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

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***Abstract*—Unified vision of Helsinki Metropolitan Area Council (YTV) aims systematically develop ITS services and associated networking technologies to follow the very latest global ITS trends. In this study, Intelligent Transport Systems (ITS) telecommunication technology, service and economical scenarios for YTV area are inspected up to 2014. Our goal set by YTV is to research and validate YTV suggested ITS services and to investigate viable telecommunication networking alternatives in an evolution timeline. At the moment, most ITS services of YTV do not require broadband connection or real-time operation, as traffic light priority and RFID-based ticking. On the other hand, there are timely broadband networking needs as supplying Internet connection to passengers. Generally, ITS service data rates are increasing and real-time operation is getting important as indicated by efforts of car manufactures to develop WLAN solutions. Also, integrated real-time ITS operation and management systems require high data rates. Generally, Quality of Service (QoS) requirements of ITS services form a base in our evaluation. Our results, compressed to technology-service scenarios, indicate that YTV has the following 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. Our results in telecommunication networking alternatives are compressed into investment sensitivity estimations that can be used to support decision making.**

Keywords – Intelligent Transport System, Networking services, Networking technologies, Investment estimation, Networking Scenarios

I. Overview

In this study, ITS telecommunication scenarios for Helsinki Municipality area are inspected up to 2014. Our study analyzes various networking technology scenarios intended to support existing and planned ITS services for busses and trams. Also, we comment relating business aspects and competition environment.

Generally, 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 as service arrangements and user interface 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 [1]. Internet, mobile phone and real-time displays at busses, trams and commuter train 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 YTV is 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 that is also part of the ITS development strategy of Finland [2]. However, the services will inevitably develop further and respective capacity and delay requirements will stringent with services such as passenger internet and video surveillance (Table I); [3]. YTV's vision is that networking solutions should have open interfaces whenever possible for scalability and device manufacturer independence. Also, they should be modular and cost effective thus enabling easy system development.

Our results to be discussed further in this paper indicate that based on inspected networking technology alternatives and respective evolution pathways, YTV has in principle three strategies for ITS development: (1) YTV can buy the networking services/technologies from a telecommunication operator, (2) build own network or (3) to realize a hybrid solution.

The paper is organized as follows. In section I the overview of the study was introduced. Section II presents the backgrounds of the search in more detail. Section III discusses about the service development in the study environment. Section IV introduces available networking development scenarios for YTV. Section V presents the cost analysis of chosen scenarios. Finally, Section VI concludes the paper.

II. Background

ITS services set technical, geographical and economical requirements for networking technology as illustrated in

Figure 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 2014. 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 that the basic services following definitions of Table I, carry a greater degree of importance in economical sense than the supplementary services. Also, the supplementary services can be realized without a joint telecommunication networking solution though their common management (requiring transmission of a larger amount of data) can 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 could increase system operation/maintenance efficiency.

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 this 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, Wi-Fi or femtocells. The role of networking alternatives of Figure 1 is elementary because they form the bases to inspect the respective ITS 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 are interference and congestion free. In Economics we strive to inspect network costs and suggest realization alternatives. In Service requirements we introduce classification of ITS services suitable to YTV, discuss the respective service requirements set to the telecommunication infra, and inspect future development.

III. SERVICE DEVELOPMENT

The project of YTV [14, 15] that we refer in this study, strives to develop cost efficient and user-friendly ITS for the expanding Helsinki Metropolitan commuting area (note that YTV has changed its name in 2010 to HSL [16]). The system includes payment of fares, real time passenger information and online data communication from and to the vehicles (Table 1). 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 that is already now practically completed. The system is planned to serve over its 15-year life cycle cost-effectively and YTV expects it to be designed such that it can be easily updated to follow technology and customer needs [4; 5].

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

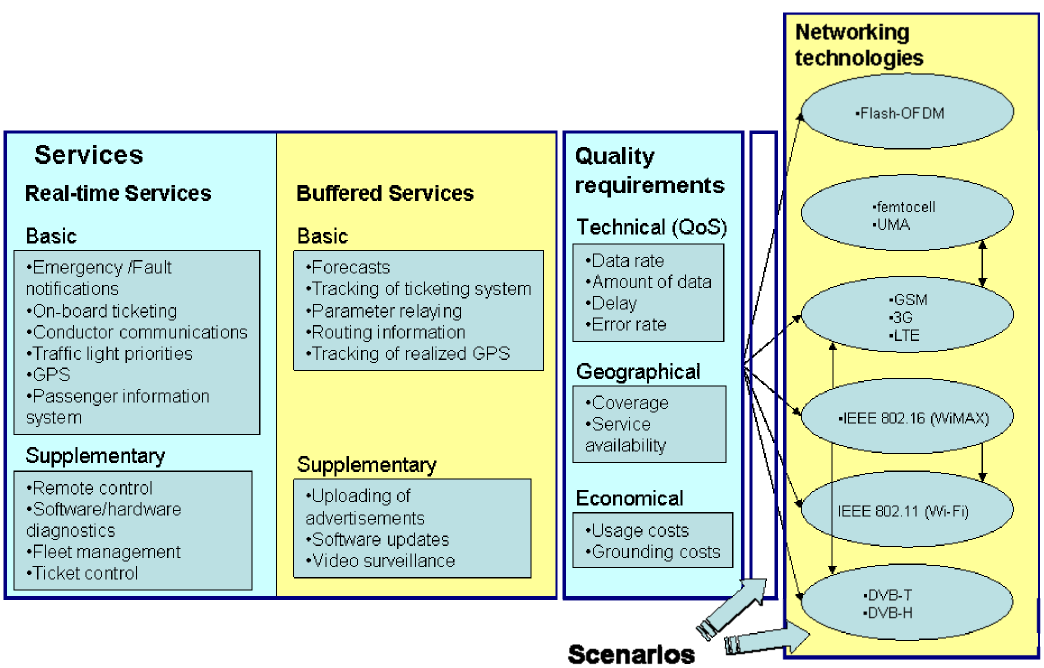

Figure 1. Study Framework

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

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 fare, 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. Open interfaces are therefore important.

TABLE I

OVERVIEW OF QOS REQUIREMENTS FOR THE EXPECTED ITS SERVICES IN THE FRAMEWORK OF THIS STUDY.

Service	Basic	Supp.	Real-time	Buff.	Note
Emergency /Fault notifications					few kbit/s
On-board ticketing					slow, real-time traffic
Passenger information					100 kb/s / vehicle
Conductor (in a train) communications					GSM/UMTS, slow, real-time traffic
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					few
download					10b/vehicle/24 h
Software updates					max 10 Mb / vehicle/24 h
Video surveillance					max 1 Gb / vehicle / 24h

IV. NETWORKING DEVELOPMENT SCENARIOS FOR YTV

Let us now consider various networking alternatives by following Figure 2. The thick lines represent main evolution pathways and the dashed lines supplementary pathways that relate to networking technologies that can be used in some special circumstances as for instance to support geographic high telecommunication traffic density areas. Universal Mobile Access (UMA) of 3GPP refers to development of seamless handover in multimode 2G+/3G/Wi-Fi handsets. The femtocell technology can increase short range (up to 50 meters) 3G coverage and provide new operator based service and pricing models. Digital Video Broadcasting (DVB) technologies (terrestrial (T) and handheld (H)) support video reception especially for special receivers. For further information regarding these scenarios, see [6], where they are explained and argued in more detail.

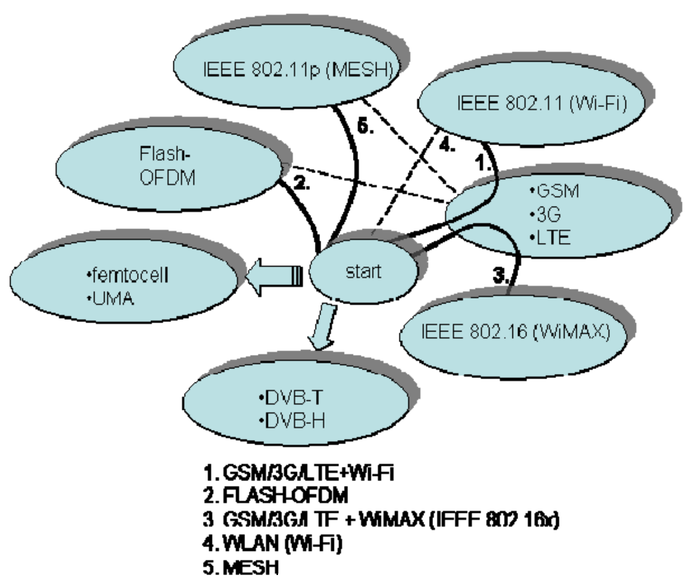

Figure 2. Networking technology development alternatives for YTV- area

Evaluation of network technologies and service environment leads us to inspect two alternative implementation scenarios. The first scenario 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 Wi-Fi and Flash-OFDM technology.

A. *Being a subscriber in operator's network*

Currently a technically simple solution is to acquire telecommunication services from mobile network operators.

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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, femtocell solutions can enable new interesting business models for both YTV and public transportation operators [7].

YTV presents a big customer for operators with approximately 1700 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 related consumer electronics can be substantially shorter.) We assume that in 2014 LTE technology should be well-established.

WLANs and femtocells can 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 data. WLAN access points can be used in smaller 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. Co-operation in femtocells with telecommunication operators can open up new business models [8]. 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.

B. Building own network

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.

A base of large capacity wireless network is a fast and reliable fibre core network. In YTV case we have estimated that the 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 in existing server rooms and power consumption would not be a significant cost factor in the overall budget. Prices are based on the manufacturers' data. In the network, own fibres and/or Ethernet-layer virtual networks (VLANs) could be separated for served parties without trading their QoS requirements. If the own network would be build and marketed wisely, YTV could charge other users as referred earlier (cities, hospital districts, fire and rescue services, operators etc.) so that YTV's own service cost could be subsidizes. If compared to annual costs municipalities need to pay for operators, the 756 k€ annual cost feels a relatively small amount.

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 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 hot-spot wireless technology.

In the 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 should 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 and to supply Wi-Fi access points 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, Flash-OFDM and 3G-LTE networks could thus be extended. Relating cost saving 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 lifespan extending up to 2014 and even

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later. After the payback period, the network would be totally owned and controlled by YTV. In this point, the most significant network expenditures would be up keeping and 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.

V. COSTS ANALYSIS FOR THE NETWORKING OPTIONS

To be able to compare the two networking options in terms of telecommunication network investment costs and especially investment sensitivities, we now discuss cost structures.

Being a subscriber in operator's network is more straightforward to analyze, because operators list publicly subscription fees. We can even expect that some volume discounts could be negotiated by YTV.

Option of building own network carries more insecurities. Especially, estimation of route kilometres, the number of required Wi-Fi access points and costs required for cable digging carries insecurities. In rural areas, building a fibre network would cost some 5-6 €/meter including work and the cable [9]. Expenses can be divided approximately fifty-fifty to work and the cable. In city areas cable digging is significantly more expensive especially due to opening and restoring asphalt and revetments. Also, existing cables and pipelines make work demanding and difficult. Thus an opportunistic network building utilizing existing cables, tunnels, and other infrastructure should be applied always when possible. Let us estimate, based on comparable projects as referred in [10], that setup 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. (This relatively low level cost estimate is based on using existing underground cable pits and channels. Without them the cost would be substantially higher, eg in the order of $40/ meter [11].) If the investment would be funded with a 5 M€ bank loan, the total expenses for 7 years annuity loan with 4.5% interest rate would be 5,8 M€ with a 25 years payback period yielding 8,3 M€. (Expenditures for the active devices were listed in the previous chapter.) Also in the case of own network, wireless access network is required to connect the vehicles. YTV estimates that at least 7000 access points are needed to provide adequate coverage.

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€. 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 per month.

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

Own wireless access network can also be supported by 3G subscription. For example, one 3G subscription in each vehicle would increase service reliability especially at the beginning when wireless coverage is not optimized and there is no longer term experience how it works. Costs of various wireless networking options are listed in Table 2.

TABLE II
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€

Total costs for fixed and wireless networking are shown in Figures 3 and 4. Calculations are done for 7 year bank loan and the monthly costs are shown on y-axis. Calculation parameter sensitivities are shown on the x-axis. The parameter change refers to a price change of a single acquisition unit. For example, in the case of the fibre, an increase of 10% could mean either an increase in the digging costs or fibre price so that it results 10% increase in the total fibre costs. The price of the fibre itself is, however, a relatively small factor in the overall costs (and also easier to predict), and it would therefore be useful to estimate especially the digging costs. However, this requires precise understanding of the current installation infrastructure in the YTV area such as access to a municipal tunnelling, piping, and electricity maps and plans. At the time of this study, the actual implementation alternatives were not yet available that results great cost sensitivities in this respect.

In Figure 3, sensitivity analysis indicates that the costs of fibre network are somewhat critical. Costs of other components are easier to estimate due to existing market information. If the fibre network would be paid in the first 7 years, it is "free" to use as long it has enough capacity to serve the users. We may estimate that the capacity of a metropolitan wide, high speed fibre core network would be enough even for the next 30 years demand [12].

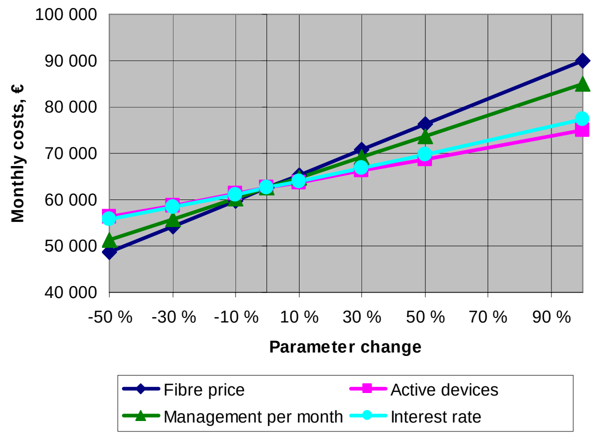

Figure 3. Sensitivities for monthly costs of fixed network

In Figure 4, we note that Flash-OFDM subscriptions are quite expensive. On the other hand, they can support high overall QoS provided that the number of subscribers remains in system limits set by the applied 450 MHz bandwidth in Finland. In-vehicle equipment for 1700 vehicles including on-board servers, Wi-Fi terminals and connections to peripherals are the most sensitive for price fluctuations. For example, if the price of in-vehicle equipment increases by 20%, it becomes more expensive than the Flash-OFDM offered by current price. In-vehicle equipment CAPEX depends on device and installation costs (including network installations) that depend on vehicle type, contractor etc. Based on earlier studies, the installation environment can vary greatly in vehicles and carriages [13]. Building and maintaining the Wi-Fi network of 7000 access points seems currently reasonable priced. However, some cost margin can be obtained using mobile subscriptions as a backup to start with.

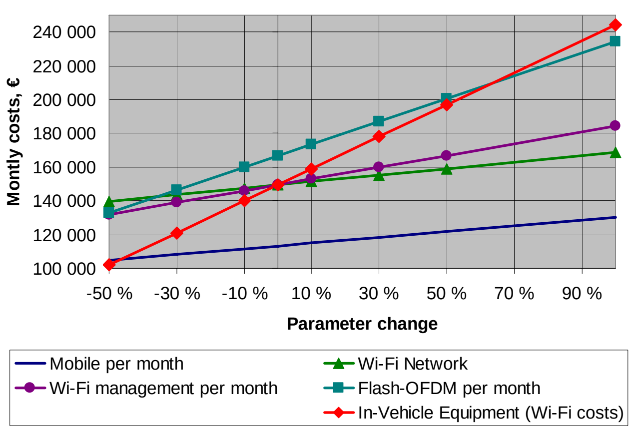

Figure 4. Sensitivities for monthly costs of wireless network

Sensitivity analysis indicates that there are certain cost parameters, where price fluctuations result major changes in overall costs. In the case of building own network, the fibre price has a significant role in the total costs. Especially the in-vehicle equipment costs and the Flash-OFDM subscriptions contain significant uncertainties. Fibre and in-vehicle equipment price uncertainty could be reduced substantially with a detailed implementation plan and by carrying out more detailed studies. By introducing new revenue components into the case of building own network, the cost structure could be improved and make the business case more solid. Especially, use of femtocells to supply common services for operators and YTV should be further investigated. In summary, a separate service mapping and related investment analysis is recommended for rigorous project risk management.

VI. Conclusions

We have inspected telecommunication networking, services and economics for YTV ITS solutions. In summary, we started by listing the required and optional buffered and real-time ITS services. When telecommunication networks get faster, need for buffered services will reduce. Core networking can be basically based on buying 3G/LTE service from telecommunication operators or to build own optical network. 3G/LTE can naturally support access networking too. If the optical network solution would be selected it carries significant initial costs and greatest investment sensitivities relate to fibre network setup costs. In this scenario, YTV could even rent extra optical network capacity to telecommunication operators. The second option, buying capacity from a telecommunication operator, would carry costs more in OPEX. Common services should be decided and negotiated with the network operator. Core networking solutions should be supplemented by Wi-Fi base stations. Usage of femtocells could support new business models with the network operators. ITS solutions require investments also to vehicles where Wi-Fi equipment (routers) and installation costs are important. If prices of Wi-Fi equipment develop positively, as it seems now, all applications of Wi-Fi technology will come more favourable. Installation costs will reduce due to vehicle manufacturers incorporating telecommunication infra to new vehicles.

In summary, cost structure and sensitivity analysis should always be used to support ITS investment decision making and to find appropriate pricing models for services. Application of ITS in any city area faces similar problem framework as we have discussed in this paper and therefore scenarios of YTV should also be applicable in a more general level. We have provided examples of various aspects that should be considered when establishing city-wide ITS networking solutions. If establishment of own optical core network is seriously considered even in some extent by YTV, investment economics can be improved if part of the network capacity is rented to third parties, as telecom operators, companies or officials in the YTV area of municipalities. Generally, cooperation with telecommunication operators can be useful. For instance, there are services that interest both YTV and network operators as femtocell technology. Therefore, searching and

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supporting common services should be used to support mutually beneficial business solutions.

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