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 evaluation of telecommunication networking scenarios. Typical technical QoS parameters include data rate, delay, error rate, packet loss and coverage. Service associated performance qualifiers include pricing models, purchasing, operation and maintenance as well as certain parameters in service concept and in user interfaces.

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 Ltd., 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 by also travel cards or purchased even by mobile phones. A common 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 be inevitably 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 real-time support is desired. All solutions should have open interfaces when ever possible and they should be modular and cost effective thus enabling 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.

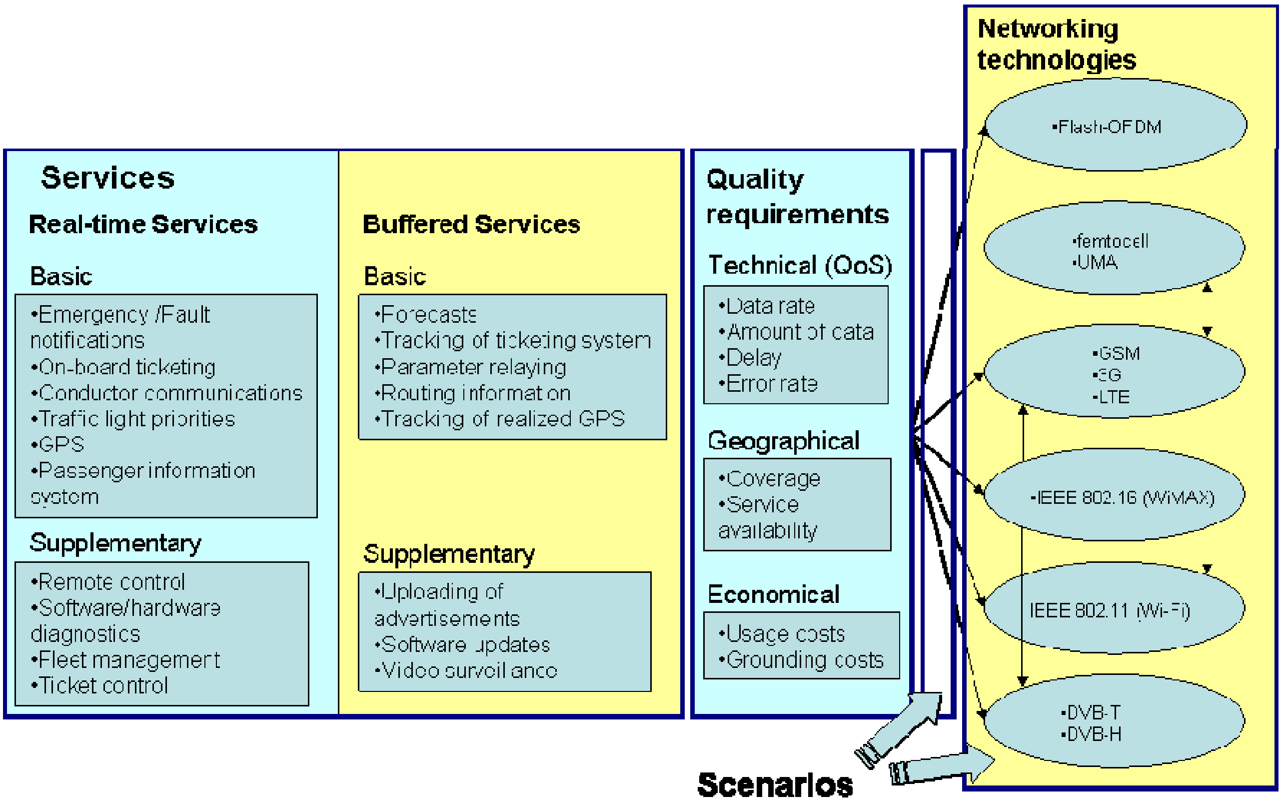

Fig. 1 Study framework

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 Quality of Service (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 carry a greater degree of importance than the supplementary services. Also, 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 and on-time realized system diagnostics and software updates can increase system operation/maintenance quality. Geographical quality requirements effect 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 more usable and/or profitable services also. 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 is constrained by 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 congestion free. In Economics we strive to inspect related costs and suggest argumented realization alternatives. in Service requirements we introduce classification of ITS services suitable for 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 user- friendly ITS for the expanding Helsinki Metropolitan area 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 the 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].

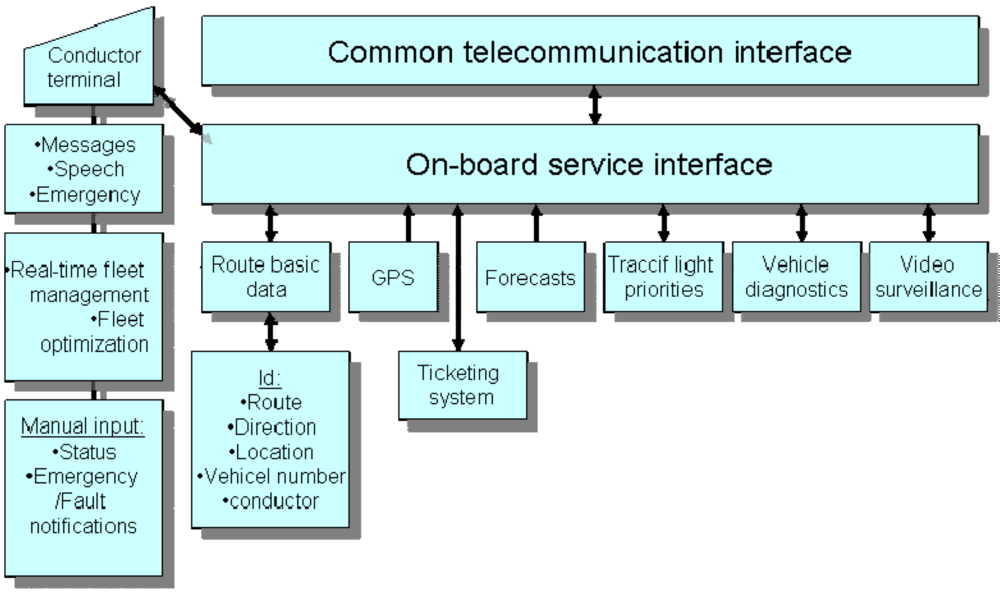

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Fig. 2. Overview of the planned ITS services for Helsinki Metropolitan Area

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, a data storage requirement for video surveillance service depends on picture quality and channel delay. Top priority basic services for YTV and their respective descriptions are as follows:

Ticketing system is intended for selling tickets for passengers and to follow up ticketing. 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.

Ticketing system is designed to be modularly updated to follow technology / service development. In addition, open interfaces to other fair, ticketing and information systems are required. This enables flexible interfaces to equipment and at least partially, also to some other services. System components are tracked in the duration of the project for applicable updates from device manufacturers.

Table I – QoS requirements for the expected key ITS services in the area of the study

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

4. Comparing network technologies

Let us now consider potential telecommunication network technology options for YTV-area. This inspection is based great deal on city-wide telecommunication networking pilots [Mahmud, 2006] as summarized in Table II. The table lists basic characteristics of each technology, such as downlink- and uplink rates, latency and average monthly fee. 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) that will provide significant improvement to these technologies.

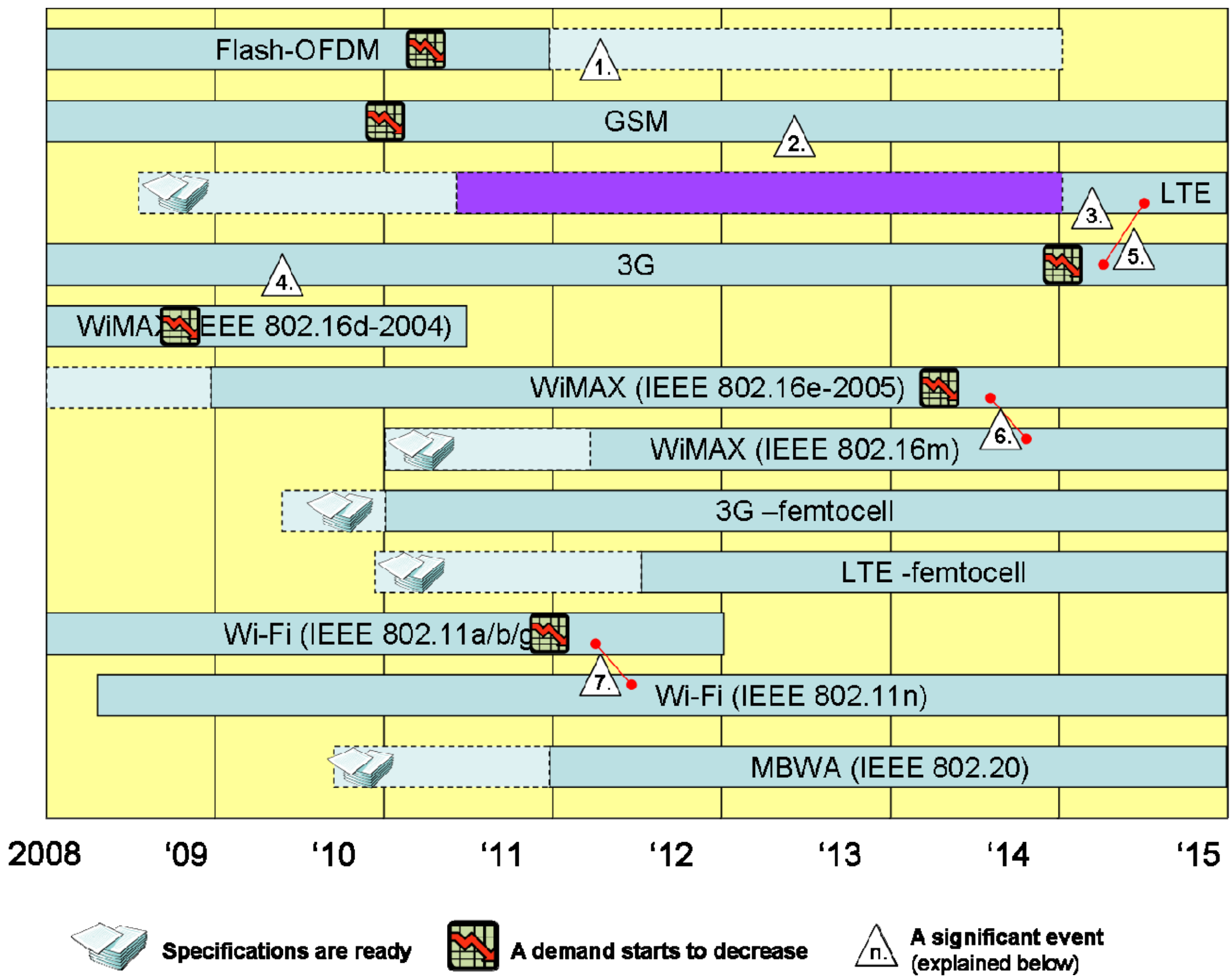

Fig 3. Technology roadmap for YTV up to 2015

Figure 3 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 degree of progressiveness. Specification ready -estimates are taken from the respective standardization bodies. Current technologies and their fitness to the expected service profiles are estimated in Tables II, III and Figure 4.

Let us now return to Fig3. In this figure, solid blocks illustrates when a specific technology is available on the market. Dashed blocks present 'unclear' time periods, when the technology is still under development and waiting for market entry or that it might also potentially disappear. The purple block indicates major changes in mobile phone networks 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 published the exact dates for a closure of GSM networks in Finland, but probably a major frequency reallocation of GSM frequencies for 3G- and LTE will be

required. GSM networks will be closed at the latest at the end of 2015 due to closure of maintenance contracts.

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

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

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

6 IEEE 802.16m is backward compatible with IEEE 802.16e in the same way as IEEE 802.11g access points support also IEEE 802.11b terminals.

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

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 € / kk	10 – 35 € / kk	38 – 45 € / kk	30 – 60 € / kk
Basic services	Voice and other basic services, latency tolerance max. 1 s, bitstream max. 40 kb/s	Voice and other basic services, latency tolerance max. 0.5 s, and bitsream max. 384 kb/s	Voice with VoIP and other basic services, latency tolerance max. 0.1 s, and bitsream max. 1 Mb/s (2 Mb/s WiMAX)	
Supplementary services	Does not suite well (birate limit)	Applicable, must be supported with the WLAN technology	Applicable, must be supported with the WLAN technology (WiMAX might not require)	

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

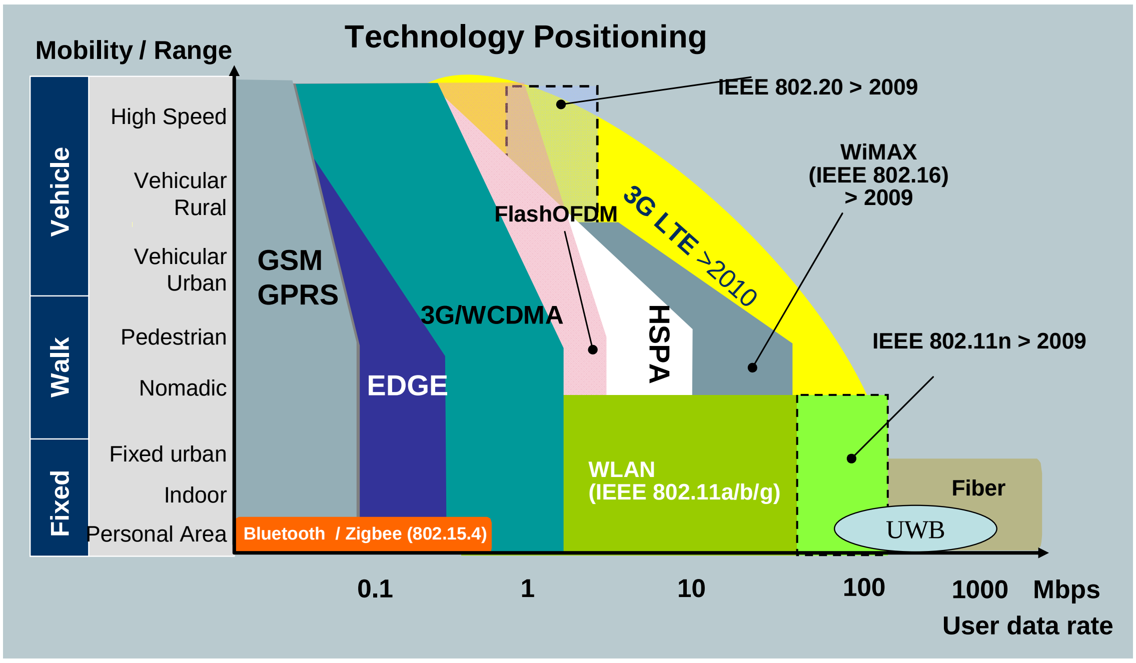

Figure 4. Comparison of various networking technologies [Adapted from UMTS Forum]

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. However, in practise the offered rates do vary from 3G specified rates. This is typical for 3G implementations.

Also, network availability varies as a function of cell load/base station density. Generally, the present 3G services work well for lower rates (384 kb/s). Working together with 3G network operators can lead to cost savings because YTV can thus outsource network management. Service prices are currently quite reasonable (Table IV).

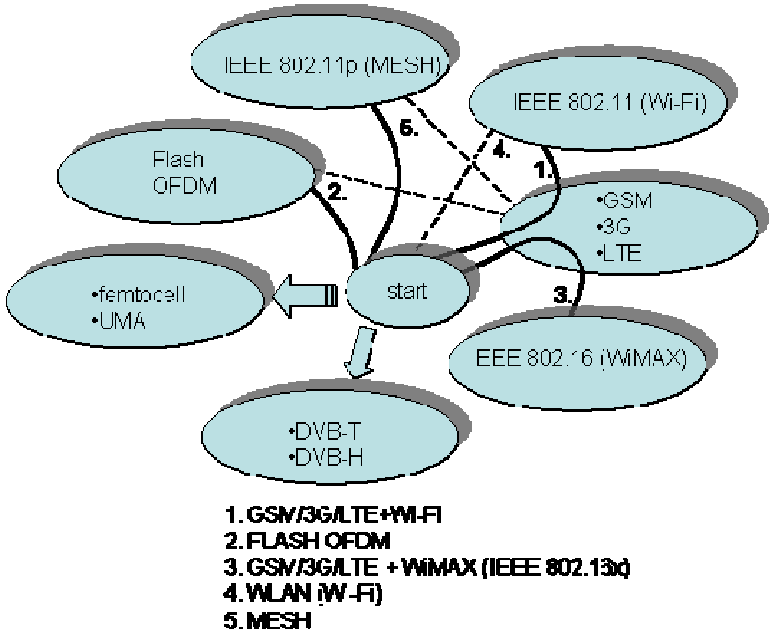

Fig. 5. Networking technology development scenarios for YTV- area

3G networking can be combined to Wi-Fi and/or WiMAX networking by using multi-routers that would be installed to busses. This would enable to use the best available connection in a particular geographical location improving QoS. However, multi-routers are nowadays relatively expensive [United business partners, 2009] and it is important to investigate if the overall cost structure which would be favourable for the offered services. Later multi-homing could also be used [Nelson, 2008]. 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 is relatively high increasing the number of required base stations in mobile access (in contrast to fixed wireless access). Also, WiMAX is relatively expensive technology [WiMAX, 2009].

An interesting aspect of vertical-handover networking is the option to support buffered services in certain bus stops and larger bus stations for loading/unloading on-board servers. Later applied multi-homing could still reduce overall costs and improve performance.

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 also high vehicle speeds up to 250 km/hour [Kim, 2004]. 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 rate 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 will 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] and it is possible that if the number of subscribers increases, data rates must be severally reduced. FLASH-OFDM technology can 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 supported very widely in most of the 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 networking. 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 in 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 mobility and QoS are currently only partially realized still standardization work is intense (Fig. 4).

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 gives 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 in these circumstances be poor.

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 transport operators order all telecommunication services from mobile phone operators. The second one, a bit more radical model is based on building own network. Both options can be supported by FLASH-OFDM technology.

6.1 Being a subscriber in operator's network

Currently the simplest solution to acquire telecommunication services for vehicles is to order them from mobile phone networks managed by telecommunication operators. Coverage of networks is country-wide, subscriptions are cheap and there is a wide variety of terminals available. 3G network capacity and performance improves in timeline and recent HSPA upgrades have increased the maximum DL speed up to 2 Mbps. Femtocell-solutions will enable new interesting business models for public transportation operators too.

In our case, YTV presents a big customer for operators with 1500 vehicles. Number of subscriptions is not, however, so large that YTV could totally control development of networks to a desired direction. Anyhow, the current technology level should be high enough to start implementing the planned real-time services.

Hardware investments should be quite straightforward until 2014. First HSPA-compatible 3G modem could be purchased and then upgraded to LTE-compatible modem as services develop. In this technology roadmap we estimate that operators will start to use LTE widely 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 lifetime for a telecommunication device is about 5-8 years. In those days LTE technology should have been already well-tested and typical telecommunication network start-up problems solved. These relate often to system parameter optimization and reliability reflecting in availability, data rates and coverage.

WLANs should be used together with mobile networks. Capacity of mobile phone networks is not cost-effective or convenient for large data transfers such as video surveillance material. Therefore WLAN access points can be used in small areas such as depots to enable buffered data transfers and relating WLAN based services. Cost for building WLAN coverage to these small areas is also relatively modest.

FLASH- OFDM subscription can be used in parallel with a mobile phone subscription for reliability. Mobile subscriptions and terminals can be purchased from multiple operators that should decrease single-operator dependency. Data streams from different subscriptions can be combined in certain stage by multi-homing to enhance performance and reliability.

In overall, subscribing services from mobile operators should be easy and reliable. Current service fees are very reasonable in Finland due to healthy competition environment and there is no reason to expect them to rise significantly in the inspected time span. 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 effected by other network users too. An important feature of operator based model is that the network is naturally owned by the operator. This restricts the way how the network can be developed from YTV point of view.

6.2 Building own network

A more radical networking option is to consider building of own network. Operating area of YTV covers 4 but reaches 12 municipalities (in traffic and waste services) in Helsinki capital area which all could utilize the same network. There are lot of municipal services and systems which can utilize mobile data connections. This can strengthen financial bases of system setup and operation.

Budgeting sketches

A base of large scale wireless network is a fast and reliable fibre 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 a significant cost factor in overall calculations. 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 (cities, hospital districts, fire and rescue services, operators etc.) so that YTV could potentially get their own services even for free. If compared to annual costs municipalities need to pay for operators, the 1 M€ annual costs is feels a relatively small amount.

Implementation of own network would require building of wireless access network between vehicles and the core fibre network. The access network could be implemented by various technologies: YTV could build cheap Wi-Fi coverage by placing access points especially to those places where capacity demand is high. Wi-Fi is now and probably also at least until year 2014 the most cost-efficient ITS related wireless technology. In city of Helsinki there are 450 traffic light controlled crossroads and 3000 bus or tram stops. This makes in total 3500 areas where access points could be placed. Some 7000 WLAN access points would give fairly adequate coverage to bus traffic roads in Helsinki. The forthcoming 802.11p technology supports especially well ITS needs and will spread along Wi-Fi. On the other hand, WiMAX technology can be used to provide larger area coverage for sparsely populated areas. It can also be used also as a core-connector supply line for Wi-Fi access points in the areas where cabling is not available or is expensive to install. If the fibre core network would be offered for telecommunication operators too, they could also build wireless coverage for some specified areas. For example, @450 and 3G-LTE networks could be extended installing new base stations and without high core network costs. This would benefit both the network operators and YTV.

Building of own network would also give freedom to develop the network based on own needs. Fibre core network can be expected to have over 30 years lifespan and it can be utilized also to support forthcoming systems, even after 2014. In our model, the payback time for the network would be about 25 years, and after that the network would be totally owned and controlled by YTV. In this point, significant network expenditures would be maintenance fees. Own network could be easily scaled to serve some specific service areas e.g. crossroads, traffic lights and different kind of vehicles. Construction and setup of own network should be naturally realized phase by phase. In the beginning, operators' networks could be widely utilized. Gradually operation of own network would then be increased.

6.3 Costs of Building Fixed Core Network

The own network consists of several components including fibre network, active devices, network management and wireless access network. To inspect the 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 YTV areas and it would cover also the most important traffic routes. In rural areas, building a fibre network would cost some 5-6 €/meter including work and the cable. Expenses can be divided roughly fifty-fifty to work and the cable. In the city areas digging work is significantly more expensive due to especially opening and restoring asphalt and revetments. Also, existing cables and pipes makes work demanding and difficult. Opportunistic network building utilizing existing cable, tunnels, and other infrastructure should be naturally applied when possible. Let us estimate based on comparable projects as referred in [Bruno, 2005I, building expenses can be estimated to 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 investment were funded with 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 value of fibre dig to ground would still remain as well as with most of other technology relating to high rate optical core network. Due to the fact that there is a solid demand for high capacity fibre network additional revenues could be earned by renting some of the fibres capacity to operators, municipals, societies, enterprises and other parties.

6.3.1 Active devices

Based on earlier experiences, expected lifecycle for active devices in the network can be approximated to be up to seven years. After that they are replaced with new devices, which have approximately 10 times better performance due to Moore's Law.

In our calculations we use a core network switch containing 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, wire-speed switching and routing. One manufacturer has offered such device for 2306€ in a big sourcing case (0% VAT). Due to a low price and stacking feature it suites well to as a component of the 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 for GE SFP modules with 10 km range is 36€ and 10km 10GE XFP module is 720€. Price development has been declining.

The unit price is 2306€ + 2x 720€ + 24 x 36€ = 4610€. With these devices 10 Gbit/s ring topology (rengasmaisia) networks can be built and connected together through 10 Gbit/s stacking ports. Each switch can be connected up to 24 access switch, which are further connected to access points of the wireless access network.

A good quality access switch containing 2 x GE uplink and 24 copper GE ports costs 872€. Optical modules are a bit more expensive in this case, but still below 50€. Thus the price for an access switch is approximately 950€.

We estimate the project could be started with 100 core switches and 500 access switches. The price for the whole investment is some 910 000€. Both manufacturers provide a guarantee for the lifecycle of switches meaning software updates are freely available and broken switches will be replaced.

With these devices there will be 12 000 GE ports in 500 places. Virtual LANs (VLAN) and traffic prioritization can be defined to the network, and also core switches are able to quick routing and packet filtering between VLANs.

If the devices would be purchased with 7 year 4.5% interest rate annuity loan, the monthly fee is 12 650€ and the total costs for 7 years are 1060 k€. During this time period, devices will be depreciated and new devices and be purchased in the same way.

6.3.2 Network maintenance and operation
Maintenance and operation activities can be outsourced to an organization focusing on this business. Typical fees for maintenance are 25 €/month for an access switch and 100 €/month for a core switch. In total the maintenance and operation expenses are 22 500 €/month.

6.3.3 Total costs for the fibre network
Monthly expenses for a network consisting of 1000 route kilometres, 500 nodes and 12 000 GE ports are 28 k€ / month (fibre) + 12,5 k€ / month (active devices) + 22,5 € / month (network maintenance) = 63 k€ / month or 756 k€ / year. We assume the devices are placed to an existing premises and the power consumption is not a significant expense component among total expenses.

One should note this kind of core network would not serve only the transport operator, but also all municipals belonging to the area of the network. There is enough capacity to serve all departments and units of municipals, and spare fibres can be also rented e.g. to operators. The network will be paid back in 25 years, but it has a longer utilization period – approximately 30-50 years.

Depending on the business model, municipals could build the network and rent some capacity for the YTV. We assume the rental fee would be 10% of the total expenses. However, if the case would be that YTV builds the network, they could rent capacity for other organizations and in the best case make even profit with this business - or at least get the own service for free.

6.3.4 Sensitivity Analysis for Fixed Core Network

Total costs of the fixed part of the network are analyzed in figure x. Calculations are done for 7 year bank loan period and the costs are shown by monthly basis (y-axis). Calculation parameters sensitivities are shown on x-axis.

Sensitivity analysis indicates that the costs of fibre network are somewhat critical. They are also difficult to evaluate due the varying building costs. Reliable and more accurate evaluations of the fibre price would be need careful calculations of the opportunistic network building which is not possible without an access to a municipal tunnelling, piping, and electricity maps and plans. It is highly probable the fibre will be the most expensive parameter anyway.

Costs of the other parameters are easier to estimate, because they are simple components or services and plenty of existing market information is available. Due to Moore's Law, the monthly fee of active devices may change after the first lifecycle (seven years) period. If the fibre network will be paid in first 7 years, it is "free" to use as long it has enough capacity to serve the users. We estimate the capacity will be enough for next 30-50 years.

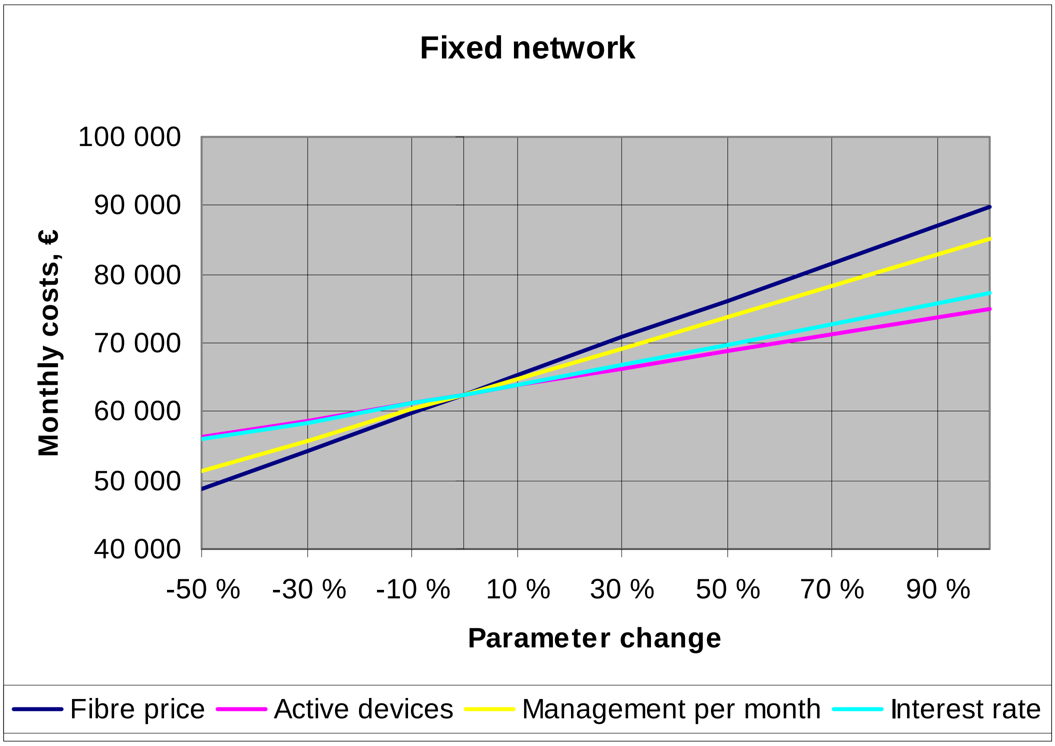

Figure 6. Sensitivity scenarios

6.4 Costs of Wireless Access Network

Fixed networking is converging to an optical fibres and Ethernet technology which are superior to competitors when it comes to the cost-efficiency. Wireless technologies have more divergence, and there seem to be no single technology which could override others. Multiple technologies and terminals able to switch between different technologies must be used.

In case of own fixed core network, it is easy to extend with wireless access points. Potential technologies are Wi-Fi for short range coverage, IEEE 802.11p in the future for vehicular use, and WiMAX for larger area coverage. Operators can also utilize the core network, which benefits both YTV and operators – new base stations covering traffic routes can be installed without the high expenses occurring from building the core connections.

In YTV area there are 450 crossing controlled by traffic lights and 3000 bus stops, so in total there are 3500 places where access points could be placed. Approximately 7000 Wi-Fi access points should cover the mainstream bus traffic in this area.

The price for an access point, antenna and an outdoor-box could be 200€, so in total it would cost 7000 x 200 € = 1,4 M€ to buy them. The network maintenance and operation could be outsourced as with the fibre network. However, in this case the price per access point should be much lower, e.g. 5 €/access point making 7000 x 5 € = 35 000 € in total in a month.

Wi-Fi is not the only technology which can be utilized to build the access network, and e.g. WiMAX can provide very alluring options in the future. Currently, however, due to equipment prices, frequency allocation issues, and terminal availability Wi-Fi might the most interesting option.

Own wireless access network can be supported with 3G subscription. For example one 3G subscription in each vehicle would increase the service reliability especially at beginning, when wireless coverage is not totally optimized and there is no long term experience how it exactly works.

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.

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€

6.4.1 Sensitivity analysis for wireless access network

FLASH-OFDM subscriptions are quite expensive, but on the other hand they can support high overall QoS provided number of subscriber remains in system limits. In-Vehicle equipment including on-board servers, wireless modems and connections to peripherals are the most sensitive for price changes. For example if the price of in-vehicle equipment increase by 30%, it becomes already more expensive than FLASH-OFDM subscriptions. A price for in-vehicle equipment is also difficult to estimate, because it is not exactly clear what kind of power supply and internal networking solutions are needed.

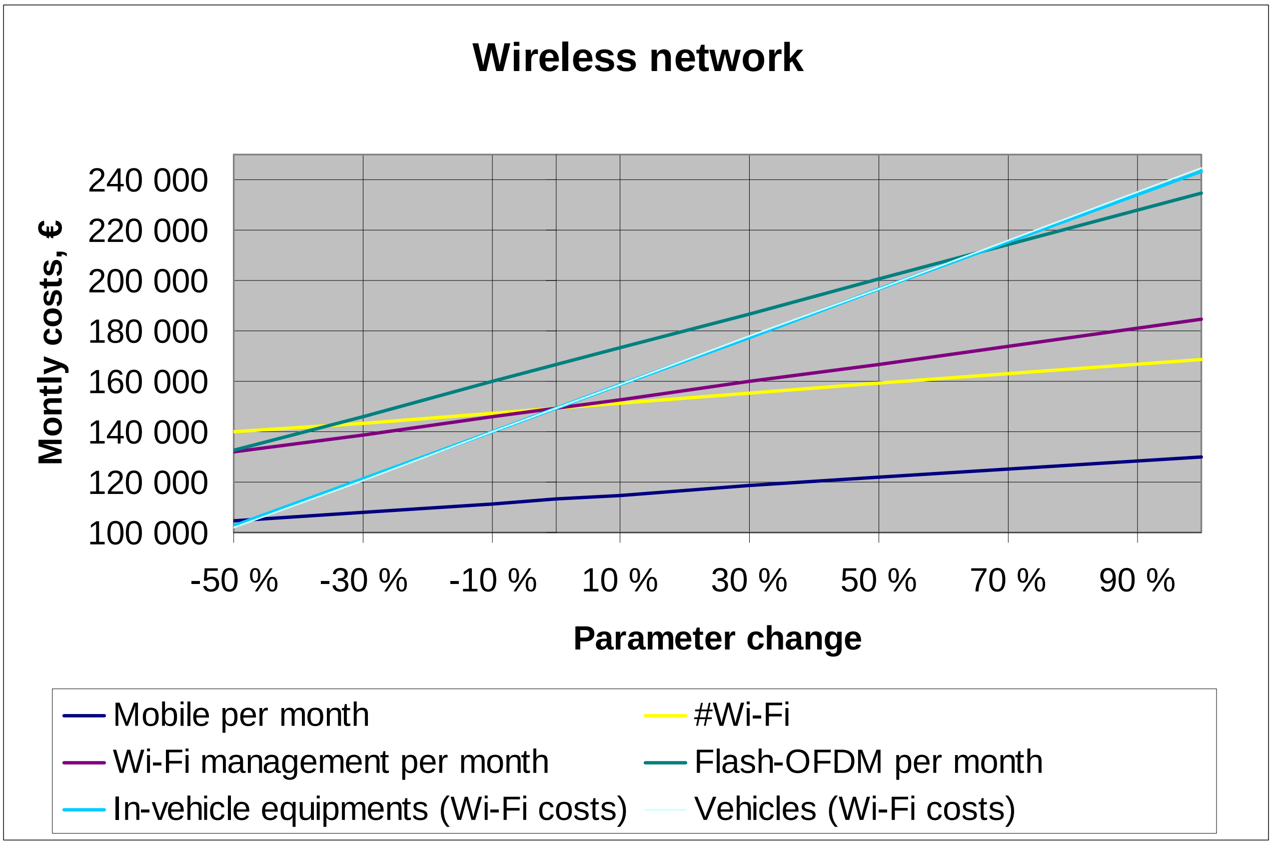

Figure 7 Sensitivities for monthly costs

Different technology combinations can be created to support needs of YTV area. For example, combination of mobile and FLASH-OFDM subscriptions can provide full coverage and high QoS for subscribers. Significantly cheaper but non-QoS-guaranteed solution would be mobile only - subscription. Specific areas such as garages could be supported with Wi-Fi APs but still with a moderate price. A full scale and very high bandwidth Wi-Fi access would cost almost the same price as a combination of FLASH-OFDM and mobile subscriptions. However, significantly cheaper FLASH-OFDM subscription prices should be negotiated if the number of subscriptions is as high as in case of YTV and the amount of traffic would not exceed specific limits. A full coverage Wi-Fi network would provide superior bandwidth to other technologies and it would enable more extensive selection of services.

7. Conclusions

In this paper we have inspected various networking solutions, respective service formulation and economics for YTV area. We have noticed that different networking technologies form interesting playground to support services and there is no single solution that would definitely be recommended. However, the relating cost structures and sensitivities can be estimated that is import to support justified decision making for YTV area.

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