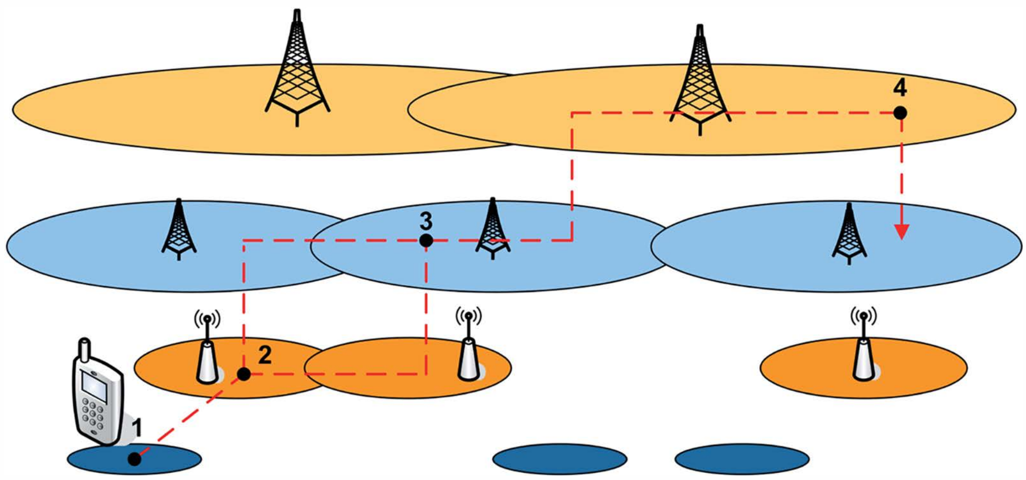
Tapio Väärämäki

Next Generation Networks, Mobility Management and Appliances in Intelligent Transport Systems



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ABSTRACT

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For quite some time there has been discussion regarding convergence of networks. Access technologies of different characteristics are converging into one heterogeneous, but ubiquitous access network, where different access technologies with different parameters complement each other. To enable such a convergence, many challenges regarding network interworking must be solved. One of the major challenges is the mobility management across heterogeneous networks.

This dissertation discusses mobility management in heterogeneous network environments. Mobility management is studied from the user point of view and a proposal of the mobility management system is suggested. The benefits of an introduced system are identified from both user and operator point of view.

Currently, the major challenges for the introduced mobility management system are related to robust link information collecting. Thus integration with a standardized solution is researched. There are promising opportunities for such an implementation, but a strong consensus among the standardization organizations is required to achieve a common solution. The mobility management policies that define how the mobile node behaves between different networks are a part of this discussion.

Intelligent Transport Systems are taken as an example of the environment where the multi-access networking provides significant advantages compared to single access connectivity. The benefits are discussed by both technology and business perspectives. The latter is supported by the techno-economic analysis that shows the strong potential of the solutions studied. The corresponding service and technology frameworks are researched and suggested as well.

Keywords: Next Generation Networks, mobility management, handover, heterogeneous networks, Intelligent Transport Systems

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This dissertation consists of publications that have been published in co-operation or co-authored with Gábor Fekete, Jani Puttonen, Timo Hämäläinen, Arto Karila, Timo Korhonen, Edward Mutafungwa, Vesa Riihimäki, Reijo Salminen, Senja Svahn and Juha Vartiainen. I would like to evenly thank all co-authors.

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Tapio Väärämäki

ACRONYMS

2G	2nd Generation
3G	3rd Generation
3GPP	3rd Generation Partnership Project
4G	4th Generation
AAA	Authentication, Authorization and Accounting
ABC	Always Best Connected
APM	Access Point Module
CR	Cognitive Radio
D-BUS	Desktop Bus
DNA	Detecting Network Attachment
DSL	Digital Subscriber Line
E2E	End-to-End
FLASH-OFDM	Fast Low-latency Access with Seamless Handover Orthogonal Frequency Division Multiplexing
FP	Framework Programme
GPRS	General Packet Radio Service
GVC	Ground-To-Vehicle Communication
GUI	Graphical User Interface
HIP	Host Identifier Protocol
HSPA	High-Speed Packet Access
ICT	Information and Communication Technology
IE	Information Element
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IMT	International Mobile Telecommunications
IMS	Internet Multimedia Subsystem
IP	Internet Protocol
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
IPC	Inter Process Communication
ITS	Intelligent Transport Systems
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
LAC	Link Access Controller
LIP	Link Information Provider
LM	Link Module
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
MICS	Media Independent Command Service
MIES	Media Independent Event Service
MIH	Media Independent Handover
MIHF	MIH Function
MIIS	Media Independent Information Service

MIP	Mobile IP
MIPv6	Mobile IPv6
MME	Mobility Management Entity
MN	Mobile Node
NGN	Next Generation Networks
NPV	Net Present Value
OVC	On-Vehicle Communication
PMIP	Proxy Mobile IPv6
RITS	Railways' Intelligent Transport Systems
QoS	Quality of Service
SAE	System Architecture Evolution
SAP	Service Access Point
SDR	Software Defined Radio
SIP	Session Initiation Protocol
TS	Train Server
UMTS	Universal Mobile Telecommunication Systems
UPE	User Plain Entity
VERHO	Vertical Handover in Heterogeneous Environment
VS	Vehicular Station
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WWAN	Wireless Wide Area Network
WLAN	Wireless Local Area Network
YTV	Helsinki Metropolitan Area Council

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LIST OF INCLUDED ARTICLES

This thesis contains seven research papers, which structurally follows the selected research approach.

[PI] Tapio Väärämäki, Timo Korhonen and Edward Mutafungwa. Wireless Telecommunications in Railways - Case Flash-OFDM. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, Volume 222(1), 2008.

[PII] Vesa Riihimäki, Tapio Väärämäki, Juha Vartiainen and Timo Korhonen. Technoeconomical Inspection of WiMAX Based High Speed Internet Connection for Trains. IET Journal on Intelligent Transport Systems, Volume 2(1), March 2008.

[PIII] Senja Svahn and Tapio Väärämäki. Networked Business Models for Train ICT System Implementation. The Business Review, Cambridge, Vol. 12(1), 2009.

[PIV] Tapio Väärämäki, Jani Puttonen and Gábor Fekete. Next Generation Network Related Standardization – Enablers for the Convergence. Proceedings of the Fourth Advanced International Conference on Telecommunications (AICT 08), Greece 2008.

[PV] Jani Puttonen, Gábor Fekete, Tapio Väärämäki and Timo Hämäläinen. Multiple Interface Management of Multihomed Mobile Hosts in Heterogeneous Wireless Environments. Proceedings of the Eight International Conference on Networks, Mexico 2009.

[PVI] Tapio Väärämäki; The VERHO Mobility Management System for Heterogeneous Network Environments, International Journal on Advances in Networks and Services, Vol. 2(2-3), 2009.

[PVII] Tapio Väärämäki, Timo Korhonen, Vesa Riihimäki, Reijo Salminen, and Arto Karila: Estimation of Telecommunication Technologies, Services and Costs to Support Public Transport Information System Requirements, Accepted to be published in The Second International Conferences on Advanced Service Computing, Portugal, November 2010.

CONTRIBUTION OF THE AUTHOR IN THE CO-AUTHORED PUBLICATIONS

The Flash-OFDM tests of publication [PI] were coordinated and reported by the author. The train communications architecture was also proposed by the author, as well as the contribution for the access technology comparison.

In publication [PII] the author proposed the RITS service framework and QoS mappings for RITS service requirements. The results of the survey of passengers' attitudes for various RITS services were delivered by the author. Plenty of VR related information was collected by the author, who also participated in the service scenario development for techno-economic analysis.

In publication [PIII] the author delivered all information regarding the RITS system and service framework. Also, the future concept was developed by the author. Actors and their roles of the business network forming the future RITS concept were contributed by the author.

The idea for publication [PIV] was developed by the author. The author contributed the parts of the article regarding IEEE 802.21 framework, mobility example scenario and the discussion section.

In publication [PV] the author contributed to the parts regarding future development of the VERHO system, IEEE 802.21 framework, and discussions parts.

Publication [PVI] was written by the author based on the ideas proposed in [PV]. The author provided an extended view on how the VERHO system should collaborate together with the IEEE 802.21 MIH framework and become a standardized implementation. Also, the evaluation of the benefits of the integration was done.

In publication [PVII] the author contributed the parts of the article regarding comparison charts, network development scenarios and techno-economic analysis of the proposed solutions.

1 INTRODUCTION

1.1 Motivation for the study

A major part of the technical solutions introduced in this dissertation is based on an assumption that there are several access networks available and that a user can have connectivity between them. Nowadays the situation is different, and the user is primarily connected to a single network at the time. Handovers occur mainly between access point of the same type, and they are referred to as horizontal handovers [1]. Vertical handovers refer instead to handovers between different access technologies.

When discussing about the future of networking, there are several terms and concepts defining it. One of the most essential terms and concepts for this study is Next Generation Networks (NGN). A telecommunication standardization sector of International Telecommunication Union (ITU) has defined the term Next Generation Networks (NGN) to describe the future networking. According to ITU [2], NGN is a packet switched network with E2E-QoS (End-to-End Quality of Service) capabilities, utilizing multiple different access technologies, decoupling services and transport, allowing them to be offered separately. NGN will support generalized mobility, which will allow a consistent provision of services to the user, no matter which access technology is used.

While NGN defines something more abstract, ITU has a bit more concrete definition for the next networking technology. 4G (4th Generation) refers to International Mobile Telecommunications Advanced (IMT-Advanced) standards defined by ITU Radiocommunication Sector (ITU-R). An IMT Advanced cellular system must have high peak data rates targeting up to 100 Mbps for high and 1 Gbps for low mobility [3, 4]. Scalable bandwidths up to at least 40 MHz should be provided. Also, a seamless mobility between heterogeneous networks is supported [5]. 4G is a packet switched network like NGN.

Some mobile phone operators have already launched early Long Term Evolution (LTE) networks and promote them as the world's first 4G networks [6, 7]. Even though the promoted networks do not meet all the set requirements of IMT-Advanced and thus do not qualify as pure 4G networks, the trend seems to have been set, and probably also all forthcoming LTE operators will call their networks 4G networks.

It is expected the first real IMT-Advanced networks could be implemented either with LTE-Advanced (LTE-A) [8] from the 3rd Generation Mobile System (3GPP) standardization association or IEEE 802.16m [9] from Institute of Electrical and Electronics Engineers (IEEE). If the strong drive by 3GPP based networks continues, it is very probable the 3GPP based implementation will be used. Operators can upgrade their system to support LTE-A, as they have done with Universal Mobile Telecommunication System (UMTS) and High-Speed Packet Access (HSPA).

4G and LTE networks will provide significant improvements to data rates of the current mobile networks. They will also upgrade the networks completely to an All-IP (Internet Protocol) era, and thus make them better compatible with Internet. For mobile operators it is vital to have such upgrades, because the amount of mobile data has exploded [10] and its growth is expected to continue exponentially [11, 12].

Even though mobile phone networks are developing fast, it is not clear whether even an improved capacity will be enough to serve increasing demands. Improving the wireless network performance is also becoming tricky, because the spectral efficiency of current radio networks is already near to known limits. Shannon's channel bound is a widely accepted upper limit for information carrying capacity of a channel [13]. For example, a downlink capacity of LTE is very near to Shannon's bound [14], and already HSPA systems provided relatively high spectral efficiency [15].

A typical scale for evaluating spectral efficiency is a rate called bit per second per hertz (b/s/Hz). HSPA can provide a spectral efficiency up to 0.5-1 b/s/Hz in good conditions. LTE can provide 1.7 b/s/Hz in a similar setup [16]. LTE-Advanced is expected to bring only minor gains here, and the capacity is rather increased by increasing bandwidth or number of receiver antennas. These improvements bring with them also some challenges. Bandwidth is a scarce resource and adding receivers will increase the power consumption that is already a problem in mobile terminals with increasing processing activities.

Where 3GPP based networks have gained a dominant market position in the area of Wireless Wide Area Networks (WWAN), the IEEE originated 802.11 [17] technologies have become a synonym for Wireless Local Area Networks (WLAN). In addition, there are several other technologies available, and for example Fast Low-latency Access with Seamless Handoff – Orthogonal Frequency Division Multiplexing (FLASH-OFDM) [18] is used to some extent in Finland [19]. Different networks with overlapping coverage areas consist a wireless overlay network [20]. Each network has its individual characteristics in terms of latency, jitter, data rate, coverage area, cost, power consumption and security [21].

If different access technologies are compared by several technical parameters, deployment and maintenance costs, physical restrictions e.g. band licenses, it is difficult to name any technology that would be superior to others.

Also, users and applications have different needs and requirements, which must be considered as well. It is realistic to think that no access technology can meet all the requirements of modern telecommunication. Rather, access technologies of different characteristics are converging into one heterogeneous, but ubiquitous access network, where different access technologies with different parameters complement each other [22].

There are several advantages converging networks can offer for both the user and service provider. In an ideal situation the main benefit for the user is a state of Always Best Connected (ABC), where the user is always connected to best available access network(s) based on individual preferences [23]. Those preferences can cover all QoS parameters as well price and other requirements. By utilizing several networks simultaneously, the throughput can be improved and packet loss, jitter, and latency reduced. Multiple networks can also support each other in situations where a service disruption occurs. For operators the benefits are obvious if load sharing may be utilized in busy situations. Also, redirecting the traffic to “cheap” networks, e.g. subscriber's own Wireless Fidelity (Wi-Fi) network connected to Internet by the operator’s Digital Subscription Line (DSL), is becoming more and more alluring due to the boom of mobile data. Femtocells are an example of this trend and 3GPP’s response for building a better and more adequate coverage to subscribers’ home with cheap base stations [24].

It does not matter in which generation network the convergence will happen, but it is about to come. All advanced smartphones are equipped with multiple accesses and radios working on several frequencies. Seamless handovers between second (2G) and third generation (3G) networks have been available for years, and the next step will be to extend the same functionality to LTE networks. The packet switched nature of LTE is, however, hindering this, because transferring a circuit switched call as packet switched requires new kinds of voice call handover solutions [25]. Internet Multimedia Subsystem (IMS) is used in one of the solutions [26]. IMS is a service control subsystem and is based on Session Initiation Protocol (SIP). IMS was designed to enable intelligent IP-based services and features to be located in the evolved 3GPP network. One key aspect focused on here is the ability to maintain services even when the user is moving across different access networks and terminal types.

Some other technology drivers towards converged networks are Software Defined Radio (SDR) and Cognitive Radio (CR). Cognitive radio is an enhancement to the traditional software radio concept wherein the radio is aware of its environment and its capabilities, is able to independently alter its physical layer behavior, and is capable of following complex adaptation strategies [27]. The cognitive radio intends to utilize licensed bands which are reserved for some other use, but are unused at a specific moment of time. The cognitive radio moves over quickly from frequencies which are sensed to be in some other use at the same time.

Software Defined Radio refers to a radio the digitized receiver signal of which can be processed with software. SDR enables a re-use of radio components for different modulations and radio interfaces on single radio equipment [28]. SDR is especially useful for new mobile terminals, when multiple radio interfaces must be supported but the space available for implementation is limited.

In addition to technology drivers and enablers, there are also other things affecting convergence. Standardization can be an important enabler, but it can present a big political challenge as well. The nature of political problems is different compared to technological ones. Standardization working groups are developing different standards for various purposes. For example 3GPP, IEEE and IETF focus on mobile phone networks, 802-networking technologies and protocol issues, respectively. Earlier there were clear boundaries between different working groups, but now due to convergence, the border lines are to disappear. The working groups need increasingly the results of each other.

Such a change might not be easy, because 3GPP based networks have been considered as strictly operator controlled networks, while the IEEE technologies are used more for implementation of non-operator controlled networks. Similar attitudes can be sensed from the results of the standardization work.

A good example of standardization related political challenges is IEEE 802.21 Media Independent Handover (MIH) framework [29]. MIH enables information collecting from both IEEE and 3GPP networks, and provides Application Programming Interfaces (API) for terminals so that they can access all necessary information for network selection and handover decision-making. To enable MIH functionality, each access technology standard needs to be amended with corresponding extensions. The MIH standard has been ratified for some time already, and IEEE is working on amendments [30, 31]. 3GPP is not, however, so enthusiastic and is thus slowing the development. A tight co-operation of both standardization organizations is required to enable MIH. Despite the slow progress of 3GPP, MIH can be seen as one of the most crucial enablers towards ultimate convergence.

One of the reasons that might drive 3GPP towards more open solutions is the current impossibility of the mobile data business. An amount of mobile data increases exponentially at the same time when the revenues stay constant or even decrease due to a price erosion. Meanwhile operators need to do new, continuous investments to capacity without gaining any additions to their profit margins.

Once the convergence is well underway, the next big debate will be about handover and network usage policies. Who should decide which networks are used and when? For the user the best option is of course the best available network according to the user's preferences. The operator, however, keeps the user rather in networks with minimal operating expenditures.

Some of the interesting development scenarios include also an open access concept that enables an open service provisioning for all interested parties. Only the costs of joining the network must be covered. The term open access refers to the independence of services and access technologies the end-user consumes [32]. Such a setup is perfectly in line with ITU's definition of NGN, where service and transport should be decoupled.

In addition to 3GPP, IEEE, and IETF, there are also plenty of other ongoing developments. For example, Tekes – the Finnish Funding Agency for Technology and Innovation has a complete research funding program [33] for converging networks and the EU, in its Framework Programme 7 (FP), is funding some big research projects such as 4WARD developing the architecture and design for Future Internet [34]. Asia Future Internet Forum(AsiaFI) was founded to coordinate research and development on Future Internet among countries in Asia, as well as with other continents [35], involving plenty of research on convergence. In the academic area, some of the most recent studies discuss why the convergence is happening and how the regulation affects it [36]. The decision-making policies raise plenty of discussion, and for example paper [37] proposes a tool and concept for developing policies for QoS management in converged networks. Paper [38] brings the policy discussion to a bigger scale by evaluating how regulation and policies can affect the whole NGN ecosystem. There are numerous proposals for solutions enabling the convergence of e.g. mobility management systems and middlewares. Papers [39-43] present just some of the most recent publications.

Trains are an interesting option when considering the future of transportation. Private motoring poses a serious threat to the environment in terms of pollution and waste of natural resources. Public transportation forms an economic alternative to this and brings with it many societal benefits. It often turns out to be faster and more convenient, especially for the urban environment, and it even provides the opportunity to work or pursue hobbies during the journey. This is especially important in case of long haul air or train travelling. Of various transportation modes, rail traffic has tremendous potential both in capacity and in speed, with modern trains exceeding velocities of 500 km/h [44].

Trains can potentially be used as mobile offices with all the expected accessories facilitated by modern integrated, mobile information and communications tools, such as laptops and printers. Trains can also enable practically uninterrupted working with adequate working space which is a highly valued asset compared with its competitors, including air traffic. The ability to work while travelling may have a significant impact on one's selection of transportation mode. Some train operators have taken this into account by offering special 'office seats' with power outlets and sometimes even with internet connections [45]. In terms of enabled services, on-board telecommunications provide a diverse service framework, potentially enabling and improving services for in-house users, cargo operators, and regular passengers [46].

The concept of Intelligent Transport Systems (ITS) refers to a worldwide framework incorporating information and communications technology to transport infrastructures and to vehicles for supporting business activities and to open up new business opportunities.

Trains and vehicles in general, are a part of the ITS service framework, which is introduced more detailed in [PII] and [PVII]. There are a selection of ITS services available, and the transport operator can decide which of them should be implemented as a part of the overall ITS system. IP can be used as the protocol for communication between all services and networks. Thus, it does not matter which access technologies are used, as long as the communication interface supports IP. Management of multiple access technologies requires similar mobility management as the mobile node in heterogeneous networking environment. However, the system is easier to implement due to a better predictability, and also the mobility management triggering can be supported with positioning information.

Utilizing several access technologies on vehicles is necessary, especially with long distance trains which travel through different terrains and areas. Some areas on the route might have only a very limited coverage for telecommunication networks, while some other areas might provide support for multiple different access technologies, e.g. WiMAX, 3G and Wi-Fi.

1.2 Problem Statement

The main focus of this dissertation is on how to enable seamless connectivity in NGN environment. A mobility management system is required to handle connectivity in heterogeneous networks. To be able to operate effectively, the mobility management system needs information about surrounding networks continuously. The interface selection must be based on controlled policies that can be defined either by the user, applications, or some other party, e.g. operator. The objective is to provide a proposal for a policy-based mobility management system that can gather decision-making information from different sources. The mobility management system covers both areas, the link information collecting and link access control.

Various mechanisms are used to gather the information, but a widely standardized and agreed solution is needed for a large scale implementation. The IEEE 802.21 MIH framework presents such a solution, but it needs to be integrated with a mobility management system. The objective is to provide a proposal how the VERHO mobility management system can be implemented with MIH. The roles of both entities are to be identified as well as the benefits of such a setup.

The standardization work plays a vital role for the development of telecommunication technologies and protocols. There is some overlapping development work going on, but also many standards need others to collaborate with. The objective is to review the NGN related standardization work and identify the most relevant standards for the VERHO system. Also the bottlenecks of the development are to be identified.

ITS solutions require connectivity management which is very similar to that of the mobile node in a heterogeneous networking environment. Depending on the vehicle, a movement of the receiver can be quite random as with a human user, or if it is a train, tram or bus operating a fixed route, then the movement is more predictable. The objective is to find the most suitable combination of access technologies for networking trains and other public transportation vehicles, and to find a solution for how to make them collaborate.

The ITS solution consists of different services that are connected to billing, reporting and other transportation operator's enterprise IT systems. A cost efficient implementation requires use of correct technologies and an implementation done by the business network. Also, carefully selected services are vital part of the viable solution. The objective is to provide a techno-economic analysis on selecting the correct combination of telecommunication services and technologies for ITS implementation and study what is the best way to implement it.

1.3 Original Contributions

The principal and original contributions provided in this thesis are as follows:

1) Development of the VERHO mobility management system and integrating it as a part of the on-going standardization work and resulting solutions as presented in Chapter 2.1.

2) Development of the service framework and technology architecture for Intelligent Transport System for trains, and illustrating the business benefits of the developed solutions as presented in Chapter 2.2.

This material has been published in a range of International Journals and Conferences during the compilation and completion of this thesis.

1.4 Structure of the Thesis

This dissertation is based on a hybrid model, where Next-Generation-Networking and Intelligent Transport Systems are combined. The NGN part goes to a greater depth to technological solutions, while ITS focuses merely on the bigger picture and also involves a business analysis part for the provided solutions.

In the first part of the dissertation [PI] the results of the Flash-OFDM field tests in a Pendolino-train are evaluated. The paper also introduces train communications architectures, a framework of ITS-services in railways, and an access-technology comparison for Ground-To-Vehicle Communication (GVC).

The second part [PII] continues the previous research [PI] by performing a techno-economical analysis of a high-speed Internet connection for trains. A framework for Railways' Intelligent Transport Systems (RITS) is developed further and several alternative networking scenarios for a Tampere-Helsinki route are provided.

The third part [PIII] analyzes the implementation of Intelligent Transport System proposed in [P1-P2]. The state of the art in available ITS services is introduced, and followed by a proposal for a future development. As a conclusion, a business network approach is suggested for this new intelligent transport system.

The next part [PIV] takes the research to the on-going standardization work related to the Next-Generation-Networks. A use-case type example is provided to illustrate how introduced solutions contribute to an overall concept in the NGN environment.

The NGN research is continued in parts [P5-P6], where the VERHO mobility management system is introduced. The first part of these two papers [PV] introduces the basic systems and its functionality. Also the benefits and limitations of the VERHO system are explained. Some prototype applications benefiting of the VERHO system are then introduced. The next part [PVI] extends the research to the IEEE 802.21 MIH framework introduced in [PIV] and explains how the VERHO system and MIH can be integrated together. The research is based on the many years spent with VerHo-project.

The final part [PVII] returns the research back to the ITS area. Telecommunication technology, service and economical scenarios for Helsinki Metropolitan Area Council (YTV) area up to 2015 are studied. The proposed solution benefits multi-access connectivity as in the case of the VERHO system presented in [P5-P6]. The paper also presents an overview of all major access technologies and their development. The results are presented in a roadmap format. The convergence of networks acts as the baseline for the research.

2 SUMMARIES OF THE PAPERS

In this chapter the summaries of the papers of the dissertation are given. Chapter 2.1 contains Next Generation Networking related papers and Chapter 2.2 Intelligent Transport System related papers.

2.1 Next Generation Networking related papers

Papers introduced in this chapter are mainly based on research done in the VerHo project [47-50] [PIV] [PV] [PVI] at University of Jyväskylä. Its research focused on heterogeneous networks and managing the mobility and connectivity in such an environment. Thus it was natural continuation for my earlier research [PI] [PII][PIII][PVII] to join the VERHO project and continue multi-access research, focusing on mobile nodes instead of complete trains this time.

This dissertation is intended to compile the work I have done on multi-access networking that forms a base for the modern and - especially - future telecommunication.

2.1.1 Next Generation Network Related Standardization – Enablers for the Convergence

[PIV] Tapio Väärämäki, Jani Puttonen and Gábor Fekete. Next Generation Network Related Standardization – Enablers for the Convergence. Proceedings of the Fourth Advanced International Conference on Telecommunications, 2008.

The fourth paper presents the on-going standardization work related to the Next-Generation-Networks (NGN) and evaluates their benefits. A use-case type example is provided to illustrate the use, benefits and relations of the introduced solutions.

Our focus is on the work of IETF related to multi-interface or multihomed mobile and stationary nodes.

A major part of the reviewed standardization work is done on Mobile IP or its amendments such as NEtworks in MOtion (NEMO), the Mobile Nodes and Multiple Interfaces in IPv6 (monami6) and Mobility EXtensions for IPv6 (MEXT). These working groups focus on developing IP mobility further by adding support to multiple available interfaces at the same time and Mobile IP support for entire mobile networks, providing mobile node bootstrapping with AAA and dealing with firewall issues as stated in [51] and IPv4-IPv6 dual stack solutions.

A contending and different approach to solve the mobility and multihoming issues is proposed by the Host Identifier Protocol (HIP) working group in the Internet area. An original intention of the working group was to solve the infamous "locator-identifier split", but mobility handling and multihoming become a natural and straightforward addition to it. Even though HIP proposes a cleaner architecture than Mobile IP, it still requires a Mobile IP like home agent called rendezvous point to handle the knowledge about the current IP address of the moving mobile node.

Enhancements for detecting a need for IP settings' renewal are developed in the Detecting Network Attachment (DNA) working group in the Internet area. The proposed solutions provide a more seamless communication by enabling a quicker acquisition of valid IP settings.

IEEE 802.21 [29] is a framework, which defines so called Layer 2.5 between OSI layers 2 and 3. Its purpose is to optimize handovers between heterogeneous access technologies so that no on-going services of the end user are terminated. This may be achieved by providing relevant information for handover decisions to the mobility management protocol or system, which is responsible for timely handovers. 802.21 supports a wide set of various access technologies: both wired and wireless technologies from IEEE, 3GPP and 3GPP2.

The base of 802.21 is an entity called MIH Function (MIHF). It consists of three services: Media Independent Event Service (MIES), Media Independent Command Service (MICS), and Media Independent Information Service (MIIS). MIH Protocol is used for communication between network entities, e.g. between a terminal and a base station.

3GPP's approach towards heterogeneous networking is more operator centric and controlled the same way as in the IEEE and IETF standardization organizations. However, a development towards All-IP networks in SAE (System Architecture Evolution – also referred LTE nowadays) provides new opportunities for network convergence when the mobility is handled by IETF specified protocols. In SAE, Mobility Management Entity (MME) performs, e.g. authentication and mobility management. User Plane entity (UPE) manages and stores UE context and manages ciphering, packet routing, etc. Mobility with non-3GPP technologies is handled through the SAE anchor [52].

The protocols for non-3GPP mobility management will be on IETF protocols. For host-based mobility management Mobile IPv4, Mobile IPv6, and dual-stack MIPv6 are proposed. Network-based mobility management is handled by Mobile IPv4 in Foreign Agent mode or Proxy Mobile IPv6.

A high number of various standards can cause confusion – which of them to use and when? We provide a mobility example scenario, where introduced standards and techniques are employed for their purposes to illustrate how to utilize them and what is the role of each individual standard in enabling the convergence. The example scenario can be seen in Figure 1.

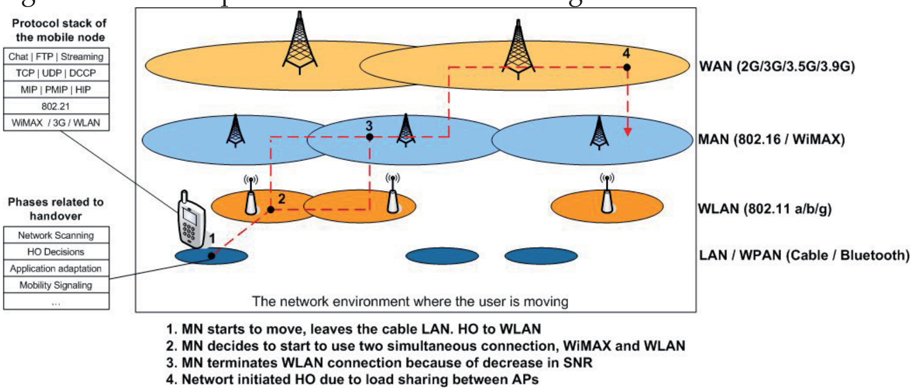

FIGURE 1 The mobility example scenario

The example scenario involves multiple handovers between different networks. The IEEE 802.21 standard and the IETF IP mobility management standards, including the Monami6 and DNA techniques, are used to obtain all necessary information for decision-making. The decision-making procedures and policies are under heavy development, and there are no commonly agreed solutions. Also, even though there are several mobility management concepts available, there isn't any standardized one yet. Our own VERHO system is a noteworthy candidate, as it can be used to enable interplay of introduced standards.

The development of NGN related standards and technologies is characterized by technological and political issues. In the technical area the major challenges relate to signalization and decision-making. The latter is also a political challenge, because operator oriented 3GPP pushes for network based mobility management, while IEEE and IETF see a mobile node based mobility management as a suitable solution. Such decision can also affect the selection of technical solutions, e.g. PMIP vs. MIP. Thus coordination and common agreements are needed for the reviewed standardization work, or otherwise widely accepted solutions are difficult to implement.

2.1.2 Multiple Interface Management of Multihomed Mobile Hosts in Heterogeneous Wireless Environments

[PV] Jani Puttonen, Gábor Fekete, Tapio Väärämäki and Timo Hämäläinen. Multiple Interface Management of Multihomed Mobile Hosts in Heterogeneous Wireless Environments. Proceedings of the Eight International Conference on Networks, Mexico 2009.

The fifth paper presents a solution for intelligent network interface selection and handover control for heterogeneous multi-access environments, particularly for the 4th generation mobile communication system. A policy based vertical handover controller system, called VERHO, utilizes input from several cross-layer sources, the Mobile IPv6 protocol and network interface selection to achieve both proactive and intelligent vertical handovers between a variety of access interfaces. Real-time link status information, access point scanning support, user profiles, policies and Multiple Attribute Decision Making algorithms provide flexibility in interface selection and result in an Always-Best-Connected (ABC) access for the user.

The reason for developing the VERHO mobility management system is a need for controlling IP mobility as "smoothly" as possible. Mobile IP handles the IP mobility management in an application transparent way. Thus the applications flows and even possible transport layer connections do not break when MN is moving between IP subnets. Also, with multiple interfaces pure MIPv6 implementations usually have some static priority for each interface, and the interface with the biggest priority is chosen for use. However, static priority based interface selection may not be sufficient for users with different preferences nor for applications with different demands in heterogeneous environments [50].

The VERHO system is designed to manage available interfaces, links and access points in a multi-interfaced mobile IP-networked device. Basically, the system gathers information about available interfaces (link types, access points, etc.), decides dynamically during run-time about how the interfaces could be utilized best and performs IP handovers using Mobile IPv6. The system has a cross-layer design, since the goal is to provide link information to interested layers. Figure 2 shows the VERHO cross-layer interaction.

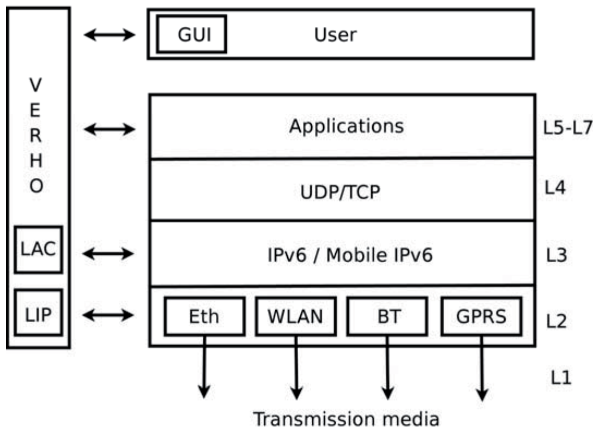

FIGURE 2 VERHO cross-layer interaction

The VERHO system consists of two core components, i.e. Link Information Provider (LIP) and Link Access Controller (LAC), and utilizes several other components:

- LIP extracts link information from network interfaces (Link Layer),
- LAC gets information from LIP and controls MIPv6 handovers (Network Layer),
- Users can set their profiles through a GUI and see some statistics from the underlying system.
- Applications can utilize information provided by LIP and LAC (Application Layer),
- Mobile IPv6 is controlled based on the decision done in LAC.

The architecture is shown in Figure 3. As shown in the figure, the components communicate with each other over Desktop Bus (D-BUS) that is a messaging bus mainly for local inter-process communication (IPC) and remote procedure call (RPC) on a single host.

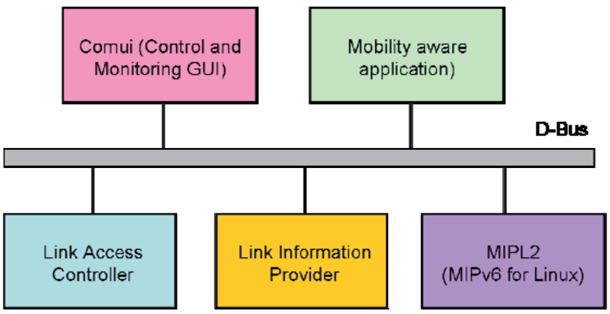

FIGURE 3 VERHO D-Bus architecture

LIP extracts link information about the available network interfaces and links [49] and makes it available over D-BUS for consumption. LIP consists of two main parts, the Link Module (LM) and the Access Point Module (APM). Both modules contain a list of submodules, one for each specific access technology. The supported technologies are IEEE 802.11 WLAN, Bluetooth, GPRS/UMTS and wired IEEE 802.3 Ethernet interfaces. The modular architecture enables an easy extendibility of the system.

Link information is provided by two means. Whenever an event takes place in a monitored interface that the LM is capable of listening to or when a new interface appears, a signal is sent over D-BUS carrying the new link information. Other components, i.e. information consumers, can also request information about the interfaces when needed.

The information provided by different network interfaces is quite heterogeneous. Thus a scaling to a common dimension is often necessary. Link Module unifies the information on parameters Signal Strength, Tx Power Level and Bitrate. Otherwise, comparing available technologies would be difficult.

The Access Point Module of LIP provides information and controlling facilities for access point management. APM manages an AP list for each supported access technology. On events affecting APs, signals are sent to D-BUS about the change. Such changes can be:

- Appearance of new AP
- Disappearance of AP
- Chance in AP's state

The logic of the VERHO system resides in the Link Access Controller (LAC). LAC consumes LIP (LM and APM) information and controls MIPv6 handovers. LAC manages a list of all network interfaces. Each interface is assigned a flag and a preference value. The flag can indicate

- The interface state: Enabled or disabled.
- Preference Value calculation: Automatic or Manual.
- Interface state management: Automatic or Manual.

If the interface state is disabled, the interface is not allowed to be used by MIPv6. By default, the interface state is managed automatically by LAC, based on the information received from LIP. Manual control is also possible, e.g. when external applications need to do it. Preference values for interfaces are calculated by LAC dynamically, and they change due to changing link information. Just as in interface state management, preference value calculation can also be managed manually by some outside party. At any point in time, the interface in an Enabled state and with the highest preference value is chosen to be used. In case where there are several available connections with similar properties, a hysteresis or extra interface-specific priorities might help in avoiding ping-ponging.

Comui is the controlling and monitoring interface for the VERHO system. It is a graphical interface developed with the GTK+ toolkit and is available for the Maemo platform. Comui allows users to monitor and control the system and choose how much they want to participate in the link selection decisions.

In summary, the VERHO system is a mobility management system for heterogeneous network environments such as 4th generation mobile communication networks. A modular architecture divides a responsibility of link information gathering and control to two separate modules, LIP and LAC. The link selection is based on preference value calculation, which enables a selection of the best available link for the user. Mobility aware applications can benefit of information provided by VERHO and adjust their behavior based on the available link information.

2.1.3 The VERHO Mobility Management System for Heterogeneous Network Environments

[PVI] Tapio Vaaramaki; The VERHO Mobility Management System for Heterogeneous Network Environments, International Journal on Advances in Networks and Services, Vol. 2-3, 2009.

The sixth paper continues the work published in [PV] and is a response to an invitation received from the IARIA journal to submit an extended version of the paper. The paper reviews some of the recent development in the heterogeneous networking area. As part of this, the IEEE 802.21 Media Independent Handover (MIH) framework is introduced and shown how it can be integrated with the VERHO system. MIH needs a multilink capable mobility management system to collaborate with, and the VERHO system is such one.

An essential component of the VERHO system is some IP mobility scheme, particularly Mobile IPv6 would be suitable for the purpose currently. Thus, a lot of interesting development in the standardization area since the [PV] has occurred in IETF standardization groups. Some of the interesting working areas were also reviewed in [PIV]. Some essential areas to be mentioned include:

- MIPv6 signaling and Handoff Optimization (mipshop),
- Mobility EXTensions (MEXT) [53] working group for IPv6. Among others, their work includes multihoming and firewall issues, mobile node (MN) bootstrapping with Authentication, Authorization & Accounting (AAA) and IPv4-IPv6 dual stack solutions,
- Proxy Mobile IPv6 (PMIP) [54] for network based mobility management,
- Shim6 [55] is a network layer approach for providing the split of locator/identifier of the IP address, so that multihoming can be provided for IPv6 with transport-layer survivability

The IEEE 802.21 standard introduces a MIH Function, which is located between L2 and upper layers, i.e. IP or MIP, working as a generic link layer instance to both directions. It defines generic Service Access Points (SAP) and primitives for both upper and lower layers.

MIH Function makes it possible to transmit unified information from lower layers to upper layers, regardless of the access technology used. To be able to acquire all required information, access technologies must be amended by technology specific SAPs. They are to be defined in IEEE standardization bodies such as 802.11u (SAPs for Wi-Fi) [31] and 802.16g (SAPs for WiMAX) [30] and in 3GPP/2 . An architecture of MIH function is introduced in Figure 4.

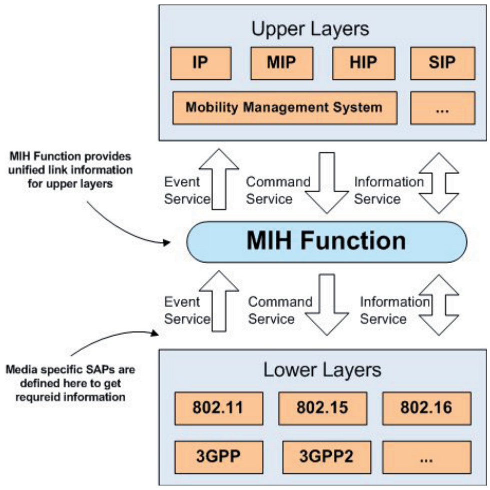

FIGURE 4 Functionality of MIH Function

The reason why MIH Function is so interesting for VERHO is related to its functionality that is pretty much similar to the LIP module, even though there are several advantages to MIH Function. The biggest challenges regarding link information collecting in LIP can be identified to three categories:

1. The amount of information the LIP module collects is limited to the number of parameters supported in each access technology. Also, the provided information is not unified, so the names of parameters and parameter values must be converted to a common scale.
2. The LIP module can collect the information only by scanning. Every time that information needs to be collected, the specific access interface must be activated and power-intense activities performed.
3. The biggest challenge with LIP is its lack of standardization, because it is our own proprietary implementation.

MIH Function can more or less solve the limitations LIP has:

1. Technology specific standard amendments, i.e. SAPs, for each technology are used to provide unified link layer information. Information is stored in Information Elements (IE) which provide all information that is essential to make intelligent handover decisions.
2. The exchange of IEs is based on request and response messages which make the information gathering effective. The mobile node can acquire information from all interesting networks via an active network interface, so there is no need to activate and burden other radios. In terms of power consumption this is extremely important.

3. MIH Function is a standardized solution. With a wide support of IEEE 802.21, the VERHO system can focus on decision-making and managing the user mobility, receiving link information and interface controlling techniques directly over MIH Function.

Even though MIH Function provides versatile link information gathering, its functionality is not limited to it. Command Service provides an interface for controlling the network interface, which is beneficial because operating system dependent implementations are not needed. Command Service also introduces the possibility of network originated handovers that can be an important feature if there is a need to implement the network controlled or originated mobility management.

The hierarchy and structure of MIH Function and VERHO is introduced in Figure 5. MIH Function works now as so called Layer 2.5 between the network and link layers. VERHO commands network interfaces and gathers network information over MIH Function. By utilizing the collected information, VERHO makes the mobility management decisions on the IP level. The VERHO system is connected to MIH Function with SAPs which are defined in the standard. In addition to lower layers, VERHO is connected to Application Layer (L7) as well as to the user that uses the services and is thus also a part of the mobility management decision-making.

Considering the development of the VERHO system, the IEEE 802.21 standard is a highly welcome addition. The link information collecting and network interface controlling have been challenging, because an operating system dependent solutions have been the only way to do it. However, IEEE 802.21 could, if it were to be rolled out widely, initiate a major change in this area. Implementing IEEE 802.21 in both, 3GPP- and 802-technologies would provide extensive access to link information. The amount of available information would not only increase significantly, but also diversify and become easier available. The better the mobility management decision-making, the better will the information available about surrounding networks be. IEEE 802.21 introduces also new ways to exchange information between mobile nodes and access points or base stations, which might be vital for the reduction of power consumption in the future.

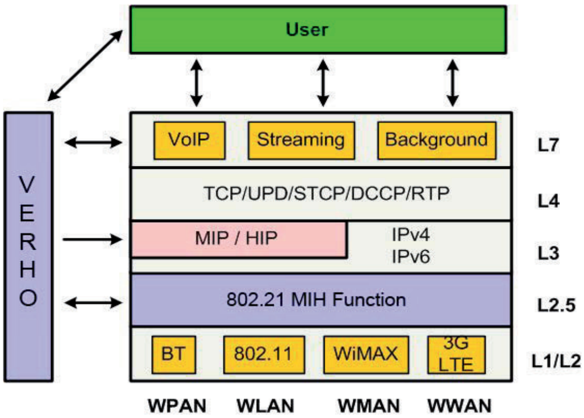

FIGURE 5 Integration of VERHO and IEEE 802.21 MIH Function

In summary, the VERHO system provides a modular approach to mobility management in heterogeneous networks. The IEEE 802.21 standard provides a versatile and unified instance for link information collecting and network interface control. It requires a mobility management system such as VERHO to work with. Integrating these two entities as a common solution results a mobility management system ready for controlling mobility in next generation All-IP networks.

2.2 Intelligent Transport System related papers

The impetus for the papers introduced in this chapter came from a feasibility study for networking trains. I was one of the persons setting up that project, and also one of the three authors of its final report [1].

The feasibility study was followed by a technical trial, where we did in-vivo tests for various access technologies in a moving train. The project was continued by a third step, when a study on business model development for providing Information and Communication Technology (ICT) services on trains was done. These two studies were combined into a single report [2].

One of the key findings is to utilize multi-access networking that is also the base idea of papers introduced in Chapter 2.1.

2.2.1 Wireless Telecommunications in Railways - Case Flash-OFDM

[PI] Tapio Väärämäki, Timo Korhonen and Edward Mutafungwa. Wireless Telecommunications in Railways - Case Flash-OFDM. Journal of Rail and Rapid Transit, volume 222(1), 2008.

In this paper the results of the Flash-OFDM field tests in a Pendolino-train are evaluated. The paper also introduces train communications architectures, a framework of ITS-services in railways, and an access-technology comparison for Ground-To-Vehicle Communication (GVC).

The train communications architectures can be divided to two separate entities as shown in Figure 6. The first entity, GVC, refers to communication between ground base stations and the vehicle. The connection can be formed by using several alternative access technologies, e.g. 3G, WiMAX or Flash-OFDM. Also multiple simultaneous technologies can be utilized for this. The second entity, On-Vehicle Communications (OVC), refers to a telecommunication network inside and between the carriages. This can be realized, for example, by Wi-Fi, or Bluetooth networking. To enable interplay between OVC and GVC networks, an intelligent router is required. We define such a router as Connection Manager (CM). Technically, the operation of CM is based on an IP mobility management scheme, which can be implemented for example with the Mobile IP protocol.

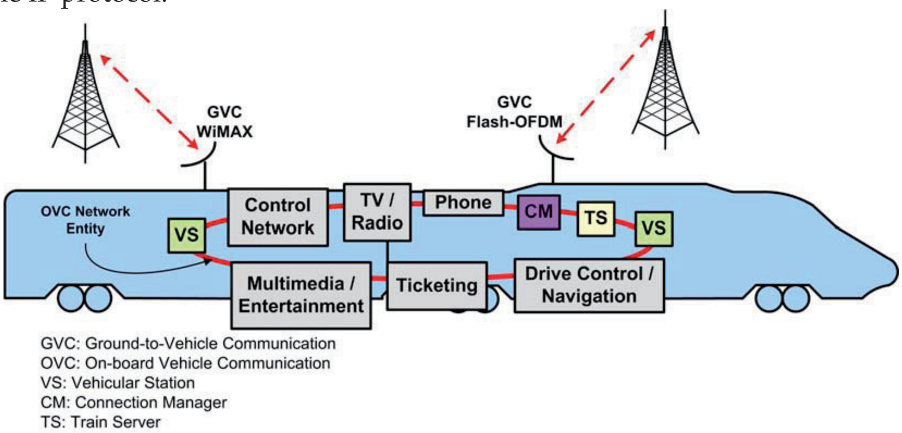

FIGURE 6 The train communications architecture

OVC consists of Vehicular Stations (VS), Train Server (TS), and CM. Train Server is used to provide ITS services for internal and external customers, e.g. on-board Internet access for passengers and transferring sales data from the restaurant carriage to the railway operator's sales system. Depending on the GVC link quality, the Train Server based buffering solutions might be required.

On Finnish railways there are several different technologies available for GVC implementation. The most interesting options include WLAN technologies, WiMAX, cellular technologies, and Flash-OFDM. In Finland the latter one is used for building a network on a 450 MHz frequency band. In the paper, satellite links are shown to play, in comparative terms, a very limited role, due to their high latency and relatively high costs. Also, In Finland, low positioning of satellites in the geosynchronous orbit also seriously limits link availability [56]. The comparison shows different characteristics of introduced technologies. Also, it is noticed that a market position and license regulation can significantly affect the network coverage. Thus, for example WLAN technologies suite better for station areas and Flash-OFDM for rural areas. The best solution can be achieved by using several technologies and combining them with a connection manager.

At the time of writing of this paper, Flash-OFMD was a new technology in Finland, and it had several advantages compared to other technologies. A low operating frequency of 450 MHz enables better propagation conditions than 2.1 GHz (3G), 2.4 GHz (WLAN), and 3.5 GHz (WiMAX). Thus it is relatively cheap to build coverage for a wide area network. Flash-OFDM is an All-IP based technology and its mobility support for up to 250 km/h with a seamless handover means it is well suited for railways. The network latency is low 20-50 ms. The downsides of the technology include its proprietary nature and the limited operating bandwidth that it has been granted [57]. Without additional frequencies, the operating speeds cannot compete against future technologies. Also, the terminal prices might stay relatively high as long as the technology remains non-standardized.

As it is claimed that Flash-OFDM should work at 250 km/h, practical field tests were undertaken to investigate the claim and also research the effect of train environment-related radio channel interferences. The tests were done in a Pendolino-train that was equipped with a Flash-OFDM terminal, a 450 MHz antenna and a GPS-receiver. The profile of the test track was selected to be that of a typical Finnish railroad. The length of the test track was 50 km, with three base stations using diverse configuration set out throughout the length of the track. To ensure that the results would be more in line with the performance of forthcoming commercial networks, the network was not specifically optimized for railway communications. The test track was chosen so that the train could speed up to 200 km/h, the maximum permitted speed in Finland at the time of the tests.

The tests indicated that the Flash-OFDM appears to suit well as a high-rate access technology for highspeed trains. The measured average downlink and uplink rates were 1 and 0.5 Mbps, respectively. The peak rates were 2.72 and 0.78 Mbps. The maximum cell radius was 11 km, but with the latest base station technology this can be increased up to 55 km. High driving speeds resulted in only a small variance for signal SNR. The Doppler transition was hardly noticeable. Handovers between the base stations worked well, and a connection to a new base station was always formed before breaking the old connection.

In summary, the test proved Flash-OFDM is well suited for developing ITS-systems and services for railways. Flash-OFDM seems to be surprisingly immune to interferences of the train environment and to offer relatively high data rates.

2.2.2 Technoeconomical Inspection of WiMAX Based High Speed Internet Connection for Trains

[PII] Vesa Riihimäki, Tapio Väärämäki, Juha Vartiainen and Timo Korhonen. Technoeconomical Inspection of WiMAX Based High Speed Internet Connection for Trains. IET Journal on Intelligent Transport Systems, vol. 2, March 2008.

The second paper provides a techno-economical analysis of high-speed Internet connection for trains. Also, the paper introduces a framework for Railways' Intelligent Transport Systems (RITS), several alternative networking scenarios for a Tampere-Helsinki route, and a techno-economical analysis for the implementation. The analysis results show high economical potential for RITS services.

The RITS business framework consists of the following components:

- Users: regular travelers, in-house users and freight (cargo) companies.
- Service groups: entertainment, infotainment, advertisements, telemetrics (operation and maintenance of trains and stations), billing and security.
- Networking solutions: these are realised by the 'ground-to-vehicle communications' (GVC) and 'onboard vehicle communications' (OVC) networking technology.
- Customer terminals: mobile handsets, personal digital assistants and laptops. Terminals must support the OVC technology investigated, for example, WLAN.

Even though the service scenarios are split into three parts – regular train passengers, freight companies and in-house customers - the network implementation is planned to be done as a single investment. The architecture for the network is the same that was presented in the previous paper [PI]. A division of customership into three segments can be seen in Figure 7. Also, potential services for various customer segments are introduced. Based on the survey we had for train passengers, an on-board Internet access and an improved quality of phone calls would be the two most important service areas for the passengers.

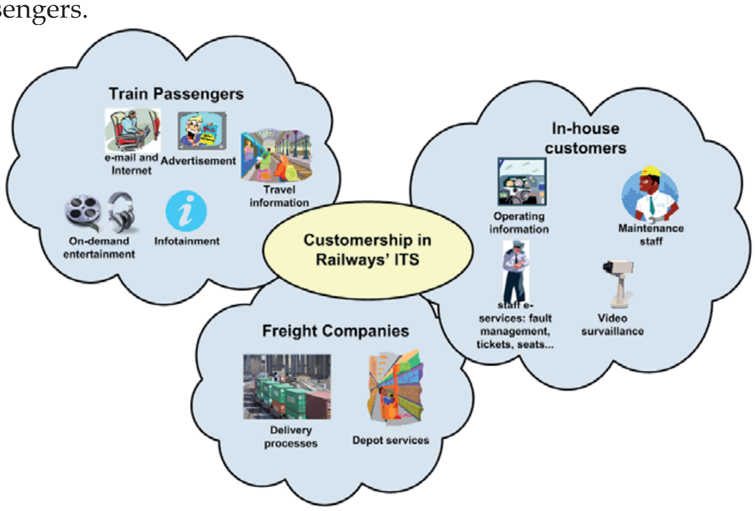

FIGURE 7 Division of customership in railways into three segments

As a base of the techno-economical analysis, a route between Tampere and Helsinki was used. A length of the route is ~ 200 km, and it is the most operated route in Finland. The overall number of daily trips is ~ 20 000. In the analysis, it is assumed that 15% of these trips are travelled in Pendolino trains.

An essential part of the revenue analysis is how to improve internal processes by developing in-house services. Based on a survey [58] done for national railways of Finland (VR), we identified the main areas that require improvement to include:

- Reducing manual work done by employees, e.g. conductors' work
- Improving information delivery processes, e.g. billing systems, restaurant supplements, etc.
- Improving maintenance processes, e.g. carriage maintenance and repairing

Depending on the selection of delivered services, savings equaling over 10% of VR's net profit could be obtained. Thus, developing internal services plays a much more vital role than developing services for regular passengers, which are hardly profitable. On the other hand, the service development for regular passengers can result improvements in the train operator's brand and passengers' attitudes towards travelling and thus result increasing passengers amounts and more revenues.

Analysis of different networking options indicates that building a WiMAX network for the Tampere–Helsinki route would cost € 1 Million. This can be considered quite expensive if compared to the costs of being a subscriber in Flash-OFDM and GPRS networks, which cost € 3500 and € 3000 per train in a year, respectively.

An estimate of the number of daily subscribers indicates the throughput demand in one train for the new information services would grow so much that the Flash-OFDM network could no longer serve all its passengers after two years of the service introduction. A mobile WiMAX network would provide high enough capacity also for the future years. At the time the paper was written, WiMAX did not support vehicular speeds over 120 km/h, but a backward compatible amendment providing mobility support up to 350 km/h is under development. This work is still to be finalized [59].

Even though the main scope of the analysis was on Pendolino trains between Tampere and Helsinki, the solution could be extended also to other trains operating the route. Provided VR has 722 passenger carriages, the overall network investment with GVC and OVC parts would be € 3 Million. If passengers could be charged € 3 per trip for the service and the share of laptop customers is assumed to grow from 10% to 15% (in total 20 000 per day) during the 7-year study period, the Net Present Value would be € 1 Million. The investment would be positive even if Average Revenue Per User (ARPU) was assumed to be € 2.5. Figure 8 shows more sensitivity analysis.

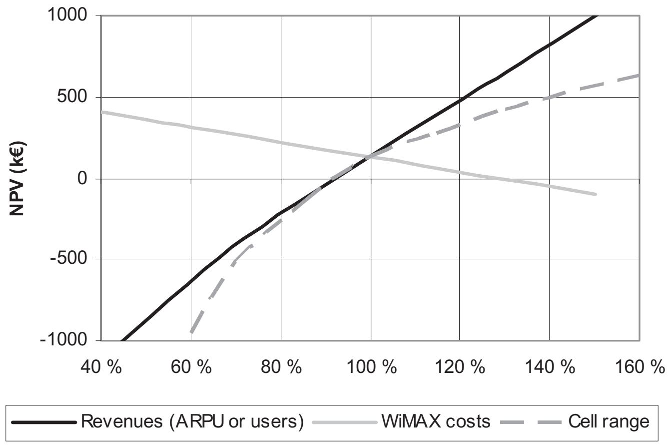

FIGURE 8 Sensitivity analysis of the WiMAX solution for passengers' communication service

One business option is to expand RITS services over all electrified railways in Finland. The overall length of these electrified railways that are used in passenger traffic is 2800 km (i.e. 50% of all Finnish railways). The number of trips outside the capital region in Finland was 12.2 million in 2005. If it is assumed that 10% of these trips do not use electrified railways, the daily traffic in our case would be 30 000 trips. Flash-OFDM would be a sufficient and profitable solution for all the trains, as in the case of Tampere-Helsinki. However, lack in the capacity may cause problems if the number of subscribers increases high enough. The WiMAX solution over Finnish electrified railroads would have investment costs of € 15 Million and NPV € -15 Million. This is 35% of the net profits of 2005 for VR. These investments would be paid back quickly if the forecasted in-house customerships and savings were realized. As a comparison, National Railways of Sweden made an investment of € 11 Million covering 85 trains [60, 61].

In summary, the RITS framework provides interesting business development and streamlining opportunities for train operators. An economic inspection reveals there are several differently priced options to implement the solution. The cheaper alternatives, GPRS and FLASH-OFDM, provide more profitable business cases in the beginning, but if the amount of subscribers grew as expected, the capacity might become an issue. Building an own WiMAX network would provide a multifold capacity, but it would also require an investment of € 1 Million for the Tampere-Helsinki route.

2.2.3 Networked Business Models for Train ICT System Implementation

[PIII] Senja Svahn and Tapio Väärämäki. Networked Business Models for Train ICT System Implementation. The Business Review Journal, Cambridge, Vol. 12(1), 2009.

The third paper analyzes the implementation of Intelligent Transport System on the trains. An essential part of the implementation is the services provided for internal and external customerships. Currently available ITS services are introduced and needs of different customer segments on ITS services are analyzed. Based on the analysis, a future concept is proposed. Furthermore, the innovations required by the new system are identified. As a conclusion, a business network approach to form this new intelligent transport system is suggested.

Based on the business framework for Railways' Intelligent Transport System (RITS) introduced in [PII], customership can be divided to three segments: in-house customers (train operator), regular passengers and freight companies. The offering of RITS services to these customer segments in Finland is relatively low, for example regular train passengers do not have reliable communication facilities, they do not get enough information about delayed trains, and there is no electronic entertainment available on board. With in-house customers the situation is quite similar, with the exception of invoicing, public announcements for passengers and e-ticketing. The major challenge is the limited availability of RITS services. For example, restaurant cash and inventory information is sent to ground systems only at few specific stations. Thus accurate supplying of stock is difficult and is based on forecasting. Another example is related to e-ticketing. A passenger must reserve the ticket one hour prior to the train leaving the first station, or otherwise conductors would not be able to download reservation information to their mobile operating devices before the train leaves. There is no real-time connectivity to business support systems. In the current situation, the third segment, freight companies, presents an exception in RITS services. Cargo related RITS services are relatively well organized, and it is difficult to identify any significant limitations there.

The pace of the development of RITS services can be inspected by identifying the innovation types related to RITS services. Freeman and Perez [62] distinguish between four different types of innovation: incremental innovations, radical innovations, new technological systems and new techno-economic paradigms. The type of innovation is determined by a scale related to the autonomy of the innovation, its scope, and how large the required change is. These are also the main characteristics one has to evaluate when considering the radicalness of an innovation.

The more complete the solution, the more radical the innovation required [63]. For example, implementing a broad RITS system requires more radical changes leading to a more challenging implementation. However, also the benefits correlate positively with the radicalness of the change.

Figure 9 depicts our proposal to evaluate innovation requirements in Finnish railways. It shows a 2-by-2 matrix, which specifies the level of the required innovation related to two characteristics. One characteristic is related to whether the markets already exist (old) or whether new markets are required (new). Another characteristic relates to technology requirements, i.e., we can either utilize the present technology or develop a new technology as required. Services in box 1 present the least and services in box 4 the most radical innovations. The radicalness order of boxes 2 and 3 depends on the market situation and technology availability, and on what kind of innovations are required there.

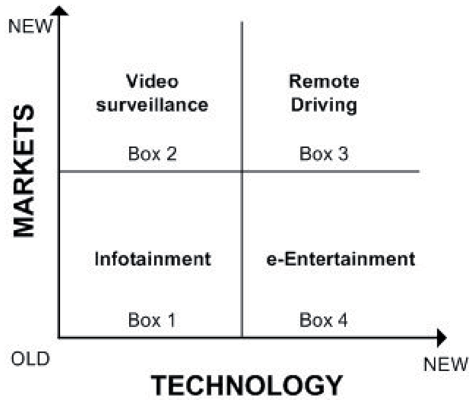

FIGURE 9 The innovation requirements in Finnish Railways

Even though the future concept for RITS was introduced already in [PI] and [PII], the implementation is still the challenging part. The system requires investments and no single player can provide all the functionality that would make the business case viable. Thus, introducing a business network view to implementation provides new interesting opportunities.

Acting within a business network in the RITS context can be argued to satisfy the requirements of the train operator better than a single system provider would. The broader the package is, the more attractive it becomes to the train operator. For example, if the business network can develop new RITS services for all the three customer segments, it is probable that the train operator would be willing to invest to this more comprehensive solution rather than to a solution which is deployed by a single company mainly for a single segment. A business network approach may provide also significant advantages in selling the proposed concept. The train operator can create just a single billing contract covering all the content services, communication towards suppliers, and maintenance services for the system.

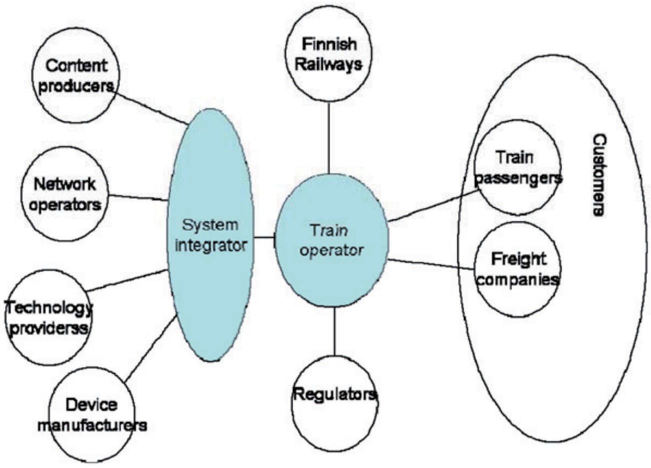

FIGURE 10 Business network forming the future RITS concept

Figure 10 introduces the business network forming the future RITS concept. In addition to train operator, the network involves:

- Content providers for information, entertainment and advertisement services,
- Network operators deploying the GVC link,
- Technology providers for required technological solutions, e.g. video surveillance,
- Device manufactures providing suitable terminals for customers to access RITS services and
- System integrator parsing together the entire offering from various companies that provide services and products and deploying them as a single package for the train operator.

The context in which the business network operates is also affected by regulators setting the boundaries and basic rules for activities of the train operators. Finally, customers play a key role in the service and system development due to such specific industry and the business processes it has.

2.2.4 Estimation of Telecommunication Technologies, Services and Costs to Support Public Transport Information System Requirements

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The seventh paper inspects Intelligent Transport Systems (ITS) telecommunication technology, for its service and economical scenarios for Helsinki Metropolitan Area Council (YTV) area up to 2015. The planned ITS services are developing rapidly, as well as their requirements for telecommunication infrastructure and capacity. The results of the study indicate YTV has several main paths for successful ITS development: (1) They can buy the networking services/technologies from a telecommunication operator, (2) They can build own network or (3) They can realize a hybrid solution.

Generally, Quality of Service (QoS) requirements of user services form a base in this evaluation. Typical technical QoS parameters include data rate, delay, error rate, packet loss and coverage. Table 1 shows an overview of QoS requirements for the expected ITS services in the framework of this study.

TABLE 1 Overview of QoS requirements for various ITS services

Service	Basic	Supp.	Real-t.	Buff.	Note
Emergency /Fault notifications	■		■		few kbit/s
On-board ticketing	■		■		slow, real-time traffic
Passenger information	■		■		100 kb/s / vehicle
Conductor communications	■		■		5.6-13 kbit/s (GSM/UMTS)
Traffic light priorities	■		■		slow, real-time traffic
Passenger Internet	■		■		1 Mb/s / vehicle
GPS	■		■		downlink GPS, uplink slow, real-time traffic
Equipment diagnostics		■	■		slow, real-time traffic
Remote control		■	■		10-100 kb/s / vehicle
Fleet management		■	■		downlink GPS, uplink slow, real-time traffic
Ticket control		■	■		slow, real-time traffic
Forecasts	■			■	below 100 kb / vehicle / 24h
Ticketing records	■			■	app. 1Mb / vehicle / 24h
Parameters	■			■	below 100 kb / vehicle / 24h
Route information	■			■	few Mb / vehicle / 24h
Realized location information	■			■	below 100 kb / vehicle / 24h
Advertisement download		■		■	few 10b/vehicle/24h
Software updates		■		■	max 10 Mb / vehicle/24 h
Video surveillance		■		■	max 1 Gb / vehicle / 24h

As Table 1 shows, the QoS requirements differ strongly, depending on the service. Some of the services require more bandwidth, e.g. video surveillance and passenger Internet, and some other services are more delay sensitive, e.g. traffic light priorities. An optimal technology solution can satisfy the service requirements of top prioritized services, and also potentially support a further development of services with lower priorities in the roll-out plan [64]. Services with the highest priority in the roll-out are:

- Ticketing system with a real-time connection to mobile phone, travel card and follow-up systems.
- Traveler information system producing location, route, and bus stop information for passengers. In addition, this information is applied for reporting and for route analysis (congestion follow-ups and real-time timetable updates).
- Traffic light priority making crossings faster for public transportation in rush hours.

Suitable access technologies for implementing the ITS services for YTV were chosen based on the set of QoS requirements and by reviewing candidate access technologies. Our list of reviewed technologies include: Flash-OFDM, mobile phone technologies (2G/3G/3.5G/LTE), WiMAX, Wi-Fi and IEEE 802.20. The technologies were compared against each other for their characteristics, market position, regulation, a degree of progressiveness, and future development.

Based on the comparison, we identified several groupings of technologies that can fulfill the needs of YTV in a competitive way.

The mobile phone networks have clearly the best existing coverage, and also their maintenance and support services are already well in place. The offered data rates are high enough to support most of the planned services, and further technology releases will increase the data rates even higher. On the other hand, these networks have plenty of existing users, and thus congestion may occur. Latency may also vary, and guaranteeing the performance of real-time applications is not always possible.

FLASH-OFDM is a proprietary networking technology used on the 450 MHz frequency band in Finland. The network aims to offer land-wide coverage with a nominal data rate of 1 Mbps. An important benefit of FLASH-OFDM is that it supports high vehicle speeds up to 250 km/hour [5]. Also a low latency of 20-50 ms is among the strengths of this technology. As such, it would be directly applicable for ITS-applications and it has indeed been tested for ITS in Helsinki area [65]. Drawbacks of this technology are related to its proprietary nature leading to relatively high terminal prices, high subscription fees and unpredictable future development of the technology itself.

Wi-Fi networking provides the cheapest and most efficient way for building a high data rate network to a limited geographical area. WLAN technology develops fast and it has well-defined interfaces to other telecommunication networks. Due to these benefits, the WLAN technology should be taken into account no matter which other networking technologies are applied. WLAN is especially applicable for on-board networking and maintenance areas such as garages and depots. Limitations of Wi-Fi are related to a limited transmission power due to its operation on open license bands, lack of QoS, and also limited mobility. The two latter ones are, however, under intense development in the corresponding standardization groups.

The available access technology alternatives can be realized in several alternative ways. The first and simpler option is to acquire telecommunication services from mobile network operators. Their network coverage for 2G is country-wide, subscriptions are cheap and there is a wide variety of terminals available. 3G network capacity and performance seems to improve rapidly, and recent HSPA upgrades increase its download rates up to 3.6 and 5 Mbps, or even higher [66]. Also, potential femtocell-solutions will enable new interesting business models for public transportation operators, too [24].

In our case, YTV represents a big customer for operators with approximately 1700 vehicles. The number of potential subscriptions is not, however, so large that YTV could necessarily control the development of the operator’s networks to a desired direction. Hardware investments should be quite straightforward until 2014. To start with, HSPA compatible 3G modems could be purchased and later upgraded to LTE-compatible modems. In this scenario, we estimate that operators would start using LTE widely in 2014 at the latest, and thus also the migration to LTE-compatible modems would happen at this time. This is in line with a rule-of-thumb that a typical life span for telecommunication devices, such as core network switches, is about 5-8 years.

In any scenario, WLANs should be used together with mobile networks. This is due to the fact that operation of mobile phone networks as such may not be cost-effective or convenient for large data transfers such as that needed for video surveillance material. FLASH-OFDM networking could be used in parallel with mobile phone subscriptions for reliability. The high subscription fees of the FLASH-OFDM network limit the wide utilization potential of the technology.

The second option to acquire telecommunication services for YTV is to build an own network. The operating area of YTV reaches 12 municipalities (in traffic and waste services) in the Helsinki capital area, which all could utilize the same network. If an own network were to be build, it could support a wide variety of municipal services for other clients apart from YTV. This would strengthen the financial bases of this scenario.

The base of any good wireless telecommunication network is a good backbone. In our case, a fibre network would consist of 1000 route kilometres, 500 node points, and 12 000 device ports. Implementing own network would require building a wireless access network between the vehicles and the core fibre network. The access network could be implemented by various technologies: YTV could build a cheap Wi-Fi coverage by placing access points especially to those places where capacity demand is high.

If compared to an operator alternative, an own network can be developed more independently and starting from one's own needs. An established fibre core network can be expected to have a lifespan extending up to 2014 and even later. After the payback period, the network would be totally owned and controlled by YTV. At this point, the most significant network expenditures would be maintenance fees. Own network could be easily tailored to serve specific service areas and needs. Cooperation with telecom operators would be mutually scaled as the own network and services develop.

In summary, YTV has planned to introduce a variety of ITS services for its internal and external customers up to 2015. By reviewing alternative scenarios for deploying the telecommunication services, two interesting scenarios or their hybrid solution can be identified. Subscribing services from telecommunication operators presents a traditional and easy approach. On the other hand, building an own network would provide more flexibility and an opportunity to develop the services to an intended direction. If an own network were to be realized, YTV could improve the business case by co-operating with other municipal actors or telecommunication operators, for example by renting the capacity for them.

3 SUMMARY

The current trend in telecommunications is from single access towards multi-access. Such a change is taking place in different environments, on single terminals as well as in complete networks, e.g. on vehicles. The networks are converging and consist of a big packet switched entity that the user can connect with by different access technologies.

In this dissertation the focus was on how to manage node mobility in a heterogeneous network environment. Also, connecting a larger network entity by multiple access interfaces was introduced, having vehicular networks as an example.

VERHO is a policy based mobility management system for heterogeneous networking environments. Its decision-making information is gathered from several sources including the user, access links, applications and other information sources, e.g. positioning information. The link selection is based on the preference values calculated from the collected decision-making information.

When considering a wide scale implementation, a unified and standardized implementation would be very important. A modular architecture of the VERHO system enables a smooth expandability, and for example new information sources can be easily amended. The MIH framework might be a significant enabler for network convergence, and a suggestion was made how the VERHO system can be integrated with it.

ITS solutions require connectivity management very similar to that of the mobile node in heterogeneous networking environment. Almost all the modern access technologies were compared, and it was explained how they could be applied in ITS solutions. One of the key aspects in these comparisons acted as a cost-driver, and the service-technology combinations were derived from techno-economic analyses. The services were identified based on the needs of various transport operators.

A deployment of ITS solutions requires multiple actors that form a business network. The actors of a required business network were identified, and a description how such a network could function was provided.

As future work, the mobility management research could be continued among others by implementing the VERHO system to a network simulator. The

VERHO system could be expanded with research topics including IEEE 802.21 and the multihoming capabilities. The simulator can then quickly indicate the expected system performance and also the potential bottlenecks. Thus, this enables us to continue system development by iteratively. Especially, decision making algorithms can be refined efficiently when the simulator tests show the immediate consequences of the tested modifications.

An interesting topic is also multihoming research, studying how to utilize multiple networking interfaces simultaneously. It is defined on a protocol level aiming to use simultaneous interfaces, but the implementation details are left undefined. For instance, how to describe the flows and how to bind them to the interfaces? Power consumption regarding multihoming and decision making policies is becoming more and more timely challenge.

Also, developing a working prototype for a mobile device that can be tested in IEEE 802.21 compatible networks to perform in-vivo testing and measurements would be beneficial. User experience is an interesting research topic to be explored with the prototype. By giving the mobile device for an end user it is possible to study the opportunities and problems encountered in heterogeneous networking.

The business impacts of multi-access networking could be covered by modeling techno-economic scenarios of the future networking scenarios to get a weighted mapping of expected development of service-technology combinations.

In the ITS area, potential future research topics include among others studying how to develop city wide Intelligent Transport Systems covering multiple forms of transportation and customerships e.g. public and private transportation. The ITS services involving all vehicles in the specific area could result notable benefits for example in traffic management and communication areas.

As well as with NGN research, analyzing techno-economics of various ITS service scenarios in various transportation operating environments would give an excellent understanding of the business benefits of developed solutions. Based on our earlier research, this area can be expected to result major cost saving opportunities.

REFERENCES

[1] J. Manner, and M. Kojo, “Mobility Related Terminology,” *RFC 3753*, June 2004.

[2] ITU-T, “Recommendation Y.2001 : General overview of NGN,” *ITU-T Publications*, 12/2004.

[3] ITU-R, “Report M.2134: Requirements related to technical performance for IMT-Advanced radio interface(s),” *ITU-R Reports*, 11/2008.

[4] ITU-R, “Background on IMT-Advanced,” *IMT-ADV/1*, March 2008.

[5] N. Kim, H. Choi, and H. Yoon, "Seamless Handoff Scheme for 4G Mobile Systems based on IP and OFDM," In the proceedings of IEEE VTS, Vehicular Technology Conference, pp. 3315-3318, 2004.

[6] Sprint Nextel. "4G Coverage and Speeds," http://nextelonline.nextel.com/en/stores/popups/4G_coverage_popup.shtml Accessed: 25.2.2010.

[7] TeliaSonera. "TeliaSonera first in the world with 4G services," http://www.teliasonera.com/press/pressreleases/item.page?prs.itemId=463244 Accessed: 3.2.2010.

[8] 3GPP, “Proposal for Candidate Radio Interface Technologies for IMT-Advanced Based onLTE Release 10 and Beyond (LTE-Advanced),” *ITU-R WP 5D Third Workshop on IMT-Advanced Focused on Candidate Technologies and Evaluation*, October, 2009.

[9] IEEE, “IEEE 802.16 Candidate Proposal for IMT-Advanced,” *ITU-R WP 5D Third Workshop on IMT-Advanced Focused on Candidate Technologies and Evaluation*, October 2009.

[10] Tilastokeskus, “Televiestintä 2008,” *Suomen virallinen tilasto. Tiede, teknologia ja tietoyhteiskunta 2009.*, June, 2009.

[11] Cisco, “Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2009-2014 ” *Cisco VNI Forecast*, February, 2010.

[12] L. Oksanen, “Langattomat Teknologiat,” *GIGA Seminari, Tekes*, February, 2009.

[13] M. Steer, “Beyound 3G,” *Microwave Magazine, IEEE* vol. 8, no. 1, pp. 76-82, February, 2007.

[14] C. Shannon, “A mathematical theory of communication,” *Bell Syst. Tech. J.*, vol. 27, 1948.

[15] H. Holma, and A. Toskala, *WCDMA for UMTS - HSPA Evolution and LTE*: John Wiley & Sons, 2007.

[16] H. Holma, and A. Toskala, *LTE for UMTS - OFDMA and SC-FDMA Based Radio Access*: John Wiley & Sons, 2009.

[17] IEEE, “Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications,” *IEEE Standard 802.11*, 1999.

[18] P. Carson, “Flash-OFDM technology,” *Flarion Whitepaper*, November, 2001.

[19] Viestintävirasto, “Markkinakatsaus 2/2009,” *Markkinat ja investoinnit*, 2009.
[20] R. H. Katz, and E. A. Brewer, *The case for wireless overlay networks*: Springer US, 1996.
[21] M. Frodigh, S. Parkvall, C. Roobol, P. Johansson, and P. Larsson, “Future-Generation Wireless Networks,” *IEEE Personal Communications,* vol. 8, no. 5, pp. 10-17, 2001.
[22] V. Gazis, N. Houssos, A. Alonistioti, and L. Merakos, "Evolving Perspectives of 4th Generation Mobile Communication Systems," In the proceedings of International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Lisbon, Portugal, pp. 15-18, 2002.
[23] E. Gustafsson, and A. Jonsson, “Always Best Connected,” *IEEE Wireless Communications,* vol. 10, pp. 49-55, 2003.
[24] D. N. Knisely, T. Yoshizawa, and F. Favichia, “Standardization of Femtocells in 3GPP,” *IEEE Communications Magazine,* vol. 47, no. 9, pp. 76-82, September 2009.
[25] A. K. Salkintzis, M. Hammer, I. Tanaka, and C. Wong, “Voice Call Handover Mechanisms in Next-Generation 3GPP Systems,” *IEEE Communications Magazine,* vol. 47, no. 2, pp. 46-56, February, 2009.
[26] 3GPP TS 23.237 v8.1.0, “IP Multimedia Subsystem (IMS) Service Continuity; Stage 2,” *Release 8*, September, 2008.
[27] J. Mitola, "Cognitive Radio for Flexible Multimedia Communications”," In the proceedings of Mobile Multimedia Communications, San Diego, USA, pp. 3-10, 1999.
[28] J. Mitola, *Software Radio Architecture*: John Wiley & Sons, 2000.
[29] IEEE Standard 802.21-2008, “IEEE standard for local and metropolitan area networks: Media independent handover services,” *IEEE Standard*, January, 2009.
[30] IEEE 802.16 Network Management Task Group, “Amendment to IEEE Standard for Local and Metropolitan Area Networks - Part 16: Air Interface for Fixed Broadband Wireless Access Systems - Management Plane Procedures and Services,” *IEEE Standard*, May 2007.
[31] IEEE P802.11 – Task Group U, “Interworking with external networks,” *IEEE Standard*, May 2009.
[32] A. Karila, T. Korhonen, R. Salminen, and T. Väärämäki, “Broadband in Public Transportation Vehicles – Technology Study,” *ÄLLI publications,* vol. 1, 2008.
[33] Tekes - the Finnish Funding Agency for Technology and Innovation. "GIGA - Converging Networks 2005-2010," http://akseli.tekes.fi/opencms/opencms/OhjelmaPortaali/ohjelmat/CONE/en/etusivu.html Accessed: 5.6.2010.
[34] 4WARD Project. "The FP7 4WARD Project," http://www.4ward-project.eu/ Accessed: 10.6.2010.
[35] AsiaFi. "Asia Future Internet Forum," http://www.asiafi.net/ Accessed: 10.6.2010.

[36] W. L. Lehr, and J. M. Chapin, “On the convergence of wired and wireless access network architectures ” *Information Economics and Policy, Wireless Technologies,* vol. 22, no. 1, March 2010.

[37] P. Gonçalves, J. Oliveira, R. Aguiar, and R. Azevedo, "Managing QoS in a NGN Using a PBM Approach " In the proceedings of Fourth International Conference on Systems and Networks Communications, 2009.

[38] J. Bauer, “Regulation, public policy, and investment in communications infrastructure,” *Telecommunications Policy,* vol. 34, no. 1-2, 2010.

[39] N. Matsumoto, M. Hayashi, and H. Tanaka, "Network Middleware Design for Bridging Legacy Infrastructures and NGN " In the proceedings of The 5th Euro-NGI conference on Next Generation Internet networks Aveiro, Portugal pp. 175-183, 2009.

[40] H. Guo, W. Ye, S. Feng, and H. Zhuang, "Cross-layer design: a software engineering perspective," In the proceedings of The 5th International Conference on Wireless communications, networking and mobile computing, Beijing, China pp. 3875-3878, 2009.

[41] A. Hasswa, H. Hassanein, and A. Taha, "Facilitating 4G Convergence Using IMS," In the proceedings of The 2009 conference on Information Science, Technology and Applications, Kuwait, pp. 59-66, 2009.

[42] S. Park, and P. Kim, "A new vertical handover mechanism for convergence of wired and wireless access networks," In the proceedings of The 23rd international conference on Information Networking, Chiang Mai, Thailand, pp. 102-107, 2009.

[43] S. Oubira, M. Frikha, and S. Tabbane, "Handoff management in 4G networks," In the proceedings of The 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly, Leipzig, Germany, pp. 592-597, 2009.

[44] EU, “Communication from the Commission on the Intelligent Car Initiative, raising awareness of ICT for smarter, safer and cleaner vehicles,” 2006.

[45] F. De Greve, “FAMOUS: a network architecture for delivering multimedia services to fast moving users,” *Wirel. Pers. Commun.,* vol. 33, pp. 281-304, 2005.

[46] J. P. Conti, “Hot spots on rails,” *IEE Commun. Eng.,* vol. 3, no. 5, pp. 18-21, 2005.

[47] J. Mäkelä, T. Hämäläinen, G. Fekete, and J. Narikka, "Intelligent Vertical Handover System for Mobile Clients," In the proceedings of 3rd International Conference on Emerging Telecommunications Technologies and Applications (ICETA 2004), Košice, Slovakia, 2004.

[48] J. Puttonen, and G. Fekete, "Interface Selection for Multihomed Mobile Hosts," In the proceedings of The 17th Annual IEEE International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC’06), September 2006.

[49] J. Puttonen, G. Fekete, J. Mäkelä, T. Hämäläinen, and J. Narikka, "Using Link Layer Information for ImprovingVertical Handovers," In the proceedings of The16th Annual IEEE International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC'06), September 2005.

[50] J. Puttonen, G. Fekete, P. Rybczyk, and J. Narikka, "Practical Experimentation of Mobile IPv6 in Heterogeneous Environment," *Acta Electrotechnica et Informatica*, 2006.

[51] F. Le, S. Faccin, B. Patil, and H. Tschofenig, "Mobile IPv6 and Firewalls: Problem Statement," *RFC 4487*, 2006.

[52] 3GPP TS 23.402, "Architecture enhancements for non-3GPP accesses," *v. 1.4.0*, 2007.

[53] IETF MEXT. "Mobile EXTensions for IPv6 (mext)," http://www.ietf.org/html.charters/mext-charter.html Accessed: 25.5.2009.

[54] S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, and B. Patil, "Proxy Mobile IPv6," *IETF RFC 5213*, August 2008.

[55] E. Nordmark, and M. Bagnulo, "Level 3 Multihoming Shim Protocol for IPv6," *Internet-Draft (work in progress), draft-ietf-shim6-proto-09*, October 2007.

[56] S. Kota, "Broadband satellite networks: trends and challenges," in Wireless Communications and Networking Conference, 2005, pp. 1472-1478.

[57] Ministry of Transport and Communication of Finland, "Decision of the license of digital mobile communication network on 450 MHz band by Council of State," 2005.

[58] J. Vartiainen, "Kehittyvät tietoliikennepalvelut junaympäristössä," Helsinki University of Technology, 2007.

[59] IEEE 802.16m Task Group, "Air Interface for Fixed and Mobile Broadband Wireless Access Systems - Advanced Air Interface," *IEEE Standard 802.16*, 2010.

[60] Icomera. "Icomera website," http://www.icomera.com/ Accessed: 8.12.2009.

[61] SJ. "SJ website," http://www.sj.se Accessed: 7.11.2009.

[62] C. Freeman, and C. Perez, "Structural crisis of adjustment: business cycles and investment behaviour," *Technical change and economic theory*, G. Dosi, C. Freeman, R. Nelson *et al.*, eds., London: Pinter Pub, 1988.

[63] A. Lundgren, *Technological Innovation and Network Evolution*, London: Routledge, 1995.

[64] A. Anderson, "Ticketing and Information System 2014," *Helsinki: YTV*, 2008.

[65] Digita Ltd. "@ 450 Wireless Broadband," http://www.450laajakaista.fi/9019/9039/9847/9081, Accessed: 1.5.2009.

[66] T. Lehto. "Sonera muuttaa mobiilidatan hinnoitteluaan," http://www.tietokone.fi/uutiset/sonera_muuttaa_mobiilidatan_hinnoitteluaan Accessed: 30.3.2010.

YHTEENVETO (FINNISH SUMMARY)

Jo jonkin aikaa tietoliikenteen eräänä kehityssuuntana on ollut verkkojen konvergenssi. Erilaisilla ominaisuuksilla varustetut tietoliikenneverkot konvergoituvat yhdeksi, kaikkialla läsnäolevaksi verkoksi, jossa eri yhteystekniikat täydentävät toisiaan. Konvergenssin mahdollistamiseksi pitää kuitenkin ratkaista monia haasteita, joista yksi merkittävimmistä on liikkuvuuden hallinta heterogeenisessa verkkoympäristössä.

Tämä väitöskirja ”Seuraavan sukupolven tietoverkot, liikkuvuuden hallinta ja sovellutukset älykkäässä liikenteessä” käsittelee liikkuvuuden hallintaa heterogeenisissä verkkoympäristöissä. Asiaa on tarkasteltu erityisesti käyttäjän näkökulmasta, ja tutkimuksessa päädytään kehittämään liikkuvuuden hallintajärjestelmä. Järjestelmän tuomia hyötyjä tarkastellaan sekä käyttäjän että operaattorin näkökulmasta.

Kehitetyn järjestelmän eräs tämän hetkisistä merkittävimmistä haasteista on tehokas tiedonkeruu saatavilla olevista verkoista. Tästä johtuen integrointia standardisoituun tiedonkeruuratkaisuun on tutkittu. Toteutusmahdollisuudet vaikuttavat lupaavilta, joskin standardointiorganisaatioiden täytyy muodostaa vahva konsensus, ennen kuin laaja-alainen toteutus on mahdollista. Erityisesti liikkuvuuden hallintaa koskeva säännöstö ja se, mihin verkkoihin käyttäjät ohjataan, on tärkeä osa tätä keskustelua.

Älykkäitä liikennejärjestelmiä käytetään esimerkkinä ympäristöstä, jossa useaan eri verkkoteknologiaan perustuva tietoliikenne tarjoaa merkittäviä etuja verrattuna yhteen verkkoteknologiaan rajoittuvaan yhteyteen. Hyödyt esitellään sekä teknologian että liiketoiminnan näkökulmasta. Liiketoimintahyötyjä puoltaa myös laaditut teknoekonomiset analyysit. Lisäksi tutkimuksessa päädytään ehdottamaan palvelu- ja teknologiaviitekehyksiä, joita voidaan soveltaa älykkään liikenteen järjestelmissä.

ORIGINAL PAPERS

PI

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Tapio Väärämäki, Timo Korhonen and Edward Mutafungwa

Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, Volume 222, Issue 1, 2008.

https://doi.org/10.1243%2F09544097JRRT155

PII

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by

Vesa Riihimäki, Tapio Väärämäki, Juha Vartiainen and Timo Korhonen

IET Journal on Intelligent Transport Systems, Volume 2, Issue 1, March 2008.

http://dx.doi.org/10.1049/iet-its:20070014

PIII

NETWORKED BUSINESS MODELS FOR TRAIN ICT SYSTEM IMPLEMENTATION

by

Senja Svahn and Tapio Väärämäki

The Business Review, Cambridge, Volume 12, Issue 1, 2009.

PIV

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by

Tapio Väärämäki, Jani Puttonen and Gábor Fekete

Proceedings of the Fourth Advanced International Conference on Telecommunications (AICT 08), Athens Greece, 2008.

https://doi.org/10.1109/AICT.2008.68

PV

MULTIPLE INTERFACE MANAGEMENT OF MULTIHOMED MOBILE HOSTS IN HETEROGENEOUS WIRELESS ENVIRONMENTS

by

Jani Puttonen, Gábor Fekete, Tapio Väärämäki and Timo Hämäläinen

Proceedings of the Eight International Conference on Networks (ICN), Mexico, 2009.

https://doi.org/10.1109/ICN.2009.82

PVI

THE VERHO MOBILITY MANAGEMENT SYSTEM FOR HETEROGENEOUS NETWORK ENVIRONMENTS

by

Tapio Väärämäki

International Journal on Advances in Networks and Services, Volume 2, Issue 2-3, 2009.

https://www.iariajournals.org/networks_and_services/netser_v2_n23_2009_paged.pdf

PVII

ESTIMATION OF TELECOMMUNICATION TECHNOLOGIES, SERVICES AND COSTS TO SUPPORT PUBLIC TRANSPORT INFORMATION SYSTEM REQUIREMENTS

by

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