Performance Comparison Between IEEE 802.11p and LTE-V2V In-coverage and Out-of-coverage for Cooperative Awareness

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Abstract—Cooperative awareness, consisting in the periodic broadcasting of messages, called beacons, to inform neighboring vehicles about maneuvers, changes of direction and other relevant mobility information, represents the core requirement to enable applications that may increase road safety and transportation efficiency. Up to few months ago, when latest 3GPP Release added to long term evolution (LTE) the support of vehicle-to-vehicle (V2V) communications, the only suitable standard was IEEE 802.11p in the U.S. and the corresponding ITS-G5 in Europe. The choice regarding the worldwide adoption of one of the two technologies is still under discussion, since both show advantages and drawbacks. In this work, we analyze IEEE 802.11p and LTE-V2V and evaluate their performance for the cooperative awareness service through simulations in a realistic highway scenario. Both in-coverage and out-of-coverage conditions are considered for LTE-V2V. Results reveal that LTE-V2V in-coverage is the best solution in terms of packet reception ratio for all the considered values of beacon size and communication range. As far as the beacon update delay is concerned, we observe that LTE-V2V in-coverage still provides the best performance when small packets are transmitted, while IEEE 802.11p gives the best results for values of the communication range higher than 100 m when the packet size is increased.

I. INTRODUCTION

One of the main focus areas of today’s vehicular industry is the development of technological solutions to improve travel safety. To this aim, several solutions have been installed in cars currently available on the market, such as sensors for collision avoidance, smart navigation systems, driver notifications, assistance and even autonomous driving. Nevertheless, every company is using proprietary technologies, which are not able to interact and cooperate with the equipments installed by the other car makers. For this reason, there is the need for a standardized system which can operate worldwide, providing an easy and efficient integration between multiple services and applications [1]. To implement this scenario, the connectivity among the different network nodes, vehicle-to-everything (V2X) communication, plays a crucial role.

Focusing on vehicle-to-vehicle (V2V), one of the most important services is the cooperative awareness, which consists in the periodic broadcast of small packets, generally called beacons, exchanged by vehicles with their neighbors to disseminate the information about position, travel direction, speed and intentions. Up to few months ago, with the aim of enabling this kind of service, wireless access in vehicular environment (WAVE) based on IEEE 802.11p in the U.S., and the corresponding cooperative-intelligent transport systems (C-ITS) based on ITS-G5 in Europe, represented the only complete standards. The situation changed in June 2017 when 3GPP introduced the support to the V2X feature in the long term evolution (LTE) standard, defining a new device-to-device (D2D) interface optimized for elevated mobility.

While IEEE 802.11p is a rather mature technology, whose capability has been tested in a large number of test beds, LTE-V2V is extremely recent, but represents a valid alternative to IEEE 802.11p thanks to the widely diffused LTE infrastructure and its flexible and modular system structure [2]. However, the use of LTE for vehicular applications is not mature yet. In particular, LTE-V2V devices are still under development, and the allocation (and management) of radio resources is still under investigation.

Several works were devoted to the study of IEEE 802.11p and LTE; as an example, [3]–[7] deal with the joint use of IEEE 802.11p and infrastructured LTE for various kinds of applications, whereas [8]–[11] provide comparisons between IEEE 802.11p and infrastructured LTE for cooperative awareness. Direct mode (LTE-D2D) for beaconing is considered in [12], but this paper adopts a custom frame structure, that is not compliant with the one defined by 3GPP. As a consequence, the novelty of this paper is to give a comparison between the two technologies in compliance with their respective standards, providing numerical results achieved through realistic simulations.

More specifically, this work focuses on the cooperative awareness service; we simulate a typical vehicular scenario (i.e., congested highway) and evaluate the performance of the two technologies using simulation platform for heterogeneous interworking networks (SHINE) [13], [14] for IEEE 802.11p and LTEV2Vsimsim [15], [16] for LTE-V2V. To allow for a fair comparison between the two technologies, we consider the same propagation characteristics, the same traffic scenario and assume the use of a dedicated channel in the 5.9 GHz band. Regarding LTE-V2V, we also consider the performance of both in-coverage and out-of-coverage modes.

The paper is organized as follows: in Section II, we give
an overview of the IEEE 802.11p standard, briefly describing the physical (PHY) and medium access control (MAC) layer procedures; in Section III, we introduce LTE-V2V and summarize the basic concepts of resources allocation in both in-coverage and out-of-coverage situations; in Section IV, we discuss the numerical results achieved through simulations, after the description of the scenario and the performance metrics; in Section V, we conclude the paper.

II. IEEE 802.11p

WAVE consists in a family of Wi-Fi-like standards specifically optimized for wireless short-range vehicular communications in the U.S and is already supported by a large number of devices available on the market. There is also a relevant on-going experimentation involving more than 1500 vehicles [17]. Regarding the PHY and MAC layers, it is based on IEEE 802.11p, defined in 2010 [18] and revised in 2012 [19]. For the data link layer, it follows IEEE 1609.4 [20], for the security layer IEEE 1609.2 [21] and for the transport layer IEEE 1609.3 [22], all updated in 2016. ETSI defines ITS-G5, which is the set of protocols and requirements that constitutes the European version of this technology. ITS-G5 follows IEEE 802.11p, but adds some modifications to higher layers. However, several ETSI definitions regarding the C-ITS were announced only recently, more precisely in 2013, and are still under revision [23].

Focusing on the PHY layer, IEEE 802.11p/ITS-G5 exploits orthogonal frequency division multiplexing (OFDM), which makes use of a large number of closely spaced orthogonal subcarriers that carry data on several parallel data streams. The entire signal is wideband (i.e., occupies a 10 MHz channel), but each subcarrier can be seen as a slowly modulated narrowband signal, allowing it to cope with severe channel conditions and, especially, to mitigate the multipath effect. The combination of the convolutional coding for forward error correction (FEC) and the adopted modulation and coding scheme (MCS) defines eight possible operating modes, resulting in a raw data rate which goes from 3 to 27 Mbps. The European C-ITS spectrum is subdivided into seven 10 MHz channels ranging from 5.855 to 5.925 GHz and is allocated in four sub-bands, depending on the kind of application and on the different requirements defined in ITS-G5.

The MAC layer adopted in ITS-G5 is based on the one described by IEEE 802.11p and is called enhanced distributed coordination access (EDCA). It follows the basic concept of distributed coordination function (DCF) but adds quality of service (QoS) attributes. The DCF implements a carrier sensing multiple access with collision avoidance (CSMA/CA) scheme. With CSMA/CA, a device listens to the channel before starting its own transmission; if the channel is detected as occupied, the transmitter delays its transmission by a random duration of time (backoff procedure). While this technique allows a fully distributed and uncoordinated access to the channel, with no need for synchronization and prior resource allocation procedure, it has as a drawback a not negligible waste of resources because of the high number of collisions that take place under heavy traffic conditions, that is when the channel becomes congested.

Regarding the cooperative awareness service, WAVE introduces the basic safety message (BSM), which defines the packet to be broadcasted in V2V communications, while ETSI similarly determines the basic service for cooperative awareness messages (CAMs) dissemination [24]. Nevertheless, the worldwide adoption of this standard seems to be delayed over time due to some uncertainties that afflict the technology, which are here summarized: i) it will require the deployment of an entirely new infrastructure for road side units (RSUs); ii) it lacks a clear business model, since operators and service providers may not achieve an adequate return on investments; at last, iii) it has shown performance limitations in real experimentations under heavy traffic conditions due to the high probability of errors [25], [26].

III. LTE-V2V

LTE constitutes a valid alternative for supporting V2X communications, since their introduction in the 3GPP standard in June 2017 [27]. While further improvements will be added to this technology in the next months or years, currently LTE-V2V is an evolution of the D2D Sidelink interface defined in the proximity-based services (ProSe) in Release 12.

Direct communication exploiting LTE uplink resources takes advantage on the use of single carrier frequency division multiple access (SC-FDMA) at the MAC layer, which provides orthogonal radio resources. In the frequency domain, the available bandwidth is divided into groups of orthogonal contiguous subcarriers, while in the time domain, data is organized in frames of 10 ms, in turn divided in subframes of 1 ms. Each subframe is made of two time slots of 0.5 ms. 12 consecutive subcarriers and one time slot form a resource block (RB). RBs are allocated on a subframe basis, thus two consecutive RBs are the smallest element of resource allocation and corresponds to 14 OFDM symbols. LTE-V2V, in order to support high speed scenarios, has only 9 OFDM symbols per subframe available for data. Depending on the adopted MCS, the number of bits carried by the couples of RBs and the number of RBs needed for the transmission of one beacon can be found according to [28]. From now on, the number of resources for the cooperative awareness service, which corresponds to the number of beacons that can be allocated in a beacon period, will be called beacon resources (BRs).

Concerning the resource allocation procedure, Release 14 adds two enhanced Sidelink modes to deal with both in-coverage (Mode 3) and out-of-coverage (Mode 4) situations.

A. In-coverage

In Sidelink Mode 3, it is assumed that the scenario is fully covered by one or multiple synchronized evolved NodeBs (eNBs), having the task of controlling resource scheduling and interference management for all LTE-V2V links through signaling on dedicated control channels. In order to achieve the maximum capacity of the network and guarantee an adequate
QoS, eNBs adopt spatial reuse of the available BRs when the distance between two transmitters using the same BR is sufficient to allow a correct decoding of the packet by the receivers. This distance is commonly denoted as minimum reuse distance \( r_{\text{reuse}} \), defined as the minimum distance between the transmitters such that the signal to noise and interference ratio (SINR) at the receivers is higher than the minimum threshold \( \gamma_{\text{min}} \), as detailed in [28].

Through coordination and synchronization, the eNBs can estimate the position of each vehicle using the uplink time difference of arrival (UTDOA) method or, alternatively, can receive periodic global navigation satellite system (GNSS) updates from the vehicle itself, probably causing a waste of resources. Moreover, the estimation of the position of the vehicles at the network side may be affected by a certain level of inaccuracy (e.g., in [29]).

In this in-coverage situation, network-controlled resource allocation is performed each time there is at least one beacon that has not been correctly decoded by one neighbor. The set of neighbors is defined as the group of vehicles within a certain radius of communication, hereafter called awareness range and denoted as \( r_{aw} \). BRs used by vehicles within \( r_{aw} \) and \( r_{\text{reuse}} \) are marked as not available and, if there are no remaining BRs for the transmission of one more beacon, the vehicle is blocked until the generation of the next beacon. At this point, a new attempt is performed. When successful, the required BRs are randomly selected among those still available.

### IV. Simulation Results

#### A. Scenario and Parameters

The simulated scenario is taken from a realistic traffic trace representing a congested highway with three lanes per direction [31]. The average speed of vehicles is 50.08 km/h, with a standard deviation of 3.21 km/h. There are approximately 2000 vehicles in 16 km of road, corresponding to a linear vehicular density of 119 vehicles/km. The simulated duration \( T_{\text{sim}} \) is 90 s. We assume a constant beacon periodicity \( T_{bc} \) of 100 ms and two possible packet sizes \( B_{bc} \): 190 and 300 bytes are values commonly found in the literature (e.g., [30]). The required \( T_{aw} \) is varied from 50 to 500 m. We consider a dedicated channel with 10 MHz bandwidth \( B_{BC} \). For both IEEE 802.11p and LTE-V2V, devices transmit with a constant equivalent radiated power \( P_{Tx} \) of 23 dBm and have an antenna gain at the receiver \( G_{r} \), equal to 3 dB. The path loss at 1 m \( L_{0} \) is set to 47.86 dB and the loss exponent \( \beta \) to 2.20.

Concerning IEEE 802.11p, the chosen MCS\(_{11p}\) is 3 (often referred as Mode 3), which corresponds to the use of a QPSK modulation and of a coding rate of 1/2 (i.e., 6 Mbps of raw data rate), suggested as the best compromise [32]. The duration of the initial interframe space \( t_{\text{initial}} \) is set to 58 \( \mu s \), the carrier sensing sensitivity \( S_{\text{min}} \), to -85 dBm and the noise power to -95 dBm. With these settings, the maximum transmission range and the maximum sensing range correspond to 540 m and 740 m, respectively.

For the LTE-V2V system, we assume that devices have half duplex (HD) radio capability, thus they cannot transmit and receive in the same subframe. We adopt a MCS\(_{LTE} \) = 2 when \( B_{bc} = 190 \) bytes and an MCS\(_{LTE} = 4 \) when \( B_{bc} = 300 \) bytes.
corresponding to the minimum ones to allocate a BR in one subframe. When under network coverage, the estimation of the position of vehicles is achieved through UTDOA and affected by an error with a 95-th percentile of 100 m, in accordance with [33]. When out-of-coverage, the sensing procedure adopts the following parameters: \( p = 0.1, k = 20 \) and \( M = 6 \) dB, in compliance with [30]. Table I summarizes the main simulation settings.

### B. Output Metrics

The cooperative awareness service is related to public safety applications, which need a highly reliable and low-latency wireless communication. Every vehicle should have an updated knowledge of its neighborhood, thus the packet loss and the update delay must be minimized. For this reason, the following two performance parameters are considered:

- **the packet reception ratio (PRR),** for the evaluation of the communication reliability, computed as the ratio between the total number of successfully received beacons and the sum of the neighbors of each vehicle. As already mentioned, a beacon is successfully decoded only when it is received with a sufficiently high SINR;
- **the update delay (UD),** for the evaluation of the communication latency, computed as the time difference between two consecutive correctly received beacons of each couple of vehicles that are within \( r_{aw} \). In particular, in the next section we evaluate the 99-th percentile of this metric, which already covers almost all cases, but we also consider the 99.9-th percentile, with the aim of ensuring the defined QoS for applications with even more stringent latency requirements.

### C. Numerical Results

Fig. 1 shows the PRR as a function of the required \( r_{aw} \), for IEEE 802.11p/ITS-G5, LTE-V2V in-coverage and LTE-V2V out-of-coverage. More precisely, Fig. 1(a) plots the PRR when \( B_{bc} = 190 \) bytes and Fig. 1(b) describes the case with \( B_{bc} = 300 \) bytes. As expected, the curves are monotonically decreasing as \( r_{aw} \) increases. With regard to the case \( B_{bc} = 190 \) bytes, we observe that LTE-V2V in-coverage provides a value of PRR above 0.99 up to 250 m of \( r_{aw} \), which is a remarkable result, while IEEE 802.11p and LTE-V2V out-of-coverage start with a PRR of 0.95 and 0.85, respectively, and decrease to 0.81 and 0.74 at 250 m. The three curves become closer for larger values of \( r_{aw} \), but LTE-V2V in-coverage still outperforms the other two schemes with a difference of about 10%. In particular, between 350 and 400 m, LTE-V2V out-of-coverage slightly overtakes IEEE 802.11p, thus offering higher reliability at very large communication distances.

Moving to the analysis of Fig. 1(b), LTE-V2V in-coverage shows the highest PRR also in this case, with a result higher than 0.99 up to 200 m. In particular, between 200 m and 300 m, the superior performance of LTE-V2V in-coverage over the other choices becomes remarkable, with up to 26% higher PRR at 250 m than IEEE 802.11p, which is in second place. For very high values of \( r_{aw} \), the difference is heavily reduced, with nearer performance in all the three cases. In the same way as in Fig. 1(a), for values of \( r_{aw} \) larger than 300 m, LTE-V2V out-of-coverage overtakes IEEE 802.11p, this time by a slightly larger amount.

Now focusing on the analysis of the communication latency, Fig. 2 shows the 99-th percentile of the UD with \( B_{bc} = 190 \) bytes (Fig. 2(a)) and with \( B_{bc} = 300 \) bytes (Fig. 2(b)) for three significant values of \( r_{aw} \) (50, 100 and 200 m). Starting from Fig. 2(a), LTE-V2V in-coverage provides a value of UD lower than 0.1 s, IEEE 802.11p starts from 0.2 s and increases to 0.4 s and LTE-V2V out-of-coverage shows the worst results, with an UD that goes from 0.7 to 2 s at 200 m.

Analyzing Fig. 2(b), we can notice that LTE-V2V in-
coverage is still the best choice, keeping an UD within 0.1 s. However, it is immediately followed by IEEE 802.11p, which offers consistent performance, with an UD going from 0.2 to 0.5 s. Also in this case, LTE-V2V out-of-coverage is in last place, showing a value of UD that goes from 0.9 s at 50 m to 2.4 s at 200 m.

Fig. 3 raises the requirement in terms of latency, showing the 99.9-th percentile of the UD with $B_{bc} = 190$ bytes (Fig. 3(a)) and with $B_{bc} = 300$ bytes (Fig. 3(b)) for the same three values of $r_{aw}$ of Fig. 2. Generally, Fig. 3(a) follows the same trend of Fig. 2(a), with LTE-V2V in-coverage outperforming the other two technologies, that show slightly increased values of the UD compared to Fig. 2(a). In particular, when $r_{aw} = 200$ m, LTE-V2V in-coverage provides delay that is 10 and 37 times lower than that obtained from IEEE 802.11p and LTE-V2V out-of-coverage, respectively. LTE-V2V out-of-coverage is still the worst, with an UD that goes from 1.7 to 3.7 s.

Examining Fig. 3(b), up to 100 m of $r_{aw}$ LTE-V2V in-coverage is the best, with a 99.9-th percentile of the UD equal to 0.1 s. Moving to $r_{aw} = 200$ m, we can see that this time IEEE 802.11p shows the lowest delay ($\sim 1.6$ s), while LTE-V2V in-coverage goes in second place, with a delay of 2.4 s. This behavior is due to the effect of saturation of BRs: we recall that blocked vehicles stop transmitting until a successful attempt of BR reassignment, but this happens more rarely when network saturation is reached. Regarding LTE-V2V out-of-coverage, it shows the highest delay for all the considered values of $r_{aw}$.

V. CONCLUSION

In this paper, we compare the performance of two technologies for cooperative awareness: IEEE 802.11p/ITS-G5 and LTE-V2V. Concerning this last one, both in-coverage
and out-of-coverage situations are considered. The evaluation of their performance is achieved through simulations in a realistic highway scenario. Results highlighted that LTE-V2V in-coverage can achieve 10% better results in the packet reception ratio and a 10 times lower update delay than IEEE 802.11p when small packets are transmitted. When a larger packet size is assumed, LTE-V2V in-coverage is still the best solution, with a maximum of 26% of improvement over IEEE 802.11p in the packet reception ratio. However, in this case IEEE 802.11p guarantees a lower update delay at high communication ranges. These results revealed that there is not an optimal technology for every condition and that the adoption of a given technology depends on the specific application requirements, especially in terms of communication range and packet size.

REFERENCES