A Comparative Study between 802.11p and Mobile WiMAX-based V2I Communication Networks

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***Abstract*—Intelligent Transportation Systems (ITS) have been under development since the 80's as part of a global strategy for solving many of our modern life transportation problems. These systems enable people to reach their destinations in a safe, efficient, and comfortable way. In order to reach that goal, several radio access technologies (RAT) such as UMTS, WiFi, WiMAX and 5.9 GHz have been proposed for next generation ITS.**

Yet, the coexistence of these technologies in the vehicles raises the challenge of choosing the most appropriate RAT. In order to address this problem and define optimal rules for the communication technology selection, comparisons on the network performance have to be done.

In this paper, we compare two of the most promising infrastructure-based wireless technologies: mobile WiMAX (based on IEEE 802.16e standard) and the 5.9 GHz technology based on the upcoming IEEE 802.11p standard. We investigate, through simulation, the potential and limitations of both technologies as a communication media for vehicle-to-infrastructure (V2I) communications. The performance of the two systems is evaluated for different vehicle speeds, traffic data rates, and network deployments.

Keywords: ITS, IEEE 802.11p, 5.9 GHz technology, IEEE 802.16e, mobile WiMAX, V2I, simulation.

I. INTRODUCTION

During the last two decades, several initiatives, like COMeSafety [4], and technical groups supported by standardization bodies, such as the IEEE 802.11p task group [1], the ISO TC204 Working Group 16 [2] and the ETSI ITS Technical Committee [3] have been created to solve many of our society transportation problems. From that perspective, three main categories of applications have been targeted: (i) road safety applications, (ii) traffic efficiency applications, and (iii) value-added applications.

- Road safety applications: the primary goal of this set of applications is to reduce road fatalities by assisting and warning the driver about the potential risks. This category covers applications like pre-crash sensing and collision risk warning.
- Traffic efficiency applications: this category is intended to relieve traffic congestion by helping to monitor the traffic flow and by providing alternative itineraries to drivers. These applications make the transportation systems not only more efficient but also more environmentally friendly by optimizing routes and decreasing gas emissions.
- Value-added applications: they include on-demand services related to infotainment, comfort or vehicle management. They can be provided either free of charge or for a fee - which could help to finance the deployment of such networks. Also, by notifying a point of interest (e.g. parking lot, restaurant, etc.), some of these applications may help to save time and thus to reduce fuel consumption.

TABLE I
ITS APPLICATIONS CATEGORIES: EXAMPLES AND REQUIREMENTS.

Application category	**Latency tolerance**	**Range**	**Example (delay requirements)**
Road safety	Low latency	Local range	Pre-crash sensing/warning (50 ms) Collision risk warning (100 ms)
Traffic efficiency	Some latency is acceptable	Medium range	Traffic information - Recommended itinerary (500 ms)
Value-added services	Long latency is accepted	Medium range	Map download update - Point of interest notification (500 ms)

In Table I we can see that the groups of services presented above have different requirements, in terms range, delay, and throughput. Indeed, they cover a wide range of applications that vary from "locally" sending a small and urgent message (e.g., in order to alert a driver about an imminent crash) to updating a map on the on-board device by downloading a big file from a remote server. Considering the conflicting requirements of the applications, several ITS architectures have been proposed by vehicular communications initiatives and standardization bodies. In particular, most of them agree on the necessity of having a variety of communication media. The two architectures, presented in Figures 1(a) and 1(b), are proposed by the European Telecommunications Standards Institute (ETSI) [4], and ISO TC204 Working Group 16 [2], respectively.

The possibility of having different communication technologies for vehicular communication yields to the necessity to understand which is the most suitable in every specific context. Indeed, since in the near future vehicles will be equipped with different access technologies, knowing the capabilities and limitations of these technologies, and knowing their availability are very important factors to make radio access technology (RAT) selection and decide whether a vertical handover should be performed to achieve an always best connected communication.

Recently, standardization bodies have given mandate to technical groups to define the application requirements for ITS applications. Moreover, business models will be developed to include the cost and benefit for the user of using a certain technology with respect to another. The last piece needed is the performance analysis of the different access technologies.

Among the communication technologies, in this paper we propose to compare two of the most promising ones: mobile WiMAX (based on IEEE 802.16e standard [6]) and the 5.9 GHz technology based on the upcoming IEEE 802.11p standard.

IEEE 802.11p-based technology [1] has been developed for the specific context of vehicular networks. In particular, it is expected to be particularly suitable for medium range and delay-sensitive road safety applications. Mobile WiMAX, on the other hand, offers a promising alternative because of its potential to offer medium to long range connectivity, full support of mobility, and high data rates with moderate delay.

Based on these characteristics, the two technologies seems intrinsically complementary in terms of range, data rates and delay. Nonetheless, to the best of our knowledge, this is the first time that the performance of the two technologies are compared through simulation. Our objective is to study the feasibility of both technologies as communication media for vehicular networks by evaluating their performances in the same simulation environment.

The remainder of this paper is structured as follows. Section II presents the related work. Section III provides an overview of both IEEE 802.16e and IEEE 802.11p standards. It summarizes the main characteristics of each access technology and compares them based on several criteria. In Section IV, we first define our simulation environment and settings and then analyze the results of the performance evaluation study we have performed. Section V concludes the paper by outlining the main obtained results and providing future work directions.

II. RELATED WORK

IEEE 802.11p [1] is a draft amendment of 802.11 whose standardization process has not been finalized yet. Meanwhile, some works have been published to introduce this upcoming standard. For example, Jiang et al. [7] have described the history of the standardization process of 802.11p, presented its spectrum band and channels, and detailed its main amendments at both MAC and physical layer. Other works have focused on the integration of an 802.11p simulation model into a simulation environment such as NS2 [8] or NCTUns [9]. Nevertheless, most of the papers were interested in evaluating the 802.11p communication protocol and potentially enhancing it. The performance studies performed in [10] and [11] have focused on the evaluation of the Enhanced Distributed Channel Access (EDCA) QoS extension supported by the 802.11p protocol. Eichler [10] has shown, by simulation and analytical means, that the use of highly prioritized messages could lead to a significant increase of the collision probability especially in dense V2V communication scenarios. To tackle this problem, he has suggested the use of a re-evaluation method—proposed in a previous work—whose objective is to "reduce the number of high priority messages and prevent long message queues". Wang et al. [11] have shown that fixing the size of the backoff window in EDCA could decrease the throughput in V2I communication scenarios. Therefore, they have proposed two approaches (a centralized and a distributed one) to adapt the size of the backoff window to the number of communicating vehicles.

Stibor et al. [12] have studied the number of potential communicating neighbor nodes, and the maximum communication duration in a multi-hop vehicle-to-vehicle (V2V) context. Their simulation results could be used to optimize the planning of multi-hop communication routes—on a highway—in order to efficiently forward emergency messages in a V2V communication scenario.

As for mobile WiMAX technology, only a few works have attempted to study its feasibility as an access media for vehicular networks. To compare WiFi and WiMAX as infrastructures for V2I communications, some measurements have been carried out by Chou et al. [13]. The preliminary results of these measurements show that, at distances under 100 m, WiFi performs better than WiMAX in terms of throughput and delay. An architecture has been proposed by Aguado et al. [14] for mobile WiMAX deployment in V2I scenarios. In the first part of the paper, the authors have detailed the proposed architecture based on a set of requirements, then evaluated its performance through simulation. The carried simulations have revealed that the inter-ASN (Access Service Networks) handover may lead to significant delays in some circumstances. Yet, they have shown that the proposed WiMAX system fulfills the requirements of demanding real-time applications such as VoIP and video conferencing which place mobile WiMAX as a competitive solution in V2I context.

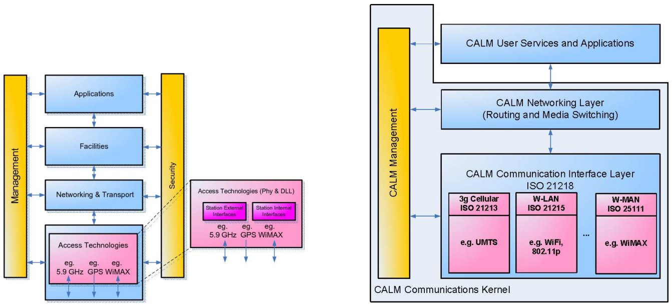
Given the specifics of the two technologies and their expected performance, it is still fundamental to compare them in the same scenario by using realistic simulation tools. The lack of works in this field between these two technologies has motivated our work.

III. IEEE 802.11P VS. IEEE 802.16E

A. IEEE 802.11p

IEEE 802.11p is an ongoing 802.11 amendment [1] that is aimed at standardizing a set of extensions for 802.11 in order to adapt it to the V2X (V2I and V2V) environment.

From that perspective, many phases of the basic 802.11 communication protocol at MAC layer have been eliminated or shortened. Indeed, unlike 802.11, 802.11p allows stations to communicate in OCB mode i.e. outside the context of a basic service set (BSS), thus avoiding the latency caused by the association phase. Moreover, there is no need to scan the channel since the OCB communication occurs in a frequency



(a) ETSI Architecture [4]. (b) ISO CALM Architecture [2].

Fig. 1. ITS station reference architectures.

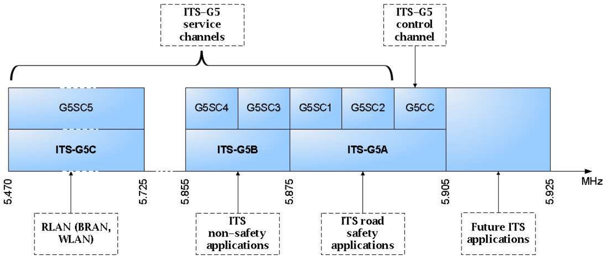


Fig. 2. European channel allocation [18].

band dedicated to ITS use[1]. Also, when exchanging frames in OCB mode, the MAC layer authentication services are not used. Yet, it is still possible to have secured communications provided by applications outside the MAC layer.

At physical layer, the amendment concerns mainly the spectrum allocation. Vehicular communications are performed in the 5 GHz range, where one channel is dedicated to control and the others to ITS services. Figure 2 illustrates in particular the European profile for the channel allocation. According to this profile, the control channel (G5CC) is used for road safety and traffic efficiency applications. It may also be used to announce ITS services operated on the service channels (G5SC1 to G5SC5). The service channels G5SC1 and G5SC2 are used for ITS road safety and traffic efficiency applications while the others (G5SC3, G5SC4 and G5SC5) are dedicated to other ITS user applications. In order to reduce the effects of Doppler spread, the use of 10 MHz channels has been adopted instead of the usual 20 MHz used by 802.11a. Consequently, all OFDM timing parameters are doubled (e.g. the guard interval, the OFDM symbol duration, etc.) and the data rates are halved (vary from 3 to 27 Mbps instead of 6 to 54 Mbps). Moreover, the European profile requires that ITS stations are able to simultaneously receive on both the control and one service channel. Therefore, two transceivers are needed. In this work, we considered the standard profile of the physical and MAC layers recently proposed by ETSI [18].

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B. IEEE 802.16e

The IEEE Std 802.16-2004 defines the air interface for fixed BWA systems in the frequency ranges 10-66 GHz - where line-of-sight (LOS) is required - and sub 11 GHz - where non-LOS (NLOS) is possible. The IEEE 802.16e-2005 amendment updates and expands IEEE Std 802.16-2004 to support subscriber stations moving at vehicular speeds and thereby specifies a system for combined fixed and mobile broadband wireless access.

In this paper, we consider the two-way PMP mode where Mobile Stations (MSs) communicate with each other only through a central base station (BS) which receives and coordinates all their transmissions. The standard offers the possibility of adapting the modulation and coding schemes (MCSs) based on the channel conditions and proposes a set of techniques such as packing and fragmentation to allow efficient use of the available bandwidth.

The MAC layer defined by the standard is connection-oriented. Each connection is associated to an admitted or active service flow (SF) whose characteristics provide the QoS requirements to apply for the protocol data units (PDUs) exchanged on that connection. Uplink flows are associated, in addition to a scheduling service, to one of these request/grant scheduling types: unsolicited grant service (UGS), real-time polling service (rtPS), extended real-time polling service (ertPS), non-real-time polling service (nrtPS), and best effort (BE). Each scheduling service is designed to meet the QoS requirements of a specific applications category.

In addition to all the features already supported by the fixed WiMAX standard, the 2005 amendment introduces a set of enhancements, namely in support of handover and security, in order to adapt the existing 2004 version of the standard to a mobile environment.

Table II summarizes the characteristics of both technologies based on several criteria.

IV. PERFORMANCE EVALUATION

A. Simulation environment and settings

For our simulations, we have used the network simulator QualNet 4.5 [15] which is the commercialized version of GloMoSim. The Advanced Wireless Library proposed by QualNet integrates a simulation model for mobile WiMAX with the support of several features such as PHY OFDMA, PMP and TDD modes, AMC capability, QoS scheduling services, etc. Nevertheless, the simulator does not include an 802.11p model. Therefore, we have first implemented the necessary changes (as reported in Section III-A) to existing 802.11a PHY and 802.11e MAC models in order to adapt them to 802.11p specifications. Note that we have adapted the power of the transmitter and the minimum sensitivity of the receiver to what has been specified in [18].

To evaluate and compare the performance of both mobile WiMAX and 802.11p technologies in V2I context we have considered a highway scenario. Our study is divided in three parts. During the first part we measure the connectivity of

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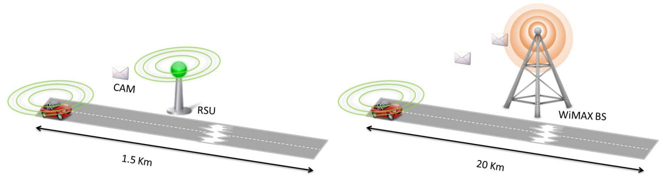
[1] A license might be needed for these bands, depending on the regulatory domain.

TABLE II
802.11P VS 802.16E

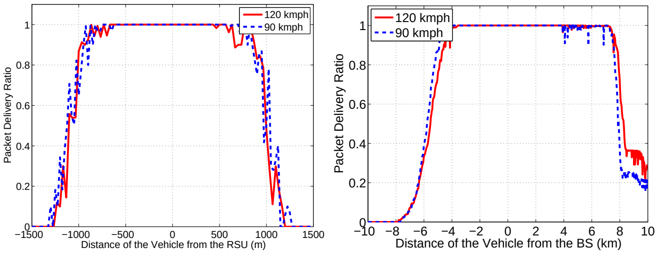
	802.11p	**802.16e**
Standardization	Draft [1]	Standard [6]
Frequency/ License	5.470-5.925 GHz free but licensed “License by rule”	10-66 GHz licensed below 11 GHz: (2.3, 2.5, 3.5, 5.8, etc.) both licensed and license-exempt
Channel bandwidth	10 MHz	Depends on the Phy profile (3.5, 5, 7.5, 10 MHz, etc.)
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 support	No Authentication prior to data exchange Instead, each packet is used for authentication by certificate based digital signatures	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
Usage	Network dedicated to vehicles (ITS stations)	Could be used by residences, companies, personal devices, ...
Other supported features		Support of AMC, ARQ, AAS, STC and MIMO

TABLE III
SIMULATION PARAMETERS

	802.11p	**802.16e**
Frequency	5.87 GHz (G5SC3)	3.5 GHz
Channel bandwidth	10 MHz	10 MHz
RSU Tx power	23 dBm (=200 mW)	33 dBm (=2 W)
RSU antenna height	2.4 m	32 m
RSU antenna gain	3 dBi	15 dBi
MS Tx power	23 dBm (=200 mW)	23 dBm (=200 mW)
MS antenna height	1.5 m	1.5 m
MS antenna gain	0 dBi	-1 dBi
Type of antenna	Omnidirectional	
Pathloss	Two-ray	
Fading model	Ricean	



(a) 802.11p coverage scenario.
(b) WiMAX coverage scenario.



(c) 802.11p coverage results.
(d) WiMAX coverage results.

Fig. 3. Coverage evaluation scenarios.

the two technologies in order to determine the radio range between a vehicle and a 802.11p road side unit (RSU), or a WiMAX base station (BS). In the second part, we compare the communication performance of the two technologies on a highway segment which length corresponds to the coverage of one BS varying the speed of the vehicle. After analyzing the performance of WiMAX, the performance of 802.11p is investigated by replacing the single BS with the number of RSUs necessary to cover the same segment. Finally, in the third part, we observed the impact of the traffic datarate on the throughput and the delay.

In order to determine the range of the 802.11p RSUs and of the WiMAX base station, we have set our simulation parameters as reported in Table III. The path loss fading model has been set to a two-ray Ricean fading model with a high line-of-sight component which is quite realistic in the highway context (unlike in an urban environment, where this assumption is not valid).

For the evaluation of the range of an 802.11p RSU, we simulated the transmission of periodic beacons (using the control channel at 5.9 GHz for 802.11p communication). Accordingly to the ETSI specifications, the basic beaconing rate is set to 10 Hz and the periodic message (also called CAM, i.e. cooperative awareness message) is 55 bytes long and contains geo-information. The scenario is illustrated in Figure 3(a).

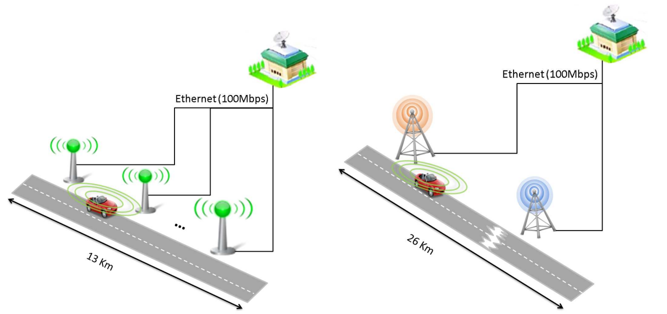
In Figures 3(c) and 3(d), we can observe the delivery ratio as a function of the vehicle distance from the RSU or the BS. Considering a packet delivery ratio greater than 90%, the cell radius coverage of 802.11p and WiMAX are then around 900 meters and 6.5 Km, respectively.

Based on these results, we have set three different network deployments for all the simulation scenarios to be considered. The first deployment corresponds to the case of a highway of 13 km fully covered by one WiMAX base station. The second deployment consists in fully covering the same road link by the equivalent number of 802.11p RSUs (as shown in Figure 4(a)). Finally, in order to observe the effect of handover on mobile WiMAX performance too, we have considered a third deployment that considers the area covered by two WiMAX BSs.

In all the 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/802.11p V2I networks). In the case of 802.11p scenarios, we simulated the transmission of the data over the G5SC3 channel, which is dedicated to non-safety applications.

The effect of increasing the number of vehicles is not considered in this paper. In fact, even with only one vehicle, by increasing the source data rate, we can analyze the upper limits that can be reached in mobile WiMAX and 802.11p V2I networks in similar conditions.

In order to have realistic movement of the vehicle on the highway, the mobility traces have been generated with SUMO 0.9.8 [16]. In particular, in order to adapt the mobility traces generated by SUMO to QualNet, we have used MOVE



(a) Deployment with several RSUs. (b) Deployment with 2 WiMAX BSs.

Fig. 4. Scenarios network deployments.

(MObility model generator for VEhicular networks) tool [17].

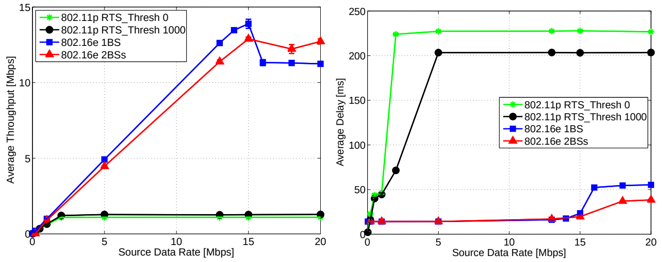
B. Performance analysis

Using the simulation parameters detailed in Section IV-A, we have considered two scenarios.

1) Scenario 1: Study of the impact of the source data rate on 802.11p/802.16e V2I networks performance: In this first scenario, we have set the average speed of the vehicle to 100 kmph, that is a realistic value of vehicles on the highway. We have varied the data rate of a CBR traffic transmitted from the source to the vehicle considering the three configurations of deployed networks. This scenario covers network traffic loads varying from 25 kbps to 20 Mbps. We have evaluated the impact of varying the source data rate on both the throughput (shown in Figure 5(a)) and the end-to-end delay (illustrated in Figure 5(b)). In the case of 802.11p, we investigated the impact of using RTS/CTS on the transmission performance. In fact, the ETSI standard [18] allows the use of this mechanism for unicast transmissions whose packet size exceeds the $dot11RTSThreshold$. Thus, giving that the packet size is set to 512 bytes, we considered two cases; first the $dot11RTSThreshold$ is set to 0 and then to 1000 bytes, which is the default value recommended by ETSI.

All the results presented in this Section are the values averaged over more than 30 runs within a 95%-confidence interval.

The obtained results allow us to derive the maximum throughput that could be reached in optimal (1 vehicle) yet realistic conditions (of speed, power, fading, etc). For IEEE 802.11p, the maximum throughput is around 1.2 Mbps while it could exceed 12 and 13 Mbps in 2 BSs and 1 BS deployment scenarios, respectively. As for the average end-to-end (E2E) delay, 802.11p experiences short delays (less than 40 ms) in low traffic conditions. However, when the source data rate exceeds the maximum that could be reached in 802.11p networks (around 1.2 Mbps), the delay significantly increases, exceeding 200 ms. When using RTS/CTS mechanism the delay further increases. The same behavior (increase of the E2E delay) is observed for WiMAX when the maximum sustainable data rate is reached, though at much lower scale since the average delay does not exceed 60 ms which fulfills even the needs of most emergency applications. However, at very low data rate (e.g. 25 kbps) 802.11p performs better than 802.16e which is convenient for exchanging small and delay-sensitive safety messages.



(a) Impact of the source data rate on the average throughput. (b) Impact of the source data rate on the average end-to-end delay.

Fig. 5. Impact of the source data rate on the average performance

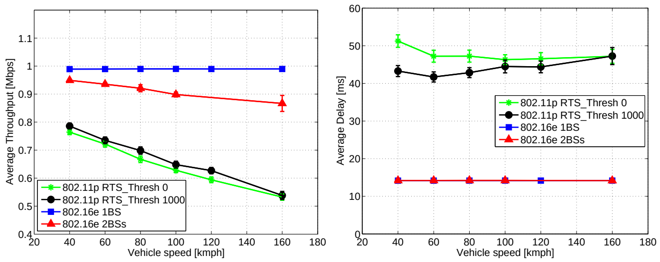
2) Scenario 2: Study of the impact of the vehicle speed on 802.11p/802.16e V2I networks performance: In this second scenario, we have set the source data rate to 1 Mbps, a value that is slightly below the limit of 1.2 Mbps that we observed in the previous scenario, but that should maintain a good throughput. We have observed the impact of varying the vehicle speed on the average throughput (plotted in Figure 6(a)) and the end-to-end delay (shown in Figure 6(b)).

For 802.11p, when the vehicle speed increases, the connectivity time to the 802.11p RSUs decreases which then reduces the amount of data received by the vehicle. Additionally, a fraction of time of this period is required to switch from one RSU to another. On the other hand, in the case of two WiMAX BSs, the handover execution requires a non-negligible time which affects the average throughput that remains lower than that of the scenario with a single BS regardless of the vehicle speed.

The average E2E delays of 802.11p and 802.16e are plotted in Figure 6(b)). Remind that in this scenario, the source data rate is set to 1 Mbps, so there is no packet loss due to buffer overflow at the IP or MAC layers. For this reason, the end-to-end delay is the same with one and two WiMAX base stations while in case of 802.11p, the delay slightly increases with the vehicle speed. One important observation that could be derived from this figure is that for both technologies, the E2E delay is lower than 15 ms (less than 10 ms for 802.11p) which fulfills the minimum requirement of most ITS safety applications. As final remark, the use of RTS/CTS mechanism slightly increases the E2E delay and affects the throughput. Nevertheless, the impact of this mechanism should be further investigated in heavy loaded vehicular traffic scenarios where it could prevent collisions and increase the packet delivery ratio but also entail longer delays.

V. CONCLUSION

In this paper, we studied the potential and limitations of both mobile WiMAX and 802.11p as communication media for vehicle-to-infrastructure (V2I) communications. We first compared the two technologies based on different criteria.



(a) Impact of the vehicle speed on the throughput

(b) Impact of the vehicle speed on the end-to-end delay

Fig. 6. Impact of the vehicle speed on the average performance

Therefore, we investigated their performance through simulation. The coverage, average throughput, and end-to-end delay were evaluated for different vehicle speeds, traffic data rates, and network deployments.

The simulation results reveal on one side the great competitiveness of mobile WiMAX technology in the context of V2I communications. In particular, this technology, offers, not only a large radio coverage and high data rates, but also reasonable and even very low delays. On the other side, the 802.11p technology is better suited to low traffic loads, where it offers very short latencies even at high vehicle speed.

The obtained results can be considered as a first step for the definition of an efficient common radio resource management (CRRM) module for vehicular networks. They could further be used as pre-defined criteria for radio access technology (RAT) selection for ITS applications. Future work will focus on extending this study to the urban environment. A broad analysis of the performance of the two technologies will be used to develop new algorithms for smart selection of the optimal RAT based on the applications requirements, the channel load, and the user's preferences.

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