Connected Vehicles for Safety Enhancement: Reliability of Beaconing in Urban Areas

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Abstract. Safety enhancement is the main objective to pursue through the exploitation of connected vehicles. To this aim, the exchange of periodic beacon messages through vehicle-to-vehicle (V2V) communications is essential to guarantee a timely and reliable alert, whatever is the targeted safety application. In this paper, we focus on beaconing in vehicular networks and we evaluate the reliability of beacons exchange between vehicles in realistic urban scenarios. Specifically, IEEE 802.11p, which is the actual standard *de facto* for vehicular communications, is considered as radio access technology and the impact of distance and obstacles on beacons reliability is evaluated. Results obtained through detailed simulations highlight the high impact of distance and obstacles, to be carefully taken into account in the application design.

Keywords: Connected vehicles · Vehicular networks · Safety · Vehicle-to-vehicle (V2V) · Beaconing · IEEE 802.11p

1 Introduction

The internet of everything is changing the world in terms of both new enabled applications (from e-health, to home automation, smart grid/traffic/lighting, etc.) and new volume of data traffic on wireless networks channels. Globally, mobile data traffic will grow 8-fold from 2015 to 2020, with a compound annual growth rate of 53% [1]. It is expected that a big part of mobile data traffic will be produced by vehicles equipped with OBUs, able to transmit and receive information through a wireless interface, thus enabling a variety of new services addressing safety, traffic management, environment monitoring, urban surveillance, Internet access, etc.

Among all these services, those related to safety gather most of the attention of both standardization bodies and governative administrations with the ambitious objective to reduce the number of road accidents. Over 1.2 million people are, in fact, killed annually because of road accidents. Studies predicted that road accidents would become the sixth largest cause of death in the world in 2020 even with the use of many safety devices, whereas it was the ninth largest cause of death in 1990 [2].

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Safety, so as most of the services enabled by transport-related information, can be obtained through cooperative vehicle-to-vehicle (V2V) wireless communications which allow vehicles to directly communicate with each other and to largely extend their awareness range beyond autonomous on-board capabilities. To this aim, a crucial role is played by the periodic transmission of packets, normally called beacons, carrying information about the vehicle type, state, position and speed.

The importance of beaconing has been recently investigated, especially focusing on its impact on channel congestion and vehicles density, possibly proposing to adapt the beacon periodicity (BP). In [3,4], for example, BP is investigated for channel congestion reduction with different radio access technologies. In [5] the impact of some parameters (such as vehicle dynamics and channel load) on safety when performing adaptive beaconing is proposed. In [6] the impact of the application requirements on the communication settings of each vehicle, and on the overall channel load generated is investigated. In [7] the effect of multi hop propagation on the reliability of a forward collision warning application is studied with the objective to show that network-coding-based propagation yields an improvement of reliability with respect to a randomized forwarding strategy. In [8], the performance of beaconing in safety applications under MAC challenging conditions is deepen in highway scenarios. Beacons reliability has been investigated in [9] as a function of different radio propagation models and different vehicular density for the cooperative collision warning application. In [10] a transmission power control scheme is proposed to let each vehicle obtaining the position information of its neighboring vehicles at a sufficient frequency for avoiding collision, showing that the beacon reliability is improved with respect to constant transmission power and that the length of consecutive failures of beacon reception from distant vehicles is reduced.

Differently from the recent literature, in this paper we focus on a scarcely investigated aspect of beaconing, which is its dependance on the inter-vehicular distance and on what happens in the presence of obstacles, such as near intersections. At the best of the author knowledge, the impact of inter-vehicular distance has been recently investigated in [10], where the focus however is on a beacon transmission power control scheme in highway scenarios without realistic mobility models. In this work, we investigate, by simulation in realistic urban scenarios, the dependance of beacons reliability on the inter-vehicular distance and obstacles taking into account real road maps and vehicular traffic.

2 Wireless Access for Connected Vehicles

The importance and the increasing interest in V2V communications, has triggered standardization efforts in both US and in Europe. As a result two families of standards have been completed, wireless access in vehicular environment (WAVE) with the IEEE 802.11p as the physical and MAC layer standard in 2010 in the US, and the first release of the ETSI cooperative-intelligent transport systems (C-ITS) called ETSI-ITS G5 in 2013 in Europe. In early 2014, different working groups within 3GPP have also started studying V2X as an additional feature for LTE-Advanced [11–13]. All these standards specify a V2V feature to address road safety, so that cars can benefit from low latency by sending each other awareness beacons. Values of BP and tolerable latency for these messages are usually fixed for a given use case to guarantee the right level of safety for a specific scenario.

3GPP started considering to enable vehicular communications through the cellular networks as one key feature of 5G. This is made possible by the low end-to-end latency guaranteed by LTE and by the supported speed are around 350 km/h [14]. One of its main advantages is the fact that the network has already been deployed (whereas, in case of large deployment of IEEE 802.11p roadside units the investment could be not negligible). However, the current implemented release of LTE lacks of a native V2V communication. A direct mode with emphasis on public safety (LTE-D2D, or Proximity Services - ProSe) has been specified within Rel. 12 and from Rel. 13 onward. Vehicular communications are explicitly introduced only from LTE Rel.14, whose standardization process is still ongoing, with the name of LTE-Vehicular (LTE-V2V) [11,12].

Thus, although LTE-V2V may represent an interesting solution for connected vehicles in the long term, thinking to short term safety applications IEEE 802.11p has an a higher degree of maturation and remains the only consolidated solution to enable V2V communications. WAVE/IEEE 802.11p (or its European version, C-ITS) represents the actual standard *de facto* for V2V communications: it was born to enable ad hoc short range communications also in high speed vehicular scenarios, with simplified signaling and low latency. This is made available by the *WAVE mode* that allows the transmission and reception of data frames with the wildcard basic service set (BSS) identity (ID) value and without the need of belonging to a particular BSS. This feature enables a fast exchange of contextual data, including position and speed. The access technology layer is based on CSMA/CA and operates in the 5.9 GHz frequency band. At the physical layer, IEEE 802.11p is based on orthogonal frequency division multiplexing (OFDM) modulation, with channels of 10 MHz and data rates between 3 and 27 Mb/s.

3 Safety Requirements

Several applications have been imagined for an improved safety, better traffic management, and entertainment to passengers. Focusing on safety applications, all of them are based on two types of messages, in spite of the names given by the various standards: single-hop periodic messages that cars broadcast containing information about the speed, position, etc., and event-driven messages whose purpose is to disseminate safety information in a specific geographical region. In this work we focus on periodic messages, called for example cooperative awareness messages in ETSI [15] and basic safety messages in IEEE [16], that are hereafter denoted beacons.

With reference to the safety applications enabled by the transmission of beacons, in Table 1, we summarize the applications foreseen by three of the main

Table 1. Safety applications and requirements for NHTSA, ETSI, and 3GPP.

Safety application	Beacon periodicity [Hz]	Communication range [m]	End-to-end latency [ms]
NHTSA			
Wrong way driver warning	10	500	100
Cooperative forward collision warning	10	150	100
Lane change warning	10	150	100
Blind spot warning	10	150	100
Highway merge assistant	10	250	100
Cooperative collision warning	10	150	100
Highway/rail collision warning	1	300	1000
Cooperative glare reduction	1	400	1000
ETSI			
Emergency electronic brake lights	10	N/A	100
Safety function out of normal condition warning	1	N/A	100
Emergency vehicle warning	10	N/A	100
Slow vehicle warning	2	N/A	100
Motorcycle warning	2	N/A	100
Vulnerable road user warning	1	N/A	100
Overtaking vehicle warning	10	N/A	100
Lane change assistance	10	N/A	100
Co-operative glare reduction	2	N/A	100
Across traffic turn collision risk warning	10	N/A	100
Merging traffic turn collision risk warning	10	N/A	100
Intersection collision warning	10	N/A	100
Co-operative forward collision warning	10	N/A	100
Collision risk warning from roadside units	10	N/A	100
3GPP			
Forward collision warning	10	N/A	100
Control loss warning	10	N/A	100
V2V use case for emergency vehicle warning	10	N/A	100
V2V emergency stop use case	10	N/A	100
V2I emergency stop use case	10	N/A	100
Queue warning	N/A	N/A	100
Warning to pedestrian against pedestrian collision	N/A	N/A	N/A
Vulnerable road user safety	1	N/A	100

international institutions and their requirements in terms of BP, communication range, and end-to-end latency. Table 1 only refers to V2V communications with periodic transmission of beacons, whereas applications based on event-driven messages and vehicle-to-infrastructure (V2I) communications are not shown.

In particular, Table 1 reports the studies of NHTSA, ETSI, and 3GPP. The numbers from NHTSA report the results of studies done during a project, in which 34 safety and 11 non-safety scenarios have been described, providing the definition and the description of each application and indicating the communication modalities and requirements in terms of end-to-end latency, BP and transmission range [17]. Requirements from ETSI can be found in [18], whereas the 3GPP working group SA1 published in [11] its first study.

As it can be observed, most safety applications are guaranteed by a BP of 10 Hz. Regarding the required communication range, requirements are only provided by NHTSA, with values from 150 to 500 m; however, such numbers appear focused on an highway scenario, and may not apply to urban scenarios. Looking at the last column of Table 1, all institutions agree that an end-to-end latency of 100 ms is required by most applications.

At the end, once the BP is fixed, the only requirement is in the latency. However, it should be remarked that such latency is easily achievable by single hop communications, even in highly congested conditions, unless the message is lost. Indeed, even if no specific requirement has been provided by the listed institutions on the reliability of beacon reception, such metric is what most studies focus on.

4 Beaconing Performance in Realistic Urban Scenarios

With the aim to investigate the performance of beaconing and the feasibility of safety services in large scale deployments, we performed simulations in the realistic scenarios hereafter detailed. The main settings are summarized in Table 2.

Table 2. Main simulation settings.

Parameter	Value
Equivalent radiated power	23 dBm
Receiver sensitivity	−85 dBm
Receiver antenna gain	3 dB
Minimum SINR	10 dB
Transmission range (LOS)	∼740 m
Packet length	160 byte
Beacon periodicity	0.1 packet/s

4.1 Settings

Simulations refer as a case study to the center part of the Italian city of Bologna (sketched in Fig. 1(a)), with the position of vehicles provided by realistic vehicular traffic traces obtained using the road traffic simulator VISSIM (more details can be found in [19–22]). Both fluent traffic and congested traffic conditions are considered, as summarized in Table 3.

Table 3. Scenarios.

Scenario	Area	Average number of vehicles
Bologna, fluent traffic	$2.88\,\text{km}^2$	455
Bologna, congested traffic		670

Simulations are application independent, since they focus on the beacon transmission reliability. In particular, each OBU periodically transmits a beacon in broadcast to all the vehicles under its radio coverage. The beacon period is set to 10 Hz, which is the value considered for most applications (as discussed in Sect. 3). Beacons of 160 byte are assumed. As an output, the beacon delivery rate (BDR) is calculated, which is the rate of packets that are correctly received. In all the performed scenarios, correctly received beacons observed an end-to-end latency well below the requirement of 100 ms, and it is thus not shown here for brevity.

The IEEE 802.11p technology is simulated taking into account the sensing and random access procedures, with collisions and retransmissions, also including hidden terminals, exposed terminals, and capture effects. The most reliable mode is used, thus the nominal bit rate is 3 Mb/s. As detailed in [23], we assume a path loss proportional to the distance raised to the power of 2.2 in line of sight (LOS) conditions [24] and we add an attenuation when buildings impair the LOS [25]; specifically, 9 dB loss per each external wall and 0.4 dB/m loss inside the buildings are assumed [25]. A packet is correctly received if both the received power is higher then the receiver sensitivity of −85 dBm and the signal to noise and interference ratio (SINR) is higher than a threshold of 10 dB. With an assumed equivalent radiated power of 23 dBm and antenna gain at the receivers of 3 dB, it follows an average radio range of nearly 740 m. As a consequence, the number of vehicles in the radio range of an OBU can exceed 200 in congested traffic conditions, as observable in Fig. 1(b), where the statistic of number of vehicles within coverage of each OBU is shown.

4.2 Results

Impact of Distance and Obstacles. In Fig. 2, the BDR is shown varying the transmitter-receiver distance[1] for the two considered scenarios. To better

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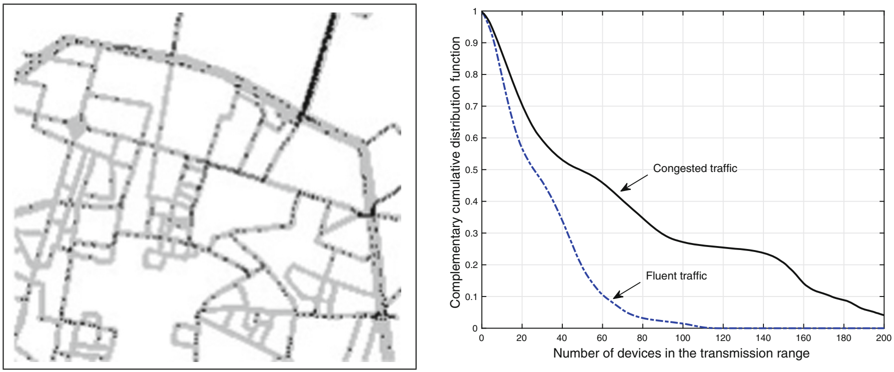
[1] Per each transmission and per each receiver, the success or loss of the packet is stored with the related transmitter-receiver distance. At the end of the simulation, the BDR is then averaged as a function of such distance.



(a) Simulated road network.

(b) Ccdf of vehicles in radio range.

Fig. 1. Simulated road network with the position of vehicles in a random instant (congested traffic) and complementary cumulative distribution function (ccdf) of the number of vehicles in the radio range of the OBUs.

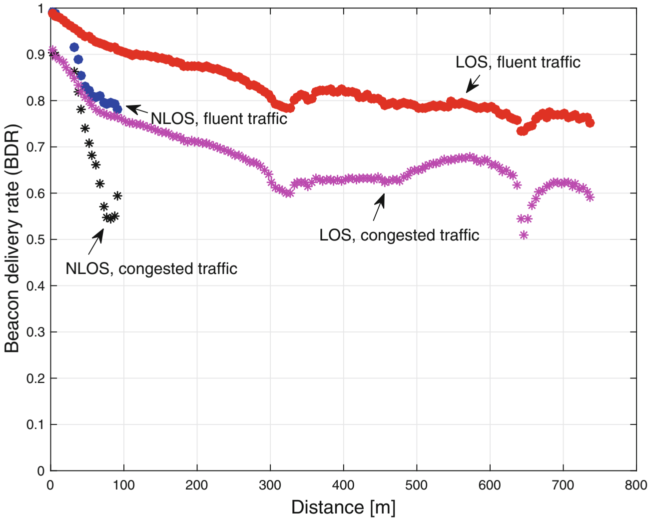


Fig. 2. Beacon delivery rate vs. transmitter-receiver distance.

highlight the impact of obstacles on the communication reliability, results under LOS and non line of sight (NLOS) conditions are shown separately.

As expected, the BDR worsens with an increasing distance (due to heavier impact of interferers) as well as an increasing vehicular density, and is significantly impacted by the presence of buildings impairing the LOS. The high attenuation caused by buildings at 5.9 GHz is shown to reduce the range from nearly 740 m in LOS conditions to a maximum of nearly 100 m in NLOS conditions.

(a) Performance within 20 m. (b) Performance within 50 m.

(c) Performance within 100 m. (d) Performance within 200 m.

Fig. 3. Beacon delivery rate as a function of the position of receiving OBUs.

The shown results imply that beaconing from connected vehicles can hardly be implemented at 10 Hz if a very high reliability is targeted. Looking at Fig. 2, in fact, a 95% reliability in LOS conditions is achievable only up to 35 m in the fluent traffic conditions and cannot be achieved in congested traffic conditions. Moreover, the BDR is further reduced in NLOS conditions.

However, it can be noted that the loss of a single beacon may not be so critical. Please note, for example, that a 75% reliability implies that the probability to loose all of 10 consecutive beacons (covering 1 s) is below 10^{-6}. Targeting 75% reliability, almost 120 m in LOS conditions and 50 m in NLOS conditions are obtained in the congested traffic case. In the same case, distances increase to more than 600 m and 90 m in the fluent traffic case, respectively.

Impact of Receiver Position. To observe the effect of the position of vehicles in the scenario, in Fig. 3 the BDR is related to the location of the receivers for the case of Bologna congested. Colors express the BDR in each position, considering the receivers that are within a parametric distance d^* from the transmitter.

If we focus for example on $d^* = 50\,\mathrm{m}$, it can be observed that the BDR remains above 98% in most roads and junctions of the scenario, and is approximately 95% in the main junction, where a congestion involving multiple lanes is occurring. Worse conditions, with average BDR below 80% can be only observed with $d^* = 200\,\mathrm{m}$ in the main junction.

5 Conclusion

In this paper, we investigated the performance of V2V beaconing using IEEE 802.11p for safety purposes. Through detailed simulations in realistic scenarios, it is shown that the achievable range is limited if a 95% or more reliability is targeted in areas where obstacles may impair the LOS (like buildings aside of junctions). It is however observed that single losses may not cause safety risks, thus a reduction of the reliability requirement could be accepted, with significant increase of the achievable distance. In the case a higher reliability is mandatory at large distances, the outcomes reveal that additional solutions might be needed, such as multi-hop communications or the use of infrastructure (either cellular base stations or roadside units).

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