Selecting Telecommunications Services and Technologies for Developing Intelligent Transport Systems in Helsinki Municipality

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1. Overview

In this study, Intelligent Transport Systems (ITS) telecommunication scenarios for Helsinki Municipality area are inspected up to 2015. Our study analyzes various networking technology scenarios intended to support the existing and planned ITS services for busses and trams. Also, we comment the relating business aspects and competition environment.

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. Service associated performance qualifiers come from pricing models, purchasing, operation and maintenance as well service arrangements and user interfaces design and operation.

Currently, city of Helsinki applies Radio Frequency Identification (RFID) – based ticketing solution, traffic light priority switching for some of the most important crossing and the city has tested broadband communications in busses using Flash-OFDM technology (Digita, 2007). Internet, mobile phone and real-time displays at stops, terminals and other central locations facilitate convenient travelling and assist in travelling planning. Tickets can be paid also by travel cards or purchased even by mobile phones. Unified vision of Helsinki Metropolitan Area Council (YTV) is to strive to systematically develop ITS services and associated networking technologies to follow the very latest global ITS trends.

At the moment, most of the ITS services do not require broadband connection or real-time operation with few exceptions as supplying Internet connection directly to passengers. However, the services will inevitably be developing further and their capacity and delay requirements will stringent. Also, there is a clear demand for integrated ITS operation and management systems that may require surprising large data rates, especially if wide scale real-time support is later desired. Solutions should have open interfaces when ever possible for scalability and device manufacturer independence and they should be modular and cost effective thus enabling also easy evolutionary system development.

Our results to be discussed further in this paper indicate that based on technology-service scenarios, YTV has in principle three paths for ITS development: (1) YTV can buy the services/technologies from a telecommunication operator, (2) build own network or (3) to realize a hybrid solution. The networking technology/service study is compressed into timeline diagrams which can then be used to support decision making of YTV.

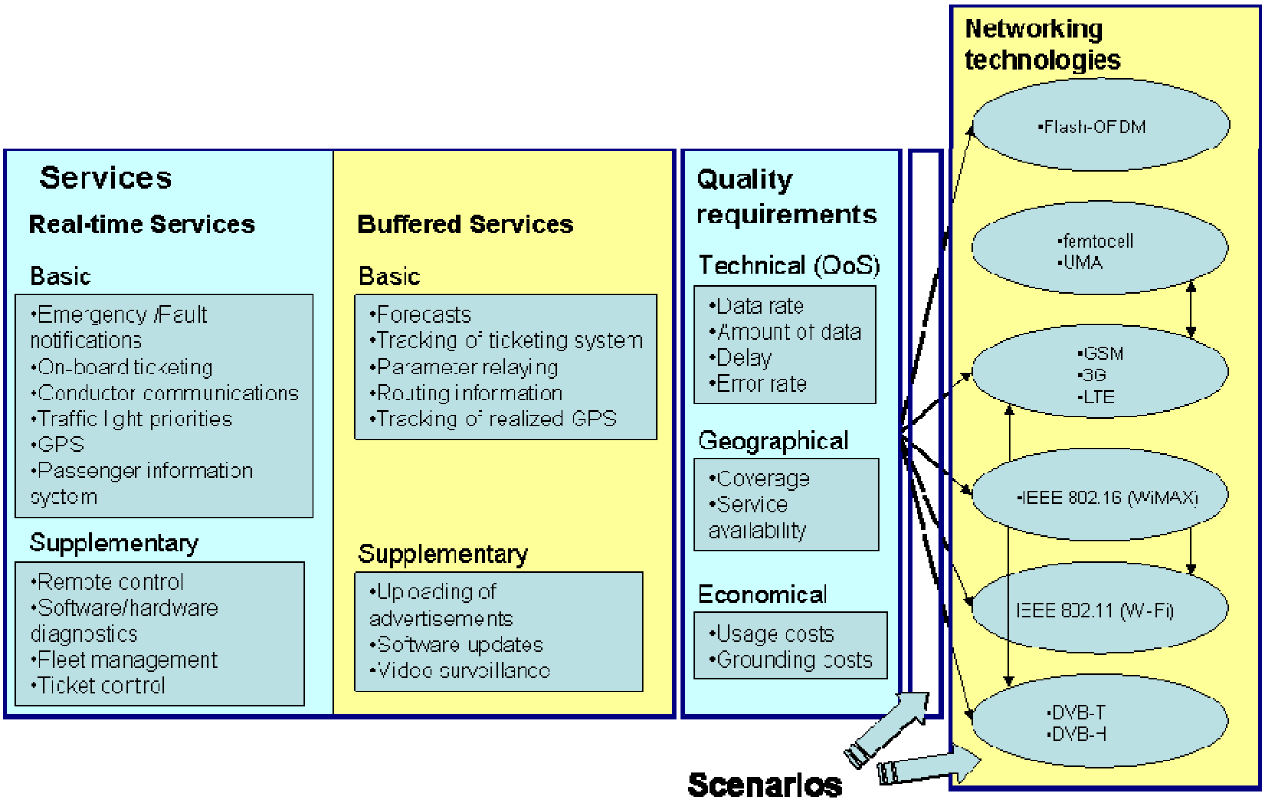

Fig. 1 Study framework

2. Background

ITS Services set technical, geographical and economical requirements for networking technology as illustrated in Fig.1. We have divided ITS services into real-time/buffered and basic/supplementary service in order to support flexible and modular networking technology development in the time span of the system evaluation up to 2015. Division to real-time/buffered services is linked to telecommunication networking QoS parameters. This means that the networking technology must satisfy technical service requirements. Division to basic/supplementary services is linked to economical constrains and flexible system realization. We assume, based on current ITS realizations, that the basic services by definition, carry a greater degree of importance than the supplementary services. Also, the supplementary services can be realized without a joint telecommunication networking solution though their common management will also bring up some significant benefits. For example, remotely controlled uploading of advertisements could allow them to be updated several times per day if required and on-time realized system diagnostics and software updates can increase system operation/maintenance quality. Geographical quality requirements affect especially overall system costs constrained to service quality. For instance, it is not necessarily required for the networking solutions to cover geographical areas that the busses do not run. However, if it is realized, passengers can be offered end-to-end telecommunication services leading to a greater degree on service engagement and potentially to some novel, more usable and/or profitable services. This can be realized especially by using heterogeneous networking concepts linking ITS networking structures to the existing networks, as GSM/UMTS and Wi-Fi cells. The role of networking scenarios of Fig.1 is elementary because they form the bases to inspect the ITS networking/service solutions for YTV. In summary, in Networking we research applicable technologies and interfaces. This inspects partly overlapping solutions. For instance, WiMAX and 802.11 mesh- networks can support about the same technical service quality though their costs and technological maturity/coverage differs. In Finland, WiMAX is operated in licensed bands and these bands can be guaranteed to be interference and congestion free. In Economics we strive to inspect related costs and suggest realization alternatives. In Service requirements we introduce classification of ITS services suitable to YTV, discuss the respective service requirements, and inspect their future development.

3. Service development backgrounds

This study is part of ITS development project of YTV called as “The Travel Card and Information System 2014” [Helsinki Metropolitan Area Council YTV, 2006]. The project strives to develop cost efficient and user- friendly ITS for the expanding Helsinki Metropolitan commuting area. The system includes payment of fares, real time passenger information and online data communication from and to the vehicles (Fig. 2). The system enables to collect fares from passengers based on agreed tariffs. The first stage of the project is realization of updated RFID-ticketing system in 2009-2011. The system is planned to serve over its 15-year life cycle cost- effectively and will be updated according to the developments in technology and customer needs [Anderson, 2008].

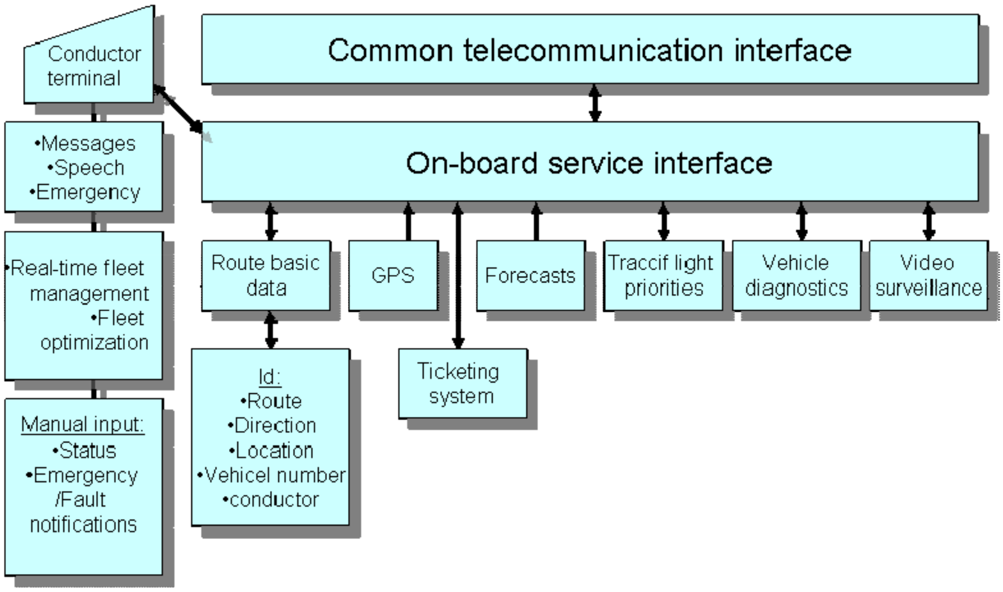

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Fig. 2. Overview of the planned ITS services for Helsinki Metropolitan Area

QoS – requirements

Tables I summarizes service QoS requirements based on device manufacturer’s data sheets and estimated service statistics. Service profiles are constrained to the assumed and required service quality. For instance, data storage requirement for video surveillance service depends on picture quality and channel delay. Top priority services for YTV can be summarized as follows:

Ticketing system is intended for selling tickets for passengers and for ticketing system follow-ups. It enables paying fares by travel card, in cash or by mobile phone.

Traveller information system produces location, route, and buss 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 targets to make crossings faster for public transportation in rush hours.

System upgrades should be modular to follow technology / service development. Also, open interfaces to other fair, ticketing and information systems are required. System components are tracked in the duration of the project for applicable updates from device manufacturers and outsourced service providers.

Table I Overview of QoS requirements for the expected ITS services in the framework of this study

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

4. Comparing network technologies

Let us now consider potential telecommunication network technology options for YTV-area. This inspection is based in great deal on city-wide telecommunication networking pilots as for instance [Mahmud, 2006], as well as in participation to system standardization bodies and is summarized in Table II. The table lists basic characteristics of each technology, such as downlink- and uplink rates, latency and examples of applied monthly fees. Also, a quick evaluation of how each technology fits to basic and supplementary services of Table I is given. Table III lists main WLAN technologies. One should note that there are new standards just under study such as IEEE 802.11p (wireless access in vehicular environments at 5.9 GHz [IEEE 802.11p]) that should be followed for potential technology and service scenario upgrades.

Table II. Comparison of cellular and WMAN technologies.

	2.5 G	3G	@450	WiMAX
Standard	GPRS, EDGE	UMTS, HSPA	Flash-OFDM	802.16e-2005
Developer	3GPP	3GPP	Flarion / Qualcomm	WiMAX –forum
Frequencies	900, 1800 MHz	900 MHz, 1.9/2.1 GHz	450 MHz	3,5 GHz
Coverage	Over 90 %	40 % – 80 % of populated area, 20 % of area	60 % of area	limited areas
Downlink rate	Max. 200 kbit/s	384 kbit/s - 2 Mbit/s (5 Mbit/s)	512 kbit/s - 1 Mbit/s	Max 2- 4 Mb/s
Uplink rate	Max. 80 kbit/s	160- 384 kbit/s	256 – 512 kbit/s	512 kbit/s - 2 Mbit/s
Mobility support	Excellent, 250 km/h	Excellent, >250 km/h	Excellent, 250km/h	Good, 120 km/h
Latency	> 500 ms	50 – 200 ms	20 – 60 ms	30 – 50 ms
Terminal prices	Look at 3G	130 – 270 €	240 – 280 €	500 €
Monthly fee	10 € / month	10 – 35 € / month	38 – 45 € / month	30 – 60 € / month
Basic services	Voice and other basic services, latency tolerance max. 1 s, bit stream max. 40 kb/s	Voice and other basic services, latency tolerance max. 0.5 s, and bit stream max. 384 kb/s	Voice with VoIP and other basic services, latency tolerance max. 0.1 s, and bit stream max. 1 Mb/s (2 Mb/s WiMAX)	
Supplementary services	Does not suite well (bit rate limit)	Applicable, must be supported with the WLAN technology	Applicable, must be supported with the WLAN technology (WiMAX might not require)	

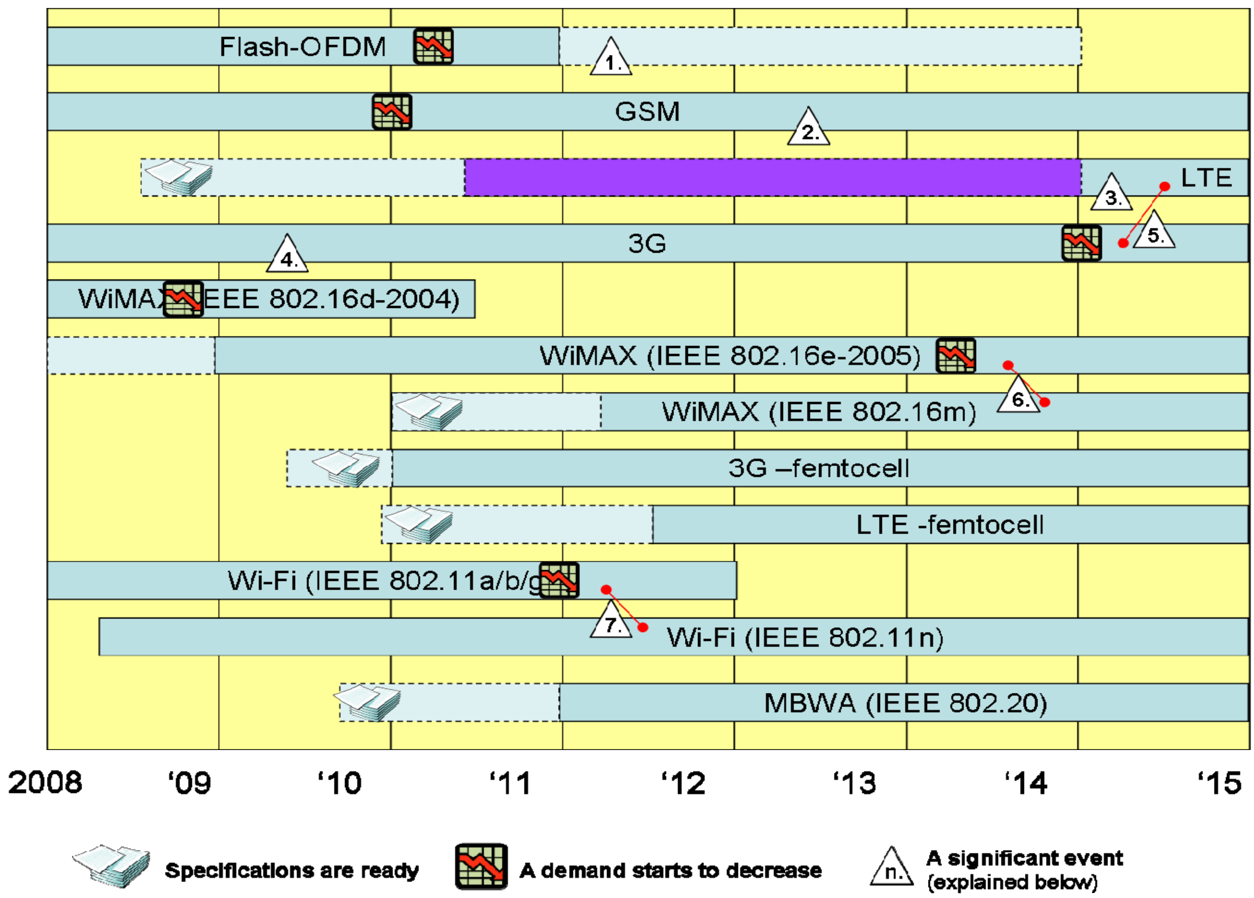

Fig 3. Technology roadmap for YTV up to 2015

Figure 4 summarizes required technical characteristics in terms of bit rate, coverage and suitability for vehicular usage.

Technologies can also be compared in terms of market position, regulation, and progressiveness. The respective roadmap is shown in Figure 3. Specification ready - estimates are taken from the respective standardization bodies. In Figure 3 solid blocks illustrates market availability of a specific technology. Dashed blocks present preparation / study time when technology is under development and waiting for market entry or that it might also potentially disappear. The purple block indicates a major change in mobile phone networks/market and the red connectors denote transitions from technology to another. The numbered events are explained as follows:

1 FLASH-OFDM market development depends heavily on terminal availability, frequency regulation and license fees of Qualcomm Inc. By 2011 and further, there will be new users especially in sparsely populated areas when wireless technologies are used to replace old copper connections.

2 Operators have not yet decided the exact dates for a closure of GSM networks in Finland but there is a demand for major frequency reallocation of GSM frequencies to 3G and LTE usage. GSM networks will be closed at the latest at the end of 2015 due to closure of maintenance contracts [HS 2008].

3 First LTE implementations will probably be seen in Finland in 2010-11. The LTE networks will be used ‘experimentally’ until 2014 (the purple block) when the transition to packet switched speech will occur, if technical conditions allow. This will cause a significant increase in the usage of LTE networks.

4 UMTS 900 implementations are spreading to wide areas. UMTS 900 will expand 3G coverage significantly especially in sparsely populated areas

5 Popularity of 3G networks will start to decrease due to LTE and there will be lot of dual-mode terminals available on the market, as like we have GSM- and 3G terminals nowadays. 3G speech will be implemented via IP multimedia subsystem (IMS), which enables circuit switching / packet switching conversions.

6 IEEE 802.16m is backward compatible to IEEE 802.16e in a similar way as IEEE 802.11g access points support IEEE 802.11b terminals.

7 IEEE 802.11n access points support some older WLAN standards - at least IEEE 802.11g.

Table III Comparison of WLAN technologies

	802.11a	802.11b	802.11g	802.11n
Release year	1999	1999	2003	2009
Frequency	5.8 GHz	2,4 GHz	2,4 GHz	2,4 / 5.8 GHz
Range	120m	140m	140m	250m
Bitrate	54 (22) Mbps	11 (5,5) Mbps	54 (24) Mbps	248 (75) Mbps
Operating modes	Ad-Hoc, Infrastructure	Ad-Hoc, Infrastructure	Ad-Hoc, Infrastructure	Ad-Hoc, Infrastructure
Market situation	Low popularity, increasing due to the frequency band	Extremely popular, the most used WLAN technology	Very popular along with the 802.11b standard	Emerging, just published

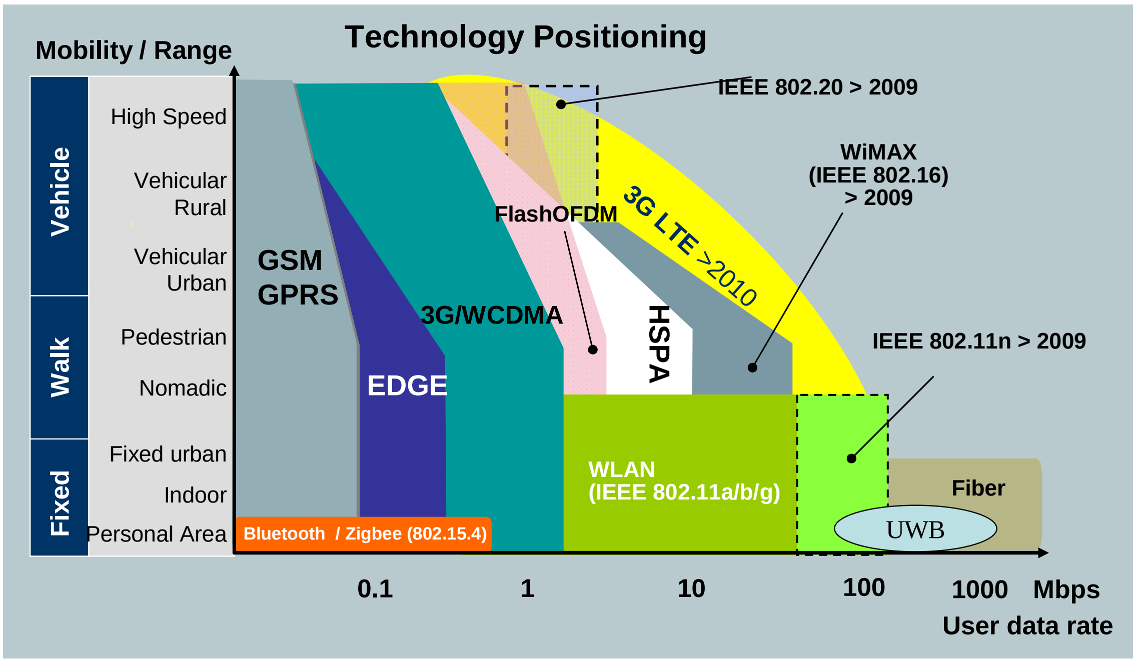

Figure 4. Comparison of networking technologies (adapted from www.umts-forum.org)

5. Networking development scenarios

Let us now consider various networking alternatives by following the scenarios of Fig.5. The thick lines present main scenarios and the dashed lines minor scenario variations.

Scenarios #1 and #3: GSM/3G/LTE+Wi-Fi / + WiMAX

The YTV area is covered by several 3G network operators with a good coverage and support of 3G High-Speed Downlink Packet Access (HSDPA) rates. In practise the offered rates do vary from THE 3G specified, up-scaled, optimum rates. This is typical for the particular operator specific 3G implementation, especially geographical base station density. Also, network availability varies as a function of loading conditions. Naturally, the 3G services work better for lower rates (as for instance for 384 kb/s). Also, latency varies and thus performance of real-time applications cannot be always guaranteed. YTV's cooperation with 3G mobile network operators can lead to cost savings for instance in network management. Note that Finnish service prices in the whole operator range are currently quite reasonable (Table IV).

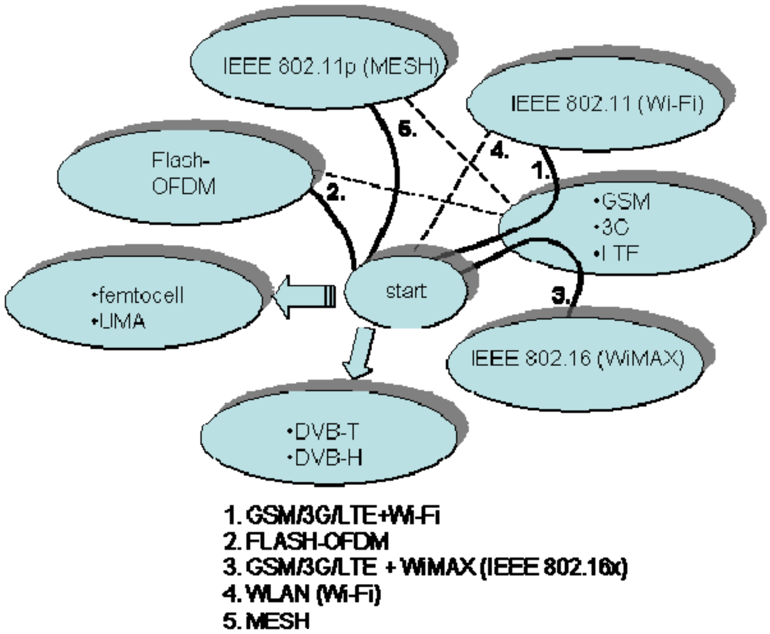

Fig. 5. Networking technology development scenarios for YTV- area

3G networking can be combined to Wi-Fi and/or WiMAX networking by using multi-routers that would be installed in busses. This would enable to use the best available connection in a particular geographical location improving QoS. Also, relating vertical-handover networking could support buffered services in certain bus stops and larger bus stations for loading/unloading of on-board servers for instance for system updates or advertisement uploads. Later multi-homing could also be used [Nelson, 2008] that would potentially reduce overall costs and improve performance.
However, multi-routers are nowadays relatively expensive [United business partners, 2009] and it is important to investigate if the overall cost structure would be favourable for the offered services. WiMAX-networking offers in principle a lucrative alternative for high rate IP-backbone connection. Especially, in Finland WiMAX works in licensed bands that guarantees interference free operation. However, the specified frequency range of 3.5 GHz resides relatively high in frequency spectrum thus increasing the number of required base stations for mobile access (in contrast to fixed wireless access). Also, WiMAX is currently an expensive technology [WiMAX, 2009].

Scenario #2: FLASH-OFDM

FLASH-OFDM is a propriety networking technology originally developed by Flarion and nowadays managed by Qualcomm. It works In Finland at 450 MHz and aims to offer land-wide coverage with a nominal rate of 1 Mb/s. An important benefit of FLASH-OFDM is that it supports high vehicle speeds up to 250 km/hour [Kim, 2004]. Also, low latency can be seen as a strength of the technology. As such, it would be directly applicable for ITS-applications and it has indeed already been tested for ITS in Helsinki area [Digita, 2007]. Based on this pilot, both network coverage and data rates were good over Helsinki city area. Drawbacks of this technology relate to the applied frequency band and its propriety-nature. It is not clear if the technology will experience such popularity that Flash-OFDM terminals would actually be available for a longer run. Also, equipment prices are relatively high [Arjona, 2008] and their price development is difficult to predict. In Finland, the 450 MHz range has a limited bandwidth [Lakkakorpi, 2008]. Therefore, if the number of subscribers increases, specified data rates might not be easily supported even if the number of base stations is significantly increased. This can happen due to base station radio interference that is more severe, the lower the operation frequency is. FLASH-OFDM technology can also be used without connection to mobile networks. However, for a longer run it will inevitably support roaming with other networks, provided, of course, that the technology survives competition.

Table IV. Sample of mobile broadband prices in Finland, May ’09 (Laajakaistavertailu.fi)

Operator	Service title	monthly fee	downlink	uplink rate	network
DNA	Nettikaista	9,80 €	384 kbps	-	DNA 3G
Saunalahti	Mobiililaajakaista	9,80 €	384 kbps	-	Elisa 3G
Elisa	Mobiililaajakaista	9,90 €	384 kbps	-	Elisa 3G
Aina	Reissunetti	9,90 €	384 kbps		DNA 3G
DNA	Nettikaista	14,80 €	512 kbps	-	DNA 3G
Saunalahti	Mobiililaajakaista	14,80 €	512 kbps	-	Elisa 3G
Elisa	Mobiililaajakaista	14,90 €	512 kbps	-	Elisa 3G
Sonera	Liikkuva laajakaista	14,90 €	512 kbps	-	Sonera 3G
KaamosCenter	450Netti	35 €	512 kbps		Digita @450
Datanator	@450 Laajakaista	38 €	512 kbps		Digita @450
Mobile.fi	Mobile.fi Lite	41,20 €	512 kbps	256 kbps	Digita @450
DNA	Nettikaista	19,80 €	1024 kbps	-	DNA 3G
Saunalahti	Mobiililaajakaista	19,80 €	1024 kbps	-	Elisa 3G
Elisa	Mobiililaajakaista	19,90 €	1024 kbps	-	Elisa 3G
Aina	Reissunetti	19,90 €	1024 kbps	-	DNA 3G
Sonera	Liikkuva laajakaista	19,80 €	1024 kbps	-	Sonera 3G
KaamosCenter	450Netti	39,90 €	1024 kbps		Digita @450
Sonera	Laajakaista Langaton	39,90 €	1024 kbps		Digita @450
Mobile.fi	Mobile.fi Standard	46,20 €	1024 kbps	512 kbps	Digita @450
Datanator	@450 Laajakaista	48 €	1024 kbps		Digita @450
DNA	Nettikaista	29,80 €	2048 kbps	-	DNA 3G
Saunalahti	Mobiililaajakaista	29,80 €	2048 kbps	-	Elisa 3G
Elisa	Mobiililaajakaista	29,90 €	2048 kbps	-	Elisa 3G
Sonera	Liikkuva Laajakaista Teho	34,80 €	3686 kbps	-	Sonera 3G
Saunalahti	Mobiililaajakaista	34,90 €	5120 kbps	-	Elisa 3G
Elisa	Mobiililaajakaista	35,00 €	5120 kbps		Elisa 3G

Scenario #4, Wi-Fi networking

WLAN is nowadays widely supported in most terminals and the technology is cheap and offers high data rates of tens or even hundreds of Mb/s. Also, 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. As such, WLAN is especially applicable for on-board networking. However, WLANs have also some limitations. They work in ISM bands and therefore interference-free operation can not be guaranteed. It is even possible that the network will be totally blocked due to interference. The Wi-FI equipment applies relatively low transmission power that restricts coverage. Also, support for QoS and especially for mobility is currently only partially realized in practise still standardization work is intense.

Scenario #5, Wireless mesh-networking

In wireless mesh-networks all network nodes work as base stations and routing follows network topology in a flexible way. When compared to conventional networking technologies, they can own enhanced performance, cost efficiency and reliability provided there are enough large capacity nodes in the service area. Mesh-networks are currently standardized in IEEE workgroups 802.11s (WLAN), 802.11p (ITS), 802.15.5 (WPNA) and 802.16j (multi-hop). Especially, 802.11p work targets to support ITS. This refers both to inter-vehicle communications as well as to direct communications to fixed base stations with a maximum link distance of few kilometres. Car manufacturers are already implementing mesh-networking that should give a strong ITS boost to this technology [Wellens, 2007; Stibor, 2007; Bahr, 2006; ArsTechnica, 2006]. Drawbacks of mesh-networks include that their capacity of is greatly affected by the number and capacity of participating nodes, and, relating to this, their QoS support can be constrained.

6. Alternative Development Scenarios

Evaluation of network technologies and service environment leads us to inspect two alternative implementation scenarios. The first one relays on traditional subscriber-operator business model, where YTV as a transport operator orders all telecommunication services from a mobile network operator. Our second model suggests building of own network. Both options can be supported by FLASH-OFDM technology.

6.1 Being a subscriber in operator's network

Currently a technically simple solution 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 download rates up to 3.6 and 5 Mbps. Also, potential femtocell-solutions will enable new interesting business models for public transportation operators too.

In our case, YTV presents a big customer for operators with approximately 1500 vehicles. Number of subscriptions is not; however, so large that YTV could necessarily control development of operator's networks to a desired direction. Anyhow, the current technology level should be adequate enough to start implementing the planned real-time services by the operator based model.

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 to use LTE widely at latest in 2014, and thus also the migration to LTE-compatible modems would happen at this time. This is in-line with a rule-of-thumb that typical life span for a telecommunication devices, such as core network switches, is about 5-8 years. (We do note that life span for some telecommunication devices such as mobile phones and other consumer electronics can be substantially shorter.) In 2014 LTE technology should have been already well-tested and typical telecommunication network start-up problems solved that often relate to system (especially base station) parameter optimization and reliability reflecting in service availability, data rates and coverage.

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 video surveillance material. WLAN access points can be used in small areas such as depots to enable buffered data transfers and relating WLAN based services. Costs for building the WLAN coverage to these small areas should also be relatively modest. FLASH- OFDM networking could be used in parallel with the mobile phone subscriptions for reliability. Mobile subscriptions and terminals can be purchased from multiple operators that should compensate operator dependency. Data streams from different subscriptions could also be combined by multi-homing to enhance networking performance and reliability.

In overall, subscribing services from mobile operators should be easy and reliable. Current service fees are also very reasonable in Finland due to healthy competition environment and there is no reason to expect them to rise significantly. However, YTV should get itself operator based guarantees of the planned QoS before making the final investment decision. This is important due to the development of overall networking loading that is affected by other network users too. An important feature of the operator based model is that the network would be basically owned by the operator potentially excluding the WLAN hot spots. This restricts the way how major part of the network would be developed from YTV point of view.

6.2 Building own network

A Operating area of YTV reaches 12 municipalities in traffic and waste services in Helsinki capital area which all could utilize the same network if an own network would be build. It could support a wide variety of municipal services also other actors than just YTV. This strengthens financial bases of this scenario.

Fibre core network
A base of large capacity wireless network is a fast and reliable fibre core network. In YTV case we have estimated that fibre network would consists of 1000 route kilometres, 500 node points, and 12 000 device ports costing 28 k€ / month (fibre) + 12,5 k€ / month (active devices) + 22,5 k€ / month (network) maintenance yielding 63 k€ / month or 756 k€ / year. In this estimation we assume the devices would be placed to existing server rooms and power consumption would not be any significant cost factor in the overall budget. Own fibres and/or Ethernet-layer virtual networks (VLANs) could be separated for served parties without trading their QoS requirements. If own network would be build and marketed wisely, YTV could charge other users as refer earlier (cities, hospital districts, fire and rescue services, operators etc.) so that YTV could potentially get their own services much cheaper or even for free. If this is compared to the annual costs municipalities would need to pay for operators, the 756 k€ annual cost feels a relatively small amount.

Wireless access
Fully operational ITS network requires wireless access points between vehicles and core network. To start with, YTV should setup cheap Wi-Fi hot spots for crowded areas and in selected areas for buffered service on-board loading. In city of Helsinki there are 450 traffic light controlled crossroads and 3000 bus or tram stops. This makes in total about 3500 areas where access points should be placed just for traffic monitoring and control. We have estimated that doubling this number of access points would give adequate coverage along major bus routes. W-Fi networking develops rapidly: For instance, IEEE 802.11p will support high speed mesh and infrastructure based ITS. WiMAX technology can be used to provide larger area coverage for sparsely populated areas and to supply Wi-FI hot spots by fixed wireless access (RF-links). By using YTV's fibre core network, telecommunication operators could setup high-speed wireless coverage areas to support other network technologies too. For example, @450 and 3G-LTE networks could thus be extended. Relating cost savings would benefit both the network operators and YTV.

Own network can be developed more independently and starting from own needs. Established fibre core network can be expected to have life span extending up to 2014 and even after. After the payback period network would be owned and controlled by YTV. In this point, 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 own network and services develop.

6.3 Costs of Building Fixed Core Network

Own networking solution include fibre core network (consisting of fibre and active devices), wireless access network, terminals and infrastructure to supervise O & M (operation and maintenance). To inspect related costs, let us now assume that the network would consist of 1000 route kilometres. The network would thus be used to connect essential geographical areas of YTV and it would cover also most important traffic routes. In rural areas of Finland, building the fibre network costs some 5-6 €/meter including work and cable. (Expenses can be divided fifty-fifty to work and the cable.) In city areas digging work is significantly more expensive especially due to opening and restoring asphalt and revetments. Also, existing cables and pipes make work more demanding. Opportunistic network building utilizes existing cables, tunnels, and other infrastructure as much as possible.

Let us estimate based on a comparable project, as referred in [Bruno, 2005], that building expenses would be 5 million Euros for the fibre network covering the assumed 1000 route kilometres. Thus, for the network it would cost 5000 €/km to dig the cable. If the investments were funded by a 5 M€ bank loan, the total expenses for 25 years annuity loan with 4.5% interest rate would be 8,3 M€. Assuming that value of money would decrease during the build-up period the same way as near-past before, the value of fibre dig to the ground and relating core infrastructure would still remain. There is a solid demand for high capacity core networking, and therefore additional revenues could further be earned by renting some fibre core capacity to operators, municipals, societies, enterprises and other parties.

6.3.1 Active devices of the core network

Based on earlier experiences, expected lifecycle for active devices in the network can be approximated to be up to seven years. Let us suppose we use core network switches consisting of 2 x 10GE (Gigabit Ethernet) XFP ports, 2 x 10 Gbit/s stacking ports, 24 x GE SFP (Small Form Pluggable) ports, two power supplies, and apply wire-speed switching and routing. An unnamed manufacturer offers these devices with a low price tag of 2306€ in a big sourcing case with 0% VAT suiting well to the applied core network. In addition to the switch, also optical modules are needed. This switch has open slots, so it supports also modules from other manufacturers. A price tag for GE SFP modules with 10 km range is 36€ and for 10km 10GE XFP module 720€. Price development has been declining. Unit price is therefore 2306€ + 2x 720€ + 24 x 36€ = 4610€. With these devices 10 Gbit/s ring topology networks can be realized and connected through 10 Gbit/s stacking ports. Each switch can then be connected up to 24 access switches, which are further connected to the access points. A high quality access switch containing 2 x GE uplink and 24 copper GE ports costs 872€. Optical modules are a bit more expensive, but still below 50€. Thus the price tag for access switch would be approximated about 950€. We estimate that the project could be started with 100 core switches and 500 access switches yielding investment cost of 910 000€. Device manufacturers provide guarantees for the switches for their whole life span meaning free-of-charge software updates and replacements.

With these devices there would be 12 000 GE ports in 500 places. Virtual LANs (VLAN) and traffic prioritization can be defined to the network, and also for core switches enabling quick routing and packet filtering between VLANs. If the devices would be purchased within the following 7 year by 4.5% interest rate annuity loan, the monthly fee would be 12 650€ and the total costs for 7 years would be 1060 k€. During this time period, devices under duty would be depreciated and new devices could be purchased in the same way.

6.3.2 Network operation and maintenance
O & M activities can be outsourced to any reliable and cost-effective organization focusing on this business. Typical maintenance fees would be about 25 €/month for each access switch and 100 €/month for core switch. Therefore, in total, O & M expenses would be 22 500 €/month.

6.3.3 Total costs of the core network
In summary, monthly expenses for the core network consisting of 1000 route kilometres, 500 nodes and 12 000 GE ports would be 28 k€ / month (fibre) + 12,5 k€ / month (active devices) + 22,5 € / month (network maintenance) yielding 63 k€ / month or 756 k€ / year. In total costs we further assume that the devices would be placed to existing premises and power consumption would not be any significant expense. Counting on these cost estimations, potentials to rent part of capacity to third parties and to the projected development of paid services we may propose that the core network could be paid back within 25 years. Its utilization period could be even longer, up to – 30-50 years. We note however, that more accurate inspection of actual payback period would require detailed techno-economical analysis.

6.3.4 Sensitivity Analysis for the Fixed Core Network

Let us now run some investment sensitivity analysis for fixed network costs (Fig. 6). We assume 7 years bank loan period and inspect monthly costs (y-axis). Calculation parameters sensitivities are shown on x-axis. Cost of fibre network is critical especially in utilization of opportunistic network building. This could be further evaluated having access to a municipal tunnelling, piping, and electricity maps and plans. Also, cost development of fibre is a critical factor. Costs of other networking elements are easier to estimate and there is plenty of market information available. If the fibre network would be paid in the first 7 years, relating costs would thereafter be substantially cheaper. Then the major costs would results from minor infrastructure updates due to expected increasing service demand and O & M costs.

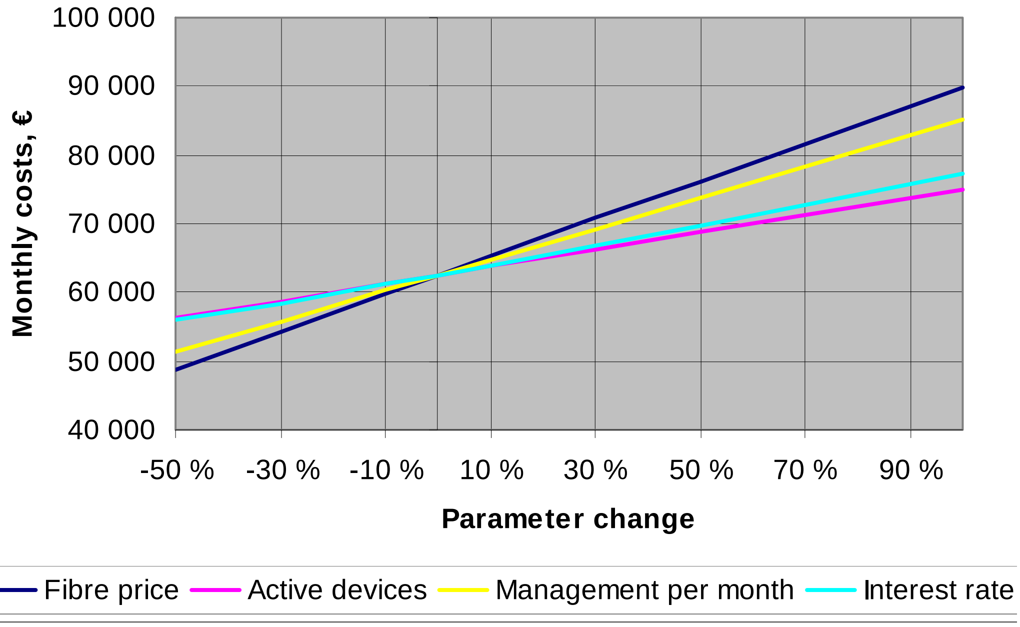

Figure 6. Sensitivity scenarios for fixed network

6.4 Costs of the Wireless Access Network

A strong trend in fixed networking is the convergence to cost-efficient optical Ethernet - based networking. Wireless technologies are more divergence, and there are several competing technologies that also currently drive development of multi-radio terminals. In the case of YTV own fixed core network, wireless access points should enable easy extendibility. Most prominent technologies include 802.11 b,g,n Wi-Fi for hot spot coverage, IEEE 802.11p for ITS vehicular communications, and WiMAX for larger area coverage. As mentioned earlier, with respect of viable ITS, there are 3500 critical access points in the YTV area and we estimate that 7000 Wi-Fi access points would cover the major bus routes. If the price for an access point, antenna and outdoor-box would be 200€, the resulting cost would be 7000 x 200 € = 1,4 M€. Another option would be to outsource wireless access network setup as well as O & M. In this case the price per access point would be much lower, for instance e.g. 5 €/access point / month yielding 7000 x 5 € = 35 000 € in total in a month. As referred earlier, Wi-Fi is not the only technology which could be applied in building the access network. For instance, for a longer run WiMAX could provide an alluring option. Currently, however, due to equipment prices, frequency allocation issues, and terminal availability we do not recommend starting wireless access network development from WiMAX networking. In any case, wireless access can be improved by 3G/LTE networking that increases service availability in coverage area boarders as well as improves data rates if multi-homing is applied. In case of operator subscriptions, prices listed in Table V are used. Acquisition of operator subscriptions is straightforward and discounts for a high number of subscriptions should be received.

Wireless access network sensitivities for various technologies are inspected in Fig. 7. To start with, we note that FLASH-OFDM subscriptions own a prominent sensitivity. However, they can support high overall QoS and serve large geographical areas provided that number of subscribers remains in system limits. We estimate that in-vehicle equipment including on-board servers, wireless modems and connections to peripherals would be the most sensitive factors in the overall price tag. For example, if the price of in-vehicle equipment would increase by 30%, it would already become more expensive than FLASH-OFDM subscriptions. However, price for the in-vehicle equipment is also difficult to estimate. For instance, it is not clear what kind of power supply and internal networking solutions are needed. Even more important, vehicle manufacturers' on-board LAN development will most probably effect to the respective costs greatly.

Table V Operator subscription fees

Access technology	Monthly Fee	Terminal Price
GPRS / 3G	10€	100€
Wi-Fi Access Point	5€	200€
Wi-Fi Terminal	0€	50€
FLASH-OFDM	40€	200€
In-Vehicle Equipment	0€	4000€

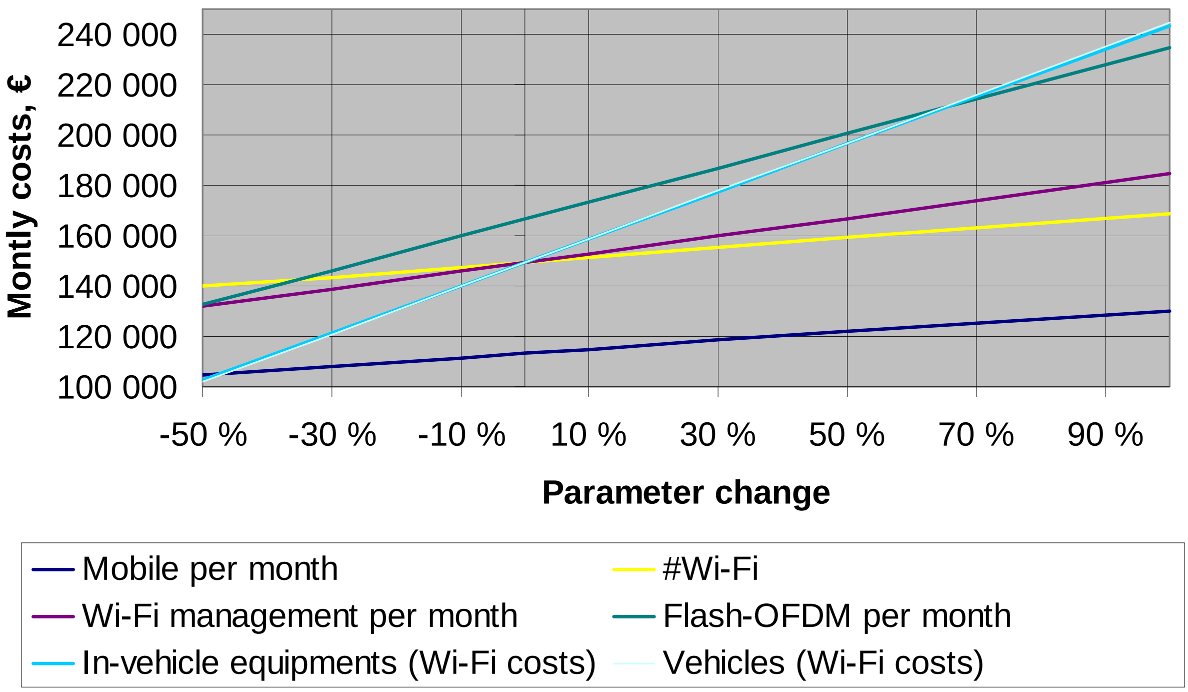

Figure 7 Wireless access network sensitivities for monthly costs

We can see that in summary, various technology combinations can be created to support needs of YTV area. For example, combination of mobile and FLASH-OFDM subscriptions can provide full geographical coverage and high QoS. Significantly cheaper, but non-QoS-guaranteed solution would be mobile only - subscriptions. Specific areas, such as garages should be supported with Wi-Fi access points. We estimate that full-scale, high bandwidth Wi-Fi access system would cost about the same as the combination of FLASH-OFDM and mobile subscriptions. However, significantly cheaper FLASH-OFDM subscriptions can be negotiated when the number of subscriptions is as high as in the case of YTV. Anyhow, full coverage Wi-Fi network would provide superior rates and support extensive palette of services.

7. Conclusions

We have inspected in this paper various networking solutions, respective service formulation and economics for YTV area consisting of City of Helsinki and surrounding municipalities. We have noticed that networking technologies form an interesting playground to support services. However, there is no single solution that we would definitely recommend. However, the relating cost structures and sensitivities can be estimated that can be used to support justified decision making for the YTV area. We have discussed core and access networking costs with various realization options and compared relating sensitivities. If the setup of own core network would be chosen, investment economics could be improved if part of capacity could be rented for third parties. Cooperation with telecommunication operators could carry benefits especially with joint Femto-cell services. If however, network development is left too much for network operators, YTV might have not adequate control to support its future visions of ITS.

References

[Anderson, 2008] Anderson, A. (2008): Ticketing and Information System 2014. Helsinki: YTV

[Arjona, 2008] A. Arjona, A. Yläjääski, J. Kerttula: Live Network Performance Challenge: FLASH-OFDM vs. HSDPA, Advanced Information Networking and Applications, International Conference on, 2008

[Ars Technica06] http://arstechnica.com/news.ars/post/20061211-8396.html

[Bruno, 2005] Raffaele Bruno, Marco Conti, and Enrico Gregori: Mesh Networks: Commodity Multihop Ad Hoc Networks,IEEE Communications Magazine , March 2005

[Digita, 2007] Digita Ltd. (2007, March 28). @ *450 Wireless Broadband*. Retrieved May 21, 2009, from Digita/Communication: http://www.450laajakaista.fi/9019/9039/9847/9081

[Helsinki Metropolitan Area Council YTV, 2006] Helsinki Metropolitan Area Council YTV. (2006, November 28). YTV - Facts about metropolitan area. http://www.ytv.fi/ENG/transport/tickets_and_fares/ticketing_news/

[Kim, 2004]Kim, Namki; Choi, Hyeeun; Yoon, Hyunsoo : Seamless Handoff Scheme for 4G Mobile Systems based on IP and OFDM, IEEE VTS ... Vehicular Technology Conference : VTC, v.60, no.5, pp.3315-3318

[Lakkakorpi, 2008] J Lakkakorpi, A Sayenko: Backhaul as a Bottleneck in IEEE 802.16 e Networks, IEEE Global Telecommunications Conference (Globecom), 2008

[Mahmud, 2006] Mahmud, Sahibzada Ali and Khan, Shahbaz and Khan, Shoaib and Al-Raweshidy, Hamed: A comparison of MANETs and WMNs: commercial feasibility of community wireless networks and MANETs, AcessNets '06: Proceedings of the 1st international conference on Access networks, 2006

[Nelson, 2008] V. Nelson et al. : Performance of SCTP in Wi-Fi and WiMAX networks with multi-homed mobiles, Proceedings of the 3rd International Conference on Performance Evaluation Methodologies and Tools, Valuetools 2008

[Wellens, 2007] M Wellens, B Westphal, P Mahonen: Vehicular Technology Conference, 2007. VTC2007

[WiMAX Forum 2008] WiMAX Forum; “WiMAX Forum® Announces First Mobile WiMAX Certified Products at WiMAX Forum Congress Asia 2008”, http://www.wimaxforum.org, 11.5.2008.