Intelligent Transportation Systems: Techno-Economic Comparison of Dedicated UHF, DSRC, Wi-Fi and LTE Access Networks
Case study of St. Petersberg, Russia

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Abstract—Intelligent Transportation Systems (ITS) are all types of communications in vehicles, between them and to infrastructure. ITS improve travelling experience through enhancements in safety, traffic efficiency and a wide range of entertainment services. This paper answers the question: how much does it cost to build and operate a dedicated Radio Access Network (RAN) for intelligent public transport? Investigated communication technologies are Ultra High Frequency (UHF) communications, Dedicated Short Range Communications (DSRC) or 802.11p, 802.11n Wi-Fi and LTE. It is shown that the 802.11 standards feature the highest Capital and Operational Expenditures (CapEx and OpEx). In comparison with LTE, DSRC-based RAN causes 2.3 times higher upfront costs (CapEx) and 6.5 times higher annual operation costs (OpEx).

Keywords—ITS; intelligent transportation; vehicular networks; C2C; V2I; V2V; techno-economic analysis; LTE; DSRC; Wi-Fi; 802.11p; 802.11n; UHF; CapEx; OpEx

I. INTRODUCTION

Intelligent Transportation Systems (ITS), when related to vehicular transport, aim at reducing the number of road accidents and enhancing general travel experience. European Telecommunications Standards Institute (ETSI) defines vehicular ITS as “telematics and all types of communications in vehicles, between vehicles (e.g., car-to-car), and between vehicles and fixed locations (e.g., car-to-infrastructure)” [1]. The “intelligence” in ITS comes from the use of communications. Although the set of general functions and requirements for ITS is being actively standardized, e.g., ETSI TC ITS [1] and ISO TC204 WG16 [2], it is hard to choose a single communication technology that suits all of the ITS applications.

Fig. 1 shows an example of public ITS, which refers to the public transport. The users in this case are not humans, but public transport vehicles, e.g., buses as in our case study. Each bus is equipped with an on-board computer that coordinates User Equipment (UE), UE in public ITS case is the equipment mounted in the bus. Such a UE is called an On-Board Unit (OBU), as in Fig. 1 Dedicated Short Range Communication (DSRC) or Wi-Fi modems. OBU connects to the backbone network through the respective access network (roadside infrastructure). The roadside infrastructure consists of the Base Stations (BSs) of LTE or Ultra High Frequency (UHF), or Road-Side Units (RSUs) of DSRC or Wi-Fi. Roadside infrastructure and UEs form a Radio Access Network (RAN). The RAN from our case study is introduced in Section II, subsection “Pilot network”.

Specific ITS implementation is defined by the services. In our case study we concentrate on the following public transport services: emergency alarm, transport route tracking, fare collection and optional video monitoring of in-bus and on the road conditions. This is not a full list of possible ITS services. For example, they can be enriched by infotainment applications for passengers as video and audio streaming or general Internet surfing [1].
in order to support the needed mobility and Quality of Service (QoS). Its performance for vehicular applications is broadly studied, e.g., [4], [5] or [6]. However, even a not adapted Wi-Fi is considered for some ITS applications due to its wide availability and technological maturity, e.g., [7]. On the other hand, LTE attracts more and more research attention due its fine QoS granularity and high mobility support [8]. Furthermore, robust communications in Ultra High Frequency (UHF) band are also considered for safety applications of ITS, e.g., [9].

Along with investigating technical applicability of different technologies, cost is often mentioned as one of the arguments. Commonly, low cost is named as one of the main advantages of DSRC. LTE in its turn is usually referred to as a more costly technology, e.g., in [8]. However, to the best knowledge of the authors, no techno-economic study has directly compared these technologies.

This paper derives and compares the costs for dedicated ITS RAN realized with different technologies, e.g., DSRC and LTE. We show the techno-economic analysis as well as corresponding legal procedures that lead to cost growth and are often neglected in research. Techno-economic analysis derives the Capital Expenditures (CapEx), i.e., upfront costs needed to deploy and launch the network, and Operational Expenditures (OpEx), i.e., reoccurring operational costs. The analysis is conducted for CapEx and one year OpEx. For the legal analysis, the main regulations and permits are pointed out that have to be obtained for legal network construction and operation.

This paper is concentrated on the case study of a dedicated Radio Access Network (RAN) deployment for a public ITS in St. Petersburg, Russia. The country is important as legal procedures, their costs and some other costs, e.g., labor, are country specific. In our case study we do not consider a possibility to reuse the existing LTE infrastructure through a Mobile Virtual Network Operator (MVNO) or in any other form of negotiation with a Mobile Network Operator (MNO). This is due to the fact that such relationships are not addressed in current legislation of the Russian Federation and, thus are not regulated by any authority. It means that the MNOs define themselves the terms for each partner on an individual basis without any upper bound. This is why we take a “worst case scenario” of building a dedicated LTE network.

First, Section II introduces our case study, its main steps, assumptions, technology limitations and resulting pilot network. Then, in Section III the institutional analysis is carried out to define the legal feasibility of the technology use for network deployment. In other words, it investigates, if it is legal to use a particular technology. If yes, it identifies the procedures that have to be carried out and the permits to be obtained. Finally, Section IV presents a techno-economic analysis. It shows a summary of RAN cost calculations for both: CapEx and OpEx. The paper is concluded with Section V.

II. CASE STUDY: GENERAL PRINCIPLES

Building a dedicated ITS RAN is a long-term project with high initial investments. Any investment project requires careful preparation, i.e., a detailed analysis of several areas: commercial, techno-economical, institutional, etc. In fact, it is about collecting and analyzing the baseline information. An important aspect is credibility of this information and the ability to correctly interpret it.

In this section, we first introduce the information need for analysis, such as target services, project requirements and prospective technologies. Then we describe the resulting pilot network. The section is concluded with a description of the pre-project analysis steps: institutional and techno-economic analysis.

A. Services, Requirements and Technologies

ITS in general includes a wide range of services from safety to entertainment. The following services are defined for our case study of intelligent public transport:

- Emergency alarm
- Transport route tracking
- Fare collection
- Video monitoring of in-bus and on the road conditions

From these services the following set of minimal requirements was derived: ubiquitous coverage of the project area, support of mobility, high robustness, high reliability, low delays, bitrate for users up to Mbps.

These requirements form the set of technologies to consider as public ITS implementation:

- UHF of local Russian standard “Citran” [10]
- Wi-Fi 802.11n [11]
- DSRC [3] or 802.11p
- LTE [12], up to release ten

Although no single technology in the current state can provide all the services and satisfy all the requirements that are demanded by ITS, a combination of them can [13]. For example, a heterogeneous ITS network could include DSRC OBUs for V2V communication and delay-sensitive services, while LTE could support V2I communication and address bandwidth-hungry services such as video transmission.

This paper does not claim choosing the set of optimal technologies, it rather analyses available technologies and their costs if they were used solely. Neither it aims at technical comparison of the technologies. The focus of the paper lies purely at cost and project analysis. Table I summarizes the relevant for our study technical characteristics of the investigated technologies.

The chosen frequency band LTE is 3400-3600 MHz. The main reason for operating in this band is its availability due to no auctioning on the frequencies. Here, the frequency obtaining procedure is the same as for DSRC or Wi-Fi, i.e., payment per BS, when complying with the regulations on equipment use. Frequency resource allocation procedures are country (regulator) specific and can be clustered by approach, but not
TABLE I. CHARACTERISTICS OF THE CHOSEN COMMUNICATION TECHNOLOGIES RELEVANT FOR PUBLIC ITS IMPLEMENTATION.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency bands, MHz</td>
<td>355-388</td>
<td>2400-2883</td>
<td>5855-5925</td>
<td>3400-3600</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>12.5/25 kHz</td>
<td>20 MHz</td>
<td>10 MHz</td>
<td>5 MHz</td>
</tr>
<tr>
<td>Multiple Access</td>
<td>TDMA</td>
<td>CSMA/CA</td>
<td>CSMA/CA</td>
<td>OFDMA</td>
</tr>
<tr>
<td>Throughput, kbps</td>
<td>12 kbps</td>
<td>Up to 100 mbps</td>
<td>Up to 18 mbps</td>
<td>Up to 40 mbps</td>
</tr>
<tr>
<td>Set-up time, ms</td>
<td>Up to 2000</td>
<td>1000</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Delay, ms</td>
<td>300</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Range, km</td>
<td>20</td>
<td>0.3</td>
<td>0.6</td>
<td>Up to 8</td>
</tr>
<tr>
<td>User mobility support</td>
<td>poor</td>
<td>poor</td>
<td>Up to 80 kmph</td>
<td>Up to 160 kmph</td>
</tr>
<tr>
<td>Scalability</td>
<td>poor</td>
<td>poor</td>
<td>poor</td>
<td>good</td>
</tr>
</tbody>
</table>

Pros (service perspective)     | Compressed voice; Emergency services; Short data dissimilation; | All the planned services; All the planned services; V2V and V2I |
Cons (service perspective)     | No broadband services; Only V2I; Short range; Only V2I; Short range; Only V2I; |

a. Measured  
b. Theoretical  
c. Empirical

UHF has the lowest throughput from the technologies and thus cannot be used for most of the entertainment applications. However, any kind of low-rate V2I services can be realized with UHF, e.g., telemetry information transmission, emergency communications localization, or data collection for traffic efficiency.

The services planned for Wi-Fi were the same as V2I for DSRC. The idea behind using Wi-Fi for ITS is that it is more mature than DSRC and, thus, can be cheaper. The DSRC-based services were all the V2V and V2I ITS applications. LTE was evaluated also as technology that can provide all of the services although yet only in a V2I fashion.

B. Pilot Network

This case study is based on a real project of creating a pilot network for public ITS. The primary goal of the pilot network is performance evaluation of communication technologies that could enable ITS. Furthermore, it allows evaluation of heterogeneous ITS scenarios and testing the key ITS applications.

The resulting pilot network is depicted in Fig. 1. The users are equipped with different OBU's. The roadside infrastructure consists of BS's, for LTE and UHF, and of RSU, for DSRC and Wi-Fi. The roadside infrastructure is connected to common Internet backbone, through which control, monitoring and user platforms are enabled.

C. Project Analysis Steps: institutional and techno-economic analyses

In the case of RAN construction for public transport it is hard to talk about profits. An Alcatel–Lucent sponsored survey showed that although safety and traffic efficiency applications are seen by users as highly important, their use is expected to be free [14]. Thus commercial analysis is constrained with a monetization problem. This problem, however, is out of the scope of the paper, although a number of solutions could be investigated, e.g., advertisement campaigns or services for the passengers. In this paper we focus on the institutional and techno-economic analysis.

Institutional analysis evaluates the possibility of successful project implementation taking into account legal, political and administrative situation. The outcome is not quantitative or financial; it characterizes the feasibility of a project. The main goal is to evaluate the combination of internal and external factors that accompany the implementation of the project. For example, if a regulatory framework for a technology is missing, such a technology cannot be used legally. Thus it does not matter how good the performance of the technology is, or how cheap it is: the use is illegal. Therefore, such technology will be discarded before further investigation, i.e., before techno-economic analysis.

Techno-economic analysis here aims at evaluating different wireless technologies, e.g., LTE and DSRC, to find the most suitable for the project from economic point of view. We do not consider the technical part here, as the technologies fulfil ITS requirements that were defined in Subsection A. The outcome of techno-economic analysis is identification of the cost drivers for each technology, its respective prospects and costs.

A combination of institutional and techno-economic analysis results in meaningful dataset that can be used for decision making. It has to be noticed and clearly understood that institutional and techno-economic analyses depend on the country, i.e., on the regulations and economic situation.

III. INSTITUTIONAL ANALYSIS OF PUBLIC ITS

ITS network built with Radio Electronic Equipment (REE) implies the need to use radio frequency spectrum. Frequency spectrum is a limited public resource that is allocated in the established legal order. The REE in any communication network must operate legally within the existing legislation. In Russian Federation this legislation is determined by the Ministry of Posts and Telecommunications of the Russian Federation (Russian acronym MINSVIAZ) and shall include for legal equipment use:

1. Frequency spectrum allocation and assignment procedures for each type of equipment under consideration, and
2. Regulatory and legal acts of the industry that define REE use requirements for ITS within public communication and data networks.
Table II summarizes an analysis of the regulatory framework for REE of considered technologies. For all the needed frequency bands there exists a respective State Commission on Radio Frequencies (SCRF) decision. SCRF decisions allow the use of equipment in communication networks between vehicles (V2V) and vehicle to infrastructure (V2I), if complying with the rest of regulatory documents. However, for each fixed Base Station (BS) or a Road Side Unit (RSU) a Frequency Use Permit (FUP) must be obtained. Obtaining a FUP takes time and requires a significant capital investment, which scales with the number of BSs or RSUs.

**TABLE II. ANALYSIS OF THE REGULATORY FRAMEWORK FOR REE OF VARIOUS TECHNOLOGIES.** It is shown that the use of DSRC equipment is illegal in Russian Federation.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Frequency bands</th>
<th>Use Permit</th>
<th>Probability of a permit being granted</th>
<th>Legal use of REE in public networks</th>
</tr>
</thead>
<tbody>
<tr>
<td>UHF, [15]</td>
<td>300-400 MHz</td>
<td>Needed</td>
<td>High</td>
<td>Allowed</td>
</tr>
<tr>
<td></td>
<td>150 000 rub. Per BS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wi-Fi, [15]</td>
<td>2.4 GHz; 5 GHz</td>
<td>Needed</td>
<td>Low</td>
<td>Allowed</td>
</tr>
<tr>
<td></td>
<td>100 000 rub. Per RSU</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSRC, [16]</td>
<td>5855-5925 MHz</td>
<td>Needed</td>
<td>Low</td>
<td>Not allowed</td>
</tr>
<tr>
<td></td>
<td>100 000 rub. Per RSU</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LTE, [15]</td>
<td>450 MHz; 791-862 MHz; 1800 MHz; 2.3-2.7 GHz</td>
<td>Needed</td>
<td>Medium</td>
<td>Allowed</td>
</tr>
<tr>
<td></td>
<td>100 000-140 000 rub. Per BS b</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[a\] Defined by State Commission on Radio Frequencies (SCRF) decisions

\[b\] Depends on the frequency range

Together with the existing regulations, radio frequency situation influences the decision if the frequency band is granted. In large cities some of the bands can already be densely populated, without ITS networks. For example, 5 GHz band can be occupied by radio access operators, and frequency band of 2.3-2.7 GHz by mobile cellular operators. Column four of the Table II reflects such spectrum population density for St. Petersburg in terms of probability that new equipment will be allowed to operate in this band. It can be seen that for Wi-Fi and DSRC the situation is complex and the free spectrum cannot be guaranteed. Thus, the presence of non-occupied frequency spectrum band is one of the main conditions for a dedicated urban ITS access network realization. A sufficient bandwidth for most of the ITS services, incl. online video, is 15-20 MHz.

Apart from frequency allocation, other regulatory documents have to define the legal operation conditions of REE. An analysis of the technical documentation in the sector “Sviaz” (“Communications”) indicates that for UHF “Citriam”, Wi-Fi and LTE there exists a mature regulatory framework for REE use in public communication and data networks. For DSRC such documents are missing and need to be developed [16].

For a commercial ITS network planning, it would be clear after the institutional analysis that DSRC could not be used for network realization. Thus, it would be discarded from techno-economic analysis. This example shows the importance of institutional analysis for time and money savings. For our case of research pilot network, the analysis is carried out for all the technologies, including DSRC, as it is a research project.

IV. TECHNO-ECONOMIC ANALYSIS

This section first introduces calculations of Capital Expenditures (CapEx), i.e., upfront expenditures, and then the Operational Expenditures (OpEx) for one year period, i.e., reoccurring expenditures over this year. The data, for both CapEx and OpEx, shall be seen as approximate relations and an example for an ITS project analysis. The costs of project analysis and design, network design, construction and launch as well as the equipment costs are based on the prices of network integrator “Telekom-Proekt” (rus., “Телеком-Проект”) and given in Russian Rubles [17]. At the time of conducting the study (September 2014) the course of Russian Ruble to Euro was 48.6:1 [18], while preparing the project and paper (2014/2015) the course changed dramatically a number of times. Thus the prices of the imported equipment, i.e., of Wi-Fi, DSRC and LTE equipment, and generally the results shall be interpreted, taking into account this complex economic situation.

A. Capital Expenditures (CapEx)

CapEx include design, construction and launch of the network, i.e., upfront costs that in our case are the following [19]:

1. Project design and examination.
2. User equipment selection and purchase.
4. Obtaining radio frequency resource.
5. Construction and installation work.

The costs of project design and examination are company and project specific. Same is for construction, installation work and network commissioning.

Equipment selection and purchase consists of two parts User Equipment (UE) or On-Board Units (OBU) selection and purchase, and Base Stations (BSs) or Road Side Units (RSUs) selection and purchase. The number of OBUs is determined by the number of users. In the public ITS case study the number of users is equal to the number of buses, i.e., 5000 for the entire St. Petersburg. This number is the same for all of the technologies. The number of BSs or RSUs depends on the area to cover and on the technology characteristics. This number is...
individual for all of the technologies and is determined during Frequency-Territorial Planning (FTP).

FTP determines the required number of BSs and their nominal frequencies for sustainable network coverage. The cost of FTP work, including BS placement and obtaining an agreement on it, is ca. 10,000 Russian Rubles per BS (according to the price list of [17]). FTP for this case study was carried out with the commercial software package ICS telecom V13 [20] for St. Petersburg, Russia: an area of 600 km², excluding the immediate suburbs. The methodology of the FTP is out of the scope of the paper and will be described in further papers. Here, it has to be noticed that although the calculations are done with a specialized program some of the cost aspects are technology-dependent and will influence the cost of planning. For example, BS or RSU site search. This process cannot be automated in the current way as requires collection of technically as well as legally feasible sites. The more sites are needed the costlier this part is.

The cost of obtaining radio frequency resource is composed of examination costs at General Radio Frequency Centre (GRFC) [15], application preparation and assistance. GRFS service costs are published on their website [15], but might be available only in Russian version.

Table III summarizes the results of FTP in the first row, stating how many BSs are needed. Then it shows the costs per BS for the CapEx components. Note that cost of frequency recourse ($c_{freq}$) is defined by the regulators and is country or even region specific. The costs of project works ($c_{pre-prof}$ and $c_{deploy}$) and any labor in general, is country and company specific, and shall be seen here just as an example. Equipment cost ($c_E$ and $c_{UE}$) will also vary from country to country due to import and retail conditions.

![Fig. 2 CapEx for public ITS network implementation with different technologies](image-url)

Eqn. (1) shows that the CapEx for public ITS is composed of two parts: BSs and UEs. In the BSs part the cost driver is the number of BSs; the costs are defined per BS, the number of which depends on the technology characteristics. The opposite is for the costs associated with the UEs. The number of UEs is always the same as it is the number of busses, where the equipment has to be located. Hence, the difference here comes solely from the technology pricing difference. The results of these calculations are summarized in Table IV and Fig. 2.

For each technology the total CapEx for a public ITS network can be calculated as:

$$CapEx = N_{BS} \times (c_{BS} + c_{freq} + c_{pre-prof} + c_{deploy}) + N_{UE} \times c_{UE}$$  

(1)
B. Operational Expenditures (OpEx)

An annual (one year) cost of operating an ITS network (OpEx) includes the following:

1. Annual payment for radio frequency resource. This payment is based on the decision #171 of the Government of the Russian Federation from 16.03.2011 [21]. The charging methodology is defined in the order #164 of the Ministry of Telecom and Mass Communications of the Russian Federation from 30.06.2011 [22]. This methodology includes rates and ratios, differentiated depending on the Radio Frequency (RF) bands, the number of RF channels and the technologies.

2. Monthly rent for BSs’ sites. Same for all the BSs of the same technology.

3. Monthly power bills for BSs. Same for all the BSs of the same technology.

4. Monthly rent for the connections to the core network. Same for all the BSs of the same technology.

5. Monthly operational costs:
   a. Salary: administration, IT-professionals, technicians, installers, drivers;
   b. Rent of offices, cabinets, garages;
   c. Special machinery, cars;
   d. Spare parts - 1% per month (for BSs and other network equipment), consumables;
   e. Taxes and other expenses.

Table V summarizes approximate operational, i.e., reoccurring, costs per base station. Note that for UHF total $c_{freq, op} = 6000 * 2 * 4$, where two is the number of nominal frequencies per sector and four is the number of sectors. For LTE total $c_{freq, op} = 20000 * 3$, where three is the number of sectors. Operation is connected to a number of the BSs as the number of operational labor would depend on how many BSs are in operation. As already noted for CapEx components, cost values are country and even region specific.

**TABLE V.** OpEx Components for Public ITS RAN Based on Different Wireless Access Technologies.

<table>
<thead>
<tr>
<th>Cost factors</th>
<th>Symb.</th>
<th>Unit</th>
<th>UHF</th>
<th>Wi-Fi</th>
<th>DSRC</th>
<th>LTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of BS</td>
<td>$N_{BS}$</td>
<td>#</td>
<td>9*</td>
<td>3000</td>
<td>1500</td>
<td>700</td>
</tr>
<tr>
<td>Radio frequency</td>
<td>$c_{freq, op}$</td>
<td>Thous.Rub/year/BS/sector</td>
<td>6*2</td>
<td>6</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>BS site rent</td>
<td>$c_{rent}$</td>
<td>Thous.Rub/month/BS</td>
<td>15</td>
<td>5</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>Power</td>
<td>$c_{power}$</td>
<td>Thous.Rub/month/BS</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Connection to the core network</td>
<td>$c_{core, con}$</td>
<td>Thous.Rub/month/BS</td>
<td>5</td>
<td>10</td>
<td>7</td>
<td>10</td>
</tr>
</tbody>
</table>

For each technology the total OpEx per year for a public ITS network can be calculated as:

$$OpEx = N_{BS} \times \left( c_{freq, op} + 12 \times (c_{rent} + c_{power} + c_{core, con} + c_{op}) \right)$$  \hspace{1cm} (2)

From Eqn. (2) it can be seen that the OpEx are defined by the number of BSs. The results of these calculations are summarized in Table V and Fig. 3.

**TABLE VI.** Total OpEx for Public ITS Network Realization with Different Technologies.

<table>
<thead>
<tr>
<th>Frequency band</th>
<th>UHF</th>
<th>Wi-Fi</th>
<th>DSRC</th>
<th>LTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total OpEx, mil. Rub</td>
<td>8.1</td>
<td>648</td>
<td>279</td>
<td>42.84</td>
</tr>
</tbody>
</table>

![Fig. 3 OpEx for public ITS network implementation with different technologies](image)

OpEx are scaled with the number of BSs, thus, Wi-Fi and DSRC show the highest costs, when used for V2I. In comparison with LTE, DSRC features 6.5 times higher operational costs and Wi-Fi even 15 times. UHF communications have the lowest OpEx as they need the lowest number of BSs. Compared to DSRC the costs of UHF are 34.4 times lower and to Wi-Fi even 80 times.

C. Summary

From the techno-economic analysis the most cost efficient technology is UHF communications of standard “Citran”. It needs the least number of Base Stations, i.e., nine, to cover the entire area of St. Petersburg. Therefore, as the number of BSs is the main cost driver for both upfront and reoccurring costs, the CapEx and OpEx are also the lowest from the four RAN technologies (up to 80 times lower). UHF can be used for voice exchange (compressed voice), emergency communication, navigation and telematics information. However, not all of the ITS services can be realized with UHF as the throughput is limited. Furthermore, it is quite challenging to handover between BSs, so the mobility can become an issue, e.g., in the
highway scenario with very high speeds. In a city scenario, the handovers are rather rare as only nine BS cover the entire area. Due to high robustness (primary applications in the military domain) and low estimated cost, UHF communications can be used for emergency services and as a back-up network.

Deployment of dedicated ITS RAN with only Wi-Fi technology after techno-economic analysis was shown to scale poorly and feature the Highest CapEx and OpEx, 795 and 648 millions of Russian Rubles respectively. Further challenges are: very complex frequency-territorial planning and difficulty in obtaining frequency resource due to high number of devices and densely populated spectrum band. Moreover, technically Wi-Fi is not an optimal technology for many ITS applications due to poor mobility support and limited range. However, it can be still a good candidate for specific V2I ITS services and use cases.

Dedicated Short Range Communications (DSRC) or IEEE 802.11p was developed to overcome the technical drawbacks of Wi-Fi for vehicular applications. In comparison to Wi-Fi the number of Road Side Units (RSU) is halved. However, the CapEx and OpEx of such network deployment are still relatively high compared to LTE or UHF. The reasons for high costs are: very complex frequency-territorial planning, difficulty in obtaining frequency resource and very costly user equipment. At the moment of writing, the cost of RSUs and UEs to be installed on the vehicle is almost the same. Thus, covering a large urban territory and a large fleet of public transport with DSRC RAN will not scale well in terms of costs. Finally, the institutional analysis shows that it is illegal to use DSRC in the Russian Federation [16] as the appropriate legislative base is missing. Already cost and feasibility issues make the technology questionable for large scale implementations in the Russian Federation. It has to be noted that the results of techno-economic analysis do not exclude the possibility to use DSRC for V2V applications only and realize V2I part with some other technology, e.g., LTE.

The most promising RAN from the trade-off of cost and technical characteristics is LTE-based. LTE is a broadband technology with moderate delays, mobile by nature. These parameters allow the realization of wide range of services from safety to infotainment. The CapEx and OpEx are although higher than for UHF, but considerably (by an order of magnitude) lower than for Wi-Fi or DSRC. Moreover, for LTE it is more likely to obtain frequency resource in the metropolitan area as it operates in the licensed spectrum. However, as LTE at the moment does not support direct communications (everything has to go through the core), for some delay critical applications it might not be enough.

Thus, it was shown that for a dedicated ITS access network, in the case study of St. Petersburg, Russia, DSRC does not confirm one of its often mentioned advantages, namely, its low cost. It has to be noted one more time that only the RAN was under consideration. For proper functioning LTE needs its own specific core network – Evolved Packet Core (EPC). In this study the core network is considered to be given for all of the technologies and did not influence the CapEx and OpEx calculations in another way than payment for connection to it.

V. CONCLUSIONS

Intelligent Transportation Systems (ITS) in relation to vehicles enable communication between vehicles (vehicle-to-vehicle) and to infrastructure (vehicle-to-infrastructure). Enabling vehicular communication has two primary aims: safety and traffic efficiency enhancement. Cost plays one of the major roles when deciding on the underlying communication technology. This paper showed a case study, i.e., results of institutional and techno-economic analysis, of a dedicated RAN design, construction and operation for public ITS.

Institutional analysis showed that all of the technologies can be legally used in Russian Federation, except for the 802.11p [16]. Techno-economic analysis pointed out that the main cost driver for the RAN implementation is the number of Base Stations (BS). The rest of the costs are scaled with this number, e.g., rent for the sites and permits to be obtained. Due to poor scalability, for full Wi-Fi coverage 3000 BS are needed, for DSRC – 1500, while for LTE – only 70 with three sectors and for UHF – only 9 with four sectors and two nominal frequencies. This pattern is then repeated in the Capital, i.e., upfront costs, and Operational Expenditures, i.e., reoccurring costs, (CapEx and OpEx). So Wi-Fi features the highest CapEx and OpEx that are 2.8 and 15.1 times higher than for LTE. Wi-Fi adaptation, 802.11p or DSRC, is often opposed to LTE as a lower cost option [8]. However, DSRC showed second highest CapEx and OpEx after Wi-Fi, respectively 2.3 and 6.5 higher than LTE. Thus, the implementation cost depends on the scenario, country, etc. and cannot be generalized. The cheapest implementation for our use case will be achieved with the UHF communications of the standard “Citran”. However, it shall be noticed that UHF has low throughput and is advised to be used as an emergency and back-up network, i.e., no entertainment. These results, however, do not prohibit using DSRC for V2V services only. The case study materials are valid for the year 2014 for the defined use case in St. Petersburg, Russia, and shall not be generalized.

REFERENCES


