ITS-G5 AND MOBILE WIMAX PERFORMANCE IN VEHICLE-TO-INFRASTRUCTURE COMMUNICATIONS

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Lucrarea de faţă este un studiu comparativ referitor la două din cele mai promiţătoare tehnologii de comunicaţii wireless propuse pentru noua generaţie de sisteme inteligente de transport: WiMAX mobil şi ITS-G5 - profilul European al viitorului standard IEEE 802.11p. Pentru a putea alege în cunoştinţă de cauză tehnologia radio de acces adecvată anumitor aplicaţii ITS, sau pentru a putea defini reguli optime de selecţie, în funcţie de cerinţele aplicaţiilor, trebuie să cunoaştem performanţa acestora în condiţii cât mai apropiate de realitate. În acest context, investigăm, prin simulare, potenţialul şi limitările acestor tehnologii în condiţiile comunicaţiilor vehicul-la-infrastructură (V2I) într-un mediu urban aglomerat. Abordarea noastră se justifică prin faptul că cele mai multe sisteme de comunicaţii ITS vor activa în aceste tipuri de zone, precum şi prin lipsa unor analize comparative în astfel de condiţii.

This paper is a comparative study of two of the most promising infrastructure-based wireless technologies proposed for the next generation of intelligent transportation systems: mobile WiMAX and ITS-G5 – the European profile of the upcoming IEEE 802.11p standard. In order to choose the right radio access technology for certain ITS applications or to be able to define optimal selection rules based on applications requirements, it is important to know their performance in conditions close to reality. In this context, we investigate, through simulation, the potential and limitations of both technologies as a communication media for vehicle-to-infrastructure (V2I) communications in an urban crowded environment. Our approach is justified by the fact that most ITS communications systems will be implemented in this kind of areas and by the lack of comparative analysis of these technologies in such conditions.

Keywords: Intelligent Transpot Systems, WiMAX, Vehicle-to-Infrastructure

1. Introduction

In recent years, several intelligent transportation system initiatives and projects have been undertaken. These research and development trials are in progress and can be considered a first step towards development of vehicular communications network. The goal of these networks is to improve road safety and traffic efficiency as well as providing Internet services to vehicles.

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A baseline European ITS Communication Architecture for intelligent transportation systems it has been developed by the EC funded specific support action COMeSafety in close cooperation with Car-to-Car Communications Consortium (C2C-CC). Although COMeSafety ended by the end of 2009, the resulting communication architecture has been taken over by ETSI TC ITS and is known as ETSI Architecture (*Figure 1*). It ultimately became the reference model for ISO TC 204 CALM concept.

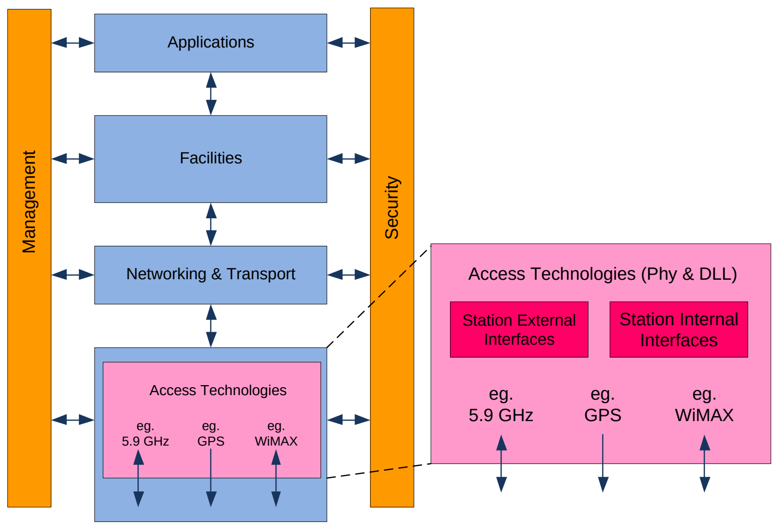

Fig. 1. ETSI architecture

Among the communication technologies, in this paper we propose to compare two of the most often discussed in the ITS literature: mobile WiMAX and ETSI ITS-G5 [1]. The European profile standard ITS-G5 is based on IEEE 802.11-2007 and it includes all features of the IEEE 802.11p (because 802.11p amendment to the basic 802.11 standard currently has draft status it could not be a normative reference). The European profile starting point was the decision of the European Commission of 5 August 2008 on the harmonized use of radio spectrum in the 5.9 GHz band for medium range and delay-sensitive road safety applications. Mobile WiMAX, on the other hand, offers medium to long range connectivity, full support of mobility and high data rates with moderate delay. Our objective was to study the feasibility of both technologies as communication media for vehicular networks by evaluating their performances in a crowded urban environment.

2. Related work

The most related reference to our work is the study performed in [2]. The authors examined the performance of the same two technologies, but they considered a more ideal highway like case. However, it can be made a comparison between the results presented in these two papers; after all, the works are complementary. Other works have focused on the integration of an 802.11p or an 802.16e simulation model into simulators such as NCTUns [3,4]. Nevertheless, regarding vehicle-to-infrastructure communications, most of the papers were interested in evaluating the 802.11p communication protocol and potentially enhancing it. The study performed in [5] has focused on the evaluation of the Enhanced Distributed Channel Access (EDCA) QoS extension supported by the 802.11p protocol. It has shown that fixing the size of the backoff window could decrease the throughput in V2I communication scenarios. Even so, some papers consider that EDCA, because is using CSMA/CA protocol, is quite heavy and needs too many messages to provide QoS functions. To cope with these problems, [6] propose a new point-to-multipoint based TDD/TDMA technique on each downlink carrier for 802.11p wireless local area network rather than random access. In infrastructure mode, downlink is the transmission from the roadside unit to onboard units. They argue the proposed algorithm is outperforming IEEE 802.11a and IEEE 802.11p in high vehicle speed mobility and long distances.

As for mobile WiMAX technology, only a few works have attempted to study its feasibility as an access media for vehicular networks. An architecture for mobile WiMAX deployment in V2I scenarios has been proposed and evaluated through simulation by Aguado et al. [7]. They have shown mobile WiMAX as a competitive solution in V2I context. Other measurements carried out by Chou et al. [8] showed that, at distances under 100 m, WiFi performs better than WiMAX in term of throughput and delay. WiFi and WiMAX are developed for high rate internet applications and therefore usually provide high rate and high reliability but no real-time support. Considering that IEEE 802.11p is optimized for vehicular use is interesting to note their return.

3. ITS-G5 vs Mobile WiMAX

ITS-G5 is an access technology based on the WLAN standard, but with focus on low delay ad-hoc data communication between vehicles and between vehicle and roadside stations; in other words, no access points are needed. The primary scope of the technology is traffic safety applications and inter-vehicle communications. The access technology ITS-G5 can be applied to three frequency bands, ITS-G5A, ITS-G5B and ITS-G5C, which are all part of the European profile for ITS in the 5 GHz band:

- ITS-G5A: operation of ITS-G5 in European ITS frequency bands dedicated to ITS for safety related applications in the frequency range 5.875 – 5.905 GHz.
- ITS-G5B: operation in European ITS frequency bands dedicated to ITS non-safety applications in the frequency range 5.855 – 5.875 GHz.
- ITS-G5C: operation of ITS applications in the frequency range 5.470 – 5.725 GHz.

For ITS-G5A the ECC already decided the designation, for ITS-G5B it is currently a recommendation. Also is considered for future extensions the frequency band 5.905 – 5.925 GHz, noting that protection of ITS applications cannot be ensured. For comparison, USA uses 75 MHz of spectrum within the band 5.850 – 5.925 GHz, Japan uses 80 MHz within the band 5.770 – 5.850 GHz.

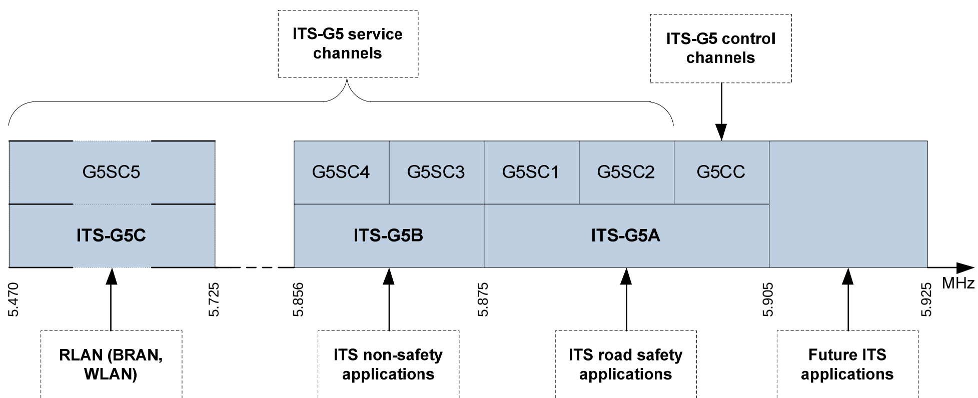

Fig. 2. European ITS channel allocation

The 30 MHz of ITS-G5A are currently divided into 3 sub-channels of 10 MHz each, where the first one, G5SC1, is the main service channel for safety and efficiency messages (for high throughput, safety messages with medium priority, multi-hop and geocast messages at the second hop), the second one, G5SC2, is a service channel used only with low transmission power for very short range communications, mainly between vehicles and roadside stations (for ad-hoc communication), and the last one at 5.895-5.905 GHz is a control channel, G5CC, which also can be used for time critical messages (for low latency, periodic packets, high priority safety messages, multi-hop and geocast messages at the first hop). While this control channel currently is common for all applications, efficiency and other services might also use its own data channel of 20 MHz in the 5.4 GHz band, as described by ITS-G5C. One of the most important feature in the European profile is the permanent listening on the control channel, therefore

ITS stations should be able to simultaneously receive on both the control and one service channel.

The maximum spectral power density for ITS stations should be limited to 23 dBm/MHz EIRP. The total power shall not exceed 33 dBm EIRP with a Transmit Power Control (TPC) range of 30 dB.

IEEE 802.11p uses the IEEE 802.11a physical layer with adaptations to support higher vehicular speeds. The rates 3, 4.5, 6, 9, 12, 18, 24 and 27 Mbps in 10 MHz channels are currently available in the standard. Most likely a low rate (e.g. 6 Mbps) will be chosen since traffic safety applications require a high reliability. All OFDM timing parameters are doubled (e.g. the guard interval, the OFDM symbol duration, etc.). The achievable communication range depends on the output power, the data rate and the environment; in theory, it shall be at least 500 m at maximum power and minimum data rate.

The IEEE 802.11p MAC is based on IEEE 802.11 which uses CSMA. Since collisions may occur indefinitely with CSMA, IEEE 802.11p does not support real-time communications with strict deadlines. The probability of collisions may however be significantly reduced with suitable congestion control. Note that testing of MAC and congestion control algorithms is ongoing in European and US projects. The MAC layer of IEEE 802.11p is enhanced with EDCA from IEEE 802.11e to support priority and QoS differentiation. Four different queues corresponding to four different service classes are provided.

To avoid the latency caused by the association phase, 802.11p allows stations to communicate outside the context of a basic service set. Moreover, there is no need to scan the channel since the communication occurs in a dedicated frequency band. Also, although the MAC layer authentication services are not used, it is still possible to have secure communications using protocols provided by applications outside the MAC layer.

WiMAX belongs to the group of networks termed metropolitan area networks (MAN), typically spanning a larger geographic area such as a city. WiMAX is a cellular system based on WMAN with focus on high rate data communication. When vehicle speeds are moderate, this is a good access technology for internet access and high speed data communications. WiMAX is not a single technology, but rather a family of interoperable technologies. The original specification, IEEE 802.16 from 2001, was intended primarily for MANs and “the last mile” connections using spectrum in the 10 to 66 GHz range. In 2004, the extension 802.16-2004 added additional physical layer specifications (including OFDM-256 and OFDMA) for the 2-11 GHz range and in 2005 a mobile version (including handovers between base stations and handovers between operators at vehicular speeds of up to 120 km/h), 802.16e, was released.

The 802.16 family of standards does not target specific frequency bands like the IEEE 802.11 does, but instead it is up to the user to apply for dedicated bands in their home frequency regulatory domains. Thus, vendors can design equipment for either licensed or unlicensed bands. The IEEE 802.16 standardizes several PHY layers: single-carrier, OFDM and OFDM access (OFDMA).

The achievable data rates for downlink and uplink are 70 Mbps – but only at close range and low vehicular speed (practically 10 Mbps at 10 km distance to the access point). The maximum range of the base station is 50 km (but then data rate is low).

Mobile WiMAX networks are usually made of indoor customer premises equipment (CPE) such as desktop modems, laptops with integrated mobile WiMAX or other mobile WiMAX devices. Mobile WiMAX devices typically have an omni-directional antenna which is of lower-gain compared to directional antennas, but are more portable. In practice, this means that in a line-of-sight environment with a portable mobile WiMAX CPE, speeds of 10 Mbps at 10 km could be delivered. However, in urban environments they may not have line-of-sight and therefore users may only receive 10 Mbps over 2 km. Higher-gain directional antennas can be used with a mobile WiMAX network with range and throughput benefits but the obvious loss of practical mobility.

Table 1

ITS-G5 vs Mobile WiMAX

	ITS-G5	**Mobile WiMAX**
Standard	based on IEEE 802.11p [9]	IEEE 802.16e [10]
Frequency	5.470-5.925 GHz Free but licensed "licence by rule"	10-66 GHz licensed, below 11 GHz (2.3, 2.5, 3.5, 5.8, etc.) both licensed and licence-exempt
Channel bandwidth	10 MHz	Depends on the PHY profile (3.5, 5, 7.5, 10 MHz, etc.)
QoS support	4 classes of QoS (EDCA extension): AC_VO, AC_VI, AC_BK, AC_BE	5 classes of QoS: UGS, ertPS, rtps, nrtPS, BE
Security	No authentication prior to data exchange. Instead, each packet is used for authentication by certificate based digital signature.	Data encapsulation protocol with a set of cryptographic suites and PKM protocol to synchronize keying data between BSs and MSs.
Media access technique	CSMA/CA No scanning, no association	TDMA, FDD or TDD
Other features		AMC, ARQ, AAS, STC and MIMO

4. Performance evaluation

Our simulations were performed using the open-source network simulator NCTUns, which exploits the real-life Linux's TCP/IP protocol stack to generate high-fidelity simulation results. It has support for both IEEE 802.16e mobile

WiMAX point-to-multipoint networks and IEEE 802.11p/WAVE. Over this platform, one can easily develop and evaluate advanced vehicle-to-infrastructure and vehicle-to-vehicle applications in the ITS research field.

To evaluate and compare the performance of both mobile WiMAX and ITS-G5 technologies in V2I context we have considered a crowded urban scenario. The simulation parameters are illustrated in *Table 2*.

Table 2

Simulation parameters

Standard	**IEEE 802.11p**	**IEEE 802.16e**
Frequency	5.875 GHz (G5SC1)	3.5 GHz
Channel bandwidth	10 MHz	10 MHz
RSU Tx power	23 dBm	43 dBm
RSU antenna height	5 m	32 m
MS Tx power	23 dBm	23 dBm
MS antenna height	1.5 m	1.5 m
MS antenna gain	0 dBi	- 1 dBi
Type of antenna	Omnidirectional	
Pathloss	Shadowing	
Fading model	Rayleigh	
Street width	6 m	
Average building distance	1 m	
Average building height	13 m	

The path loss fading model has been set to a shadowing Rayleigh with a high non line-of-sight component. RSU antenna height of 5 m was chosen because we assume the communication units are laid on poles along the road. All the other building and road parameters are intended to describe a crowded urban environment. Note that for IEEE 802.11p, we have adapted the power of the transmitter and the minimum sensitivity of the receiver specified in the European profile standard. In all scenarios we have considered a source of traffic that is connected to the RSUs/BSs through Ethernet links of 100 Mbps (to avoid any bottleneck outside the considered WiMAX/ITS-G5 V2I networks). This source sends UDP packets every 10 ms for 120 seconds to form constant bit rate streams.

```
stg -i rate.cfg 1.0.11.1 -p 8000
```

This will cause NCTUns to run an UDP sender program that binds on port 8000 on the simulated hosts. The content of the configuration file describes a traffic generation scenario.

```
type: udp
start_time: 4
on-off: 1
```

```
on:  time: 120 const 0.01 length: const 1100
end
```

The packet size has been adjusted as needed.
The capture command was:

```
rtg –u –p 8000 –o delay.txt –w throughput.txt –v
```

This command prints a summary of how many packets were captured and record the per-packet and per-second throughput results into a specified file.
Our study is divided in four scenarios.

The performance of 802.11p/802.16e for a single static node

During this first scenario we measured the performance of technologies by taking as reference a single static node feed by a single road side unit or a WiMAX base station. It is shown the throughput and average delay variation depending on packet size, as well as jitter shape for a certain size.

As indicated by *Figure 3*, identical for both technologies, the throughput decreases along with packet size. This information is useful for reserving QoS resources on access routers. In that respect, there is no difference between the two technologies, so you don't need separate configurations.

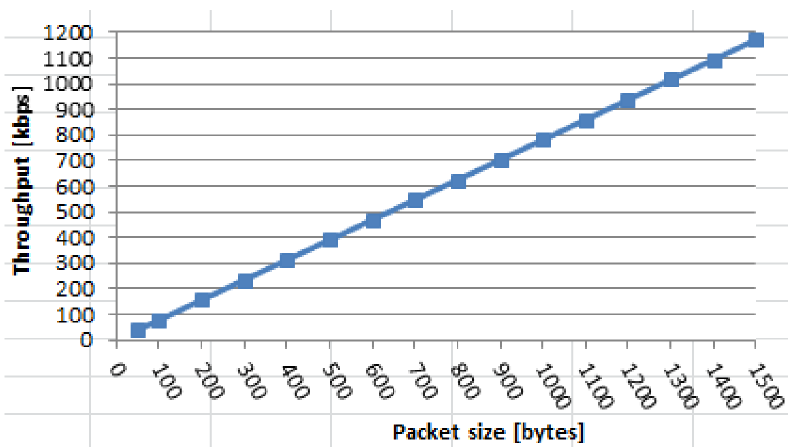

Fig. 3. Throughput for different packet sizes

The first gap between them is shown in *Figure 4*, which illustrates the time required for a packet of particular size to travel from source to receiver. As a first performance criterion, the average delay is represented for packets of different size. We note that for 802.16e, average delay is about 8 ms, with a maximum of

8.81 ms for 1500 bytes packets and 8.707 ms for 50 bytes packets. In contrast, 802.11p average delay is between 22 ms for 1500 bytes packets and 16 ms for 50 bytes packets. So, in the best 802.11p scenario, the packet travels the same distance in a twice as much time. Please note that these are delays obtained at the radio interface level, they are not end-to-end delays.

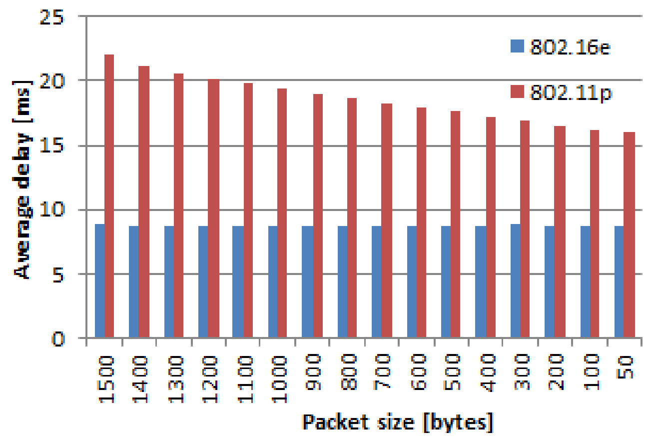

Fig. 4. Average delay for different packet sizes

The second performance criterion, jitter or packet delay variation, is illustrated in *Figure 5*. It compares jitter for packets of 1400 bytes, which corresponds to a transfer rate of approximately 1.1 Mbps. A technology is more efficient as the delay variation for different packets is lower.

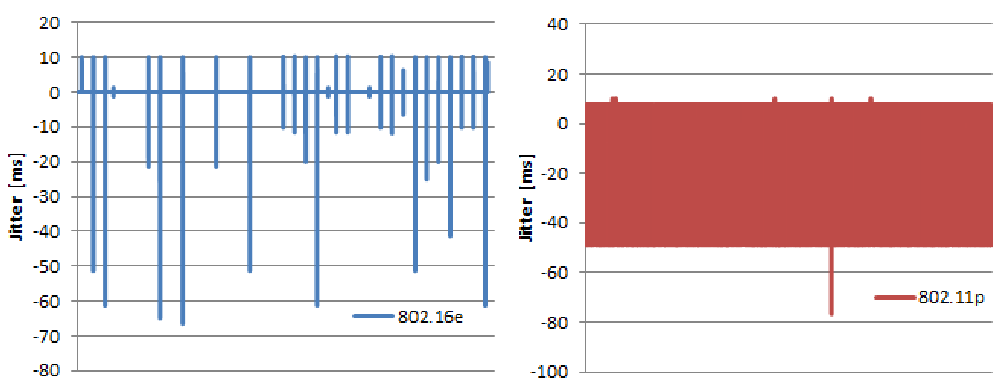

Fig. 5. Jitter for IEEE 802.16e and IEEE 802.11p

The 802.11p values, even greater, are clearly defined in a "gang of variation". Regarding 802.16e, most of the values vary very little, close to zero, but occasionally large differences occur, so the initial advantage is lost. For both technologies, the edges of variation are about the same, between 10 and 70 ms. From an application point of view, performance is defined by minimum and maximum limits, not by the changes on intermediate points.

Coverage evaluation for 802.11p/802.16e

In this scenario, we measure the connectivity of the two technologies in order to determine the radio range between a vehicle and a RSU or a WiMAX BS. We used a CBR stream of packets of 1300 bytes each, resulting approximately 1 Mbps.

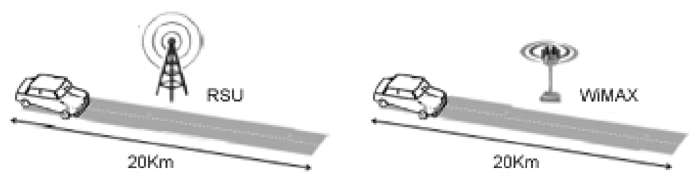

Fig. 6. Coverage scenario

In Figs. 7 and 8, we observe the data rate as a function of the vehicle distance from the RSU or the BS. Considering a data rate greater than 90% of maximum 1 Mbps, the cell radius coverage of 802.11p and WiMAX are then around 500 m and 10 km, respectively.

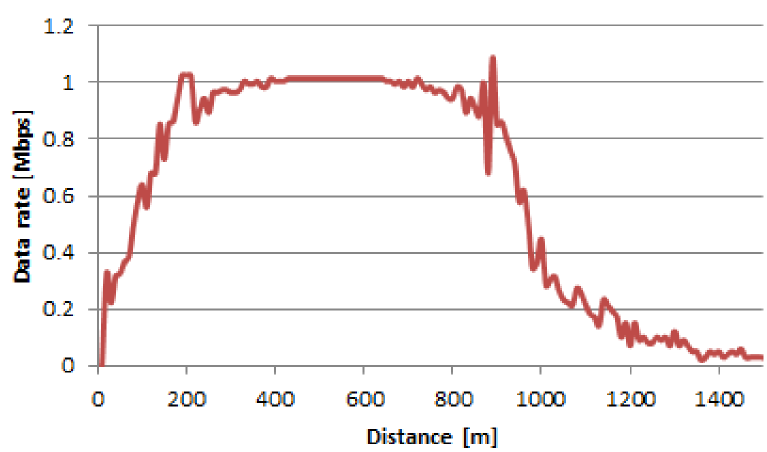

Fig. 7. 802.11p coverage results

In addition to coverage distance, we see how fast it connects and disconnects the vehicle entered in the 802.16e area. Based on these results, depending on source data rate and vehicle speed, we created the next two scenarios. For 802.16e, we used a road of 10 km fully covered by one WiMAX base station. For 802.11p, the same road is fully covered by the equivalent number of RSUs. In order to observe the effect of handover on mobile WiMAX performance we have considered the same area covered by two WiMAX BSs.

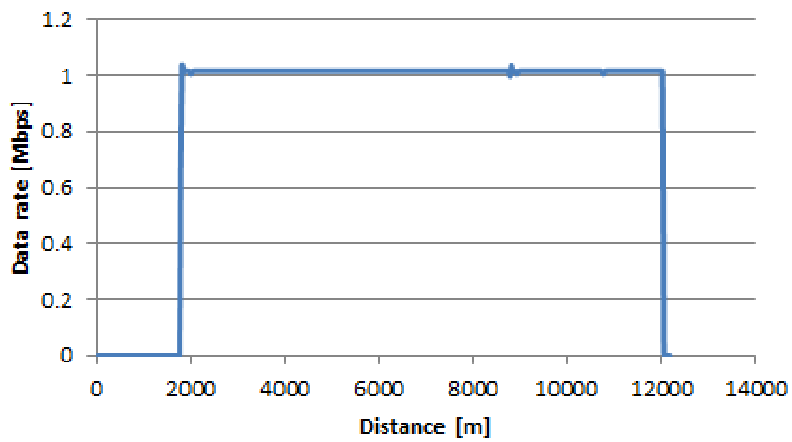

Fig. 8. WiMAX coverage results

Impact of the source data rate on V2I communication performance

To study the impact of the source data rate on V2I communication performance we have set the average speed of the vehicle to 60 km/h and varied the data rate of a CBR traffic transmitted from the source to the vehicle, starting with 1 Mbps till maximum transfer rate supported by the two technologies with acceptable packet loss.

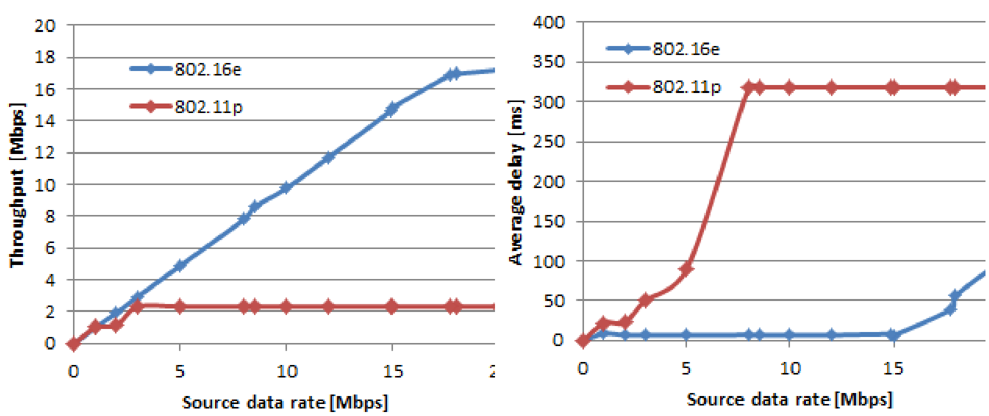

Fig. 9. Impact of source data rate on throughput and average delay

802.11p supports transfer rates of 1.2 Mbps without packets loss. Above this value, increasing source data rate does nothing else but to increase the number of packets loss, leading about 80% percent. The same happens with average delays, which increase significantly (more than 300 ms) while the incoming data rate is kept at about 2.3 Mbps. On the other hand, 802.16e supports transfer rates up to 15 – 16 Mbps without packet loss. The data rate caps at around 17 Mbps. However, packet losses remain low, up to 20% of packets. We can say that 802.16e, besides the greater throughput and smaller delays, is more resistant to packet losses. Average delays of 60 ms, at throughput a bit over 15 Mbps, meet the requirements of most applications, even those of traffic safety.

Because IEEE 802.11p is supposed to be better suited to low traffic loads and to offer very short latencies even at high speed (e.g., road safety messages, small and delay sensitive), we measured the performance of both technologies for transfers under 39 kbps.

The results are presented in *Table 4* and *5*.

Table 4

802.11p performance at low traffic loads

Source data rate	**Average delay**	**Packet loss**
39.062 kbps	16 ms	0%
15.625 kbps	16.625 ms	0%
14.063 kbps	26.522 ms	0%

Table 5

802.16e performance at low traffic loads

Source data rate	**Average delay**	**Packet loss**
39.062 kbps	8.707 ms	0%
15.625 kbps	8.858 ms	0%
14.063 kbps	8.756 ms	0%

Impact of vehicle speed on V2I communication performance

In this scenario we have set the source data rate to 1 Mbps, a value that is slightly below the limit of 1.2 Mbps. We have observed the impact of varying the vehicle speed on the average throughput and the average delay. For 802.11p, when the vehicle speed increases, the connectivity time to the RSU decreases, which then reduces the amount of data received by the vehicle. Further, a fraction of time of this period is required to switch from one RSU to another. In the case of two WiMAX base stations, the handover execution requires a non-negligible time.

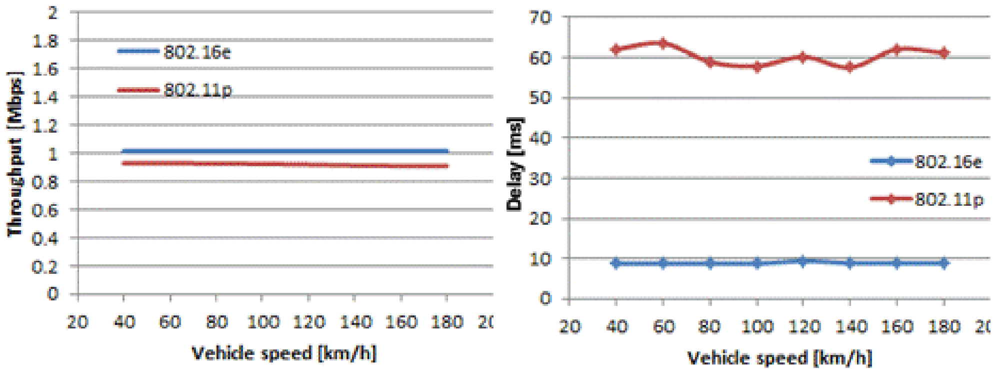

Fig. 10. Impact of vehicle speed on throughput and average delay

5. Conclusions

Within the ITS field, many applications of a diverse nature are considered and thus their communication requirements differ significantly. This makes it difficult for one wireless access technology to support all or even most of these applications. For example, traffic safety applications typically have requirements like high reliability, low latency, and real-time communications. Efficiency and comfort applications have more relaxed requirements on latency whereas ITS applications involving voice or video have lower requirements on reliability. Further, some applications may need more than one wireless access technology to fulfill their full functionality, whereas, for other applications, more than one suitable technology could be recommended. This leads to the necessity to understand which is the most suitable in every specific context. Knowing the capabilities and limitations of these technologies, and knowing their availability are very important factors to make radio access technology selection, so there is an increasing need for performance analysis of different access technologies.

In this paper we studied the potential and limitations of ITS-G5 and mobile WiMAX as communication media for V2I communications. In particular, IEEE 802.16e offers very good performances in terms of throughput, coverage range, delay and packet loss. On the other hand, the performance of 802.11p is acceptable. We must take into consideration the fact that this technology is predominantly dedicated to V2V communications found in VANET ad hoc networks. But there is no doubt that, by standardizing it, it will benefit major improvements in the V2I communications domain too.

An ITS V2I-based communication system can choose between those two technologies or can use both, depending on the technical and economic considerations. Based on these results, we can say that these two technologies are rather complementary.

REFERENCES

[1] *ETSI TS 202 663*, "European profile standard for the physical and medium access control layer of Intelligent Transport Systems operating in the 5 GHz frequency band", published by ETSI, Jan. 2010

[2] *I.C. Msadaa, P. Cataldi and F. Filati*,"A comparative study between 802.11p and Mobile WiMAX-based V2I Communications Networks", in Forth International Conference on Next Generation Mobile Applications, Services and Technologies., Amman, July 2010, pp. 186-191

[3] *S.Y. Wang and C.L. Chou*,"NCTUns Tool for Wireless Vehicular Communications Network Researches", in Simulation Modelling and Theory, **vol. 17**, no. 7, Aug. 2009, pp. 1211-1226

[4] *S.Y. Wang and C.C. Lin*,"NCTUns 5.0: A Network Simulator for IEEE 802.11p and 1609 Wireless Vehicular Network Researches", in 2nd IEEE International Symposium on Wireless Vehicular Communications,Calgary, Canada, Sept. 2008

[5] *Y. Wang, B. Ahmed, B. Krishnamachari and K. Psounis*,"IEEE 802.11p Performance Evaluation and Protocol Enhancement", in Proc. of the 2008 IEEE International Conference on Vehicular Electronics and Safety, Sept. 2008, pp. 317-322

[6] *R.A. Saeed, M.A. Abakar, A.A. Hassan and O.O. Khalifa,*,"Design and evaluation of lightweight IEEE 802.11p-based TDMA MAC method for road side-to-vehicle communications", in 2010 IEEE International Conference on Computer and Communication Engineering, Kuala Lumpur, May 2010, pp. 1-5

[7] *M. Aguado, J. Matias, E. Jacob and M. Berbineau*,"The WiMAX ASN Network in the V2I Scenario", in Proc. of the 68th IEEE Vehicular Technology Conference, 2008, pp. 1-5

[8] *C. Chou, C. Li, W. Chien and K. Lan*,"A Feasibility Study on Vehicle-to-Infrastructure Communication: WiFi vs. WiMAX", in Proc. of the 10th International Conference on Mobile Data Management: Systems, Services and Middleware, May 2009, pp. 397-398

[9] *IEEE P802.11pTM/D7.0*, IEEE Draft Standard for Information Technology Telecommunications and Information exchange between systems, Local and metropolitan area networks, Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, Amendment 7: Wireless Access in Vehicular Environments, May 2009

[10] *IEEE Std. 802.16e 2005*, IEEE Standards for Local and metropolitan area networks, Part 16: Air Interface for Fixed and Mobile BWA Systems, Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands and Corrigendum 1, 2005