On the Performance of Beaconing in 802.11p/WAVE Vehicular Ad Hoc Networks

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***Abstract*—Cooperative vehicular applications, like collision avoidance, driver assistance, and cruise control require that vehicles become aware of other vehicles in the surroundings. This cooperative awareness is achieved by *beaconing*, the exchange of periodical single-hop broadcast short status message that include data about the position, the speed, and the heading of a vehicle.**

Although several works have studied beaconing techniques both from an analytical point of view and through simulative study, none of the existing works has investigated how beaconing works on top of 802.11p/WAVE (Wireless Access for Vehicular Environment), the upcoming standard intended to deliver both safety and non-safety applications to vehicles on the roads. According to it, safety and control messages are expected to be delivered on a given frequency during a common control channel (CCH) interval set by the WAVE draft standard. The rest of the time, vehicles switch over one of available service channel (SCH) frequencies for non-safety related data exchange.

In this paper we discuss and evaluate through numerical results the main effects the WAVE channel switching procedures have on beaconing.

***Index Terms*—vehicular ad hoc network, 802.11p, WAVE, beacon**

I. Introduction

Significant activities on both governmental, industrial and academy bodies have been underway to accelerate the deployment of a new kind of network based on short range communications among moving vehicles (Vehicle-to-Vehicle, V2V) and between vehicles and roadside infrastructure (Vehicle-to-Infrastructure, V2I). This network is called a Vehicular Ad Hoc Network, VANET, and is a special case of Mobile Ad Hoc Network (MANET), characterized by a higher speed of nodes, resulting in shorter connection lifetime and more rapidly changing network topologies.

Potential applications for VANETs have been identified in the recent past and have been categorized based on their targets: on-the-road safety, traffic efficiency and management, information/entertainment of road travellers [1].

Specifically, traffic efficiency and management applications require each vehicle to have an *accurate* and *timely* knowledge of both its position and its neighborhood. These applications, in fact, foster graceful road vehicles flows, traffic coordination, and driver assistance (e.g., cooperative collision warning). A vehicle is assumed to periodically announce itself to its neighbours, through the exchange of short status messages, i.e., *beacons*. They are delivered as one-hop broadcast messages and include information about the vehicle position, its speed, and direction, as retrieved though on board sensors and positioning systems. To satisfy the application requirements, beacons are generated with typical frequency of 5-10 Hz. This high generation rate could cause congestion on the channel, especially when the car density is high.

Therefore, significant research efforts have been put forward on the design of adaptive techniques striving to reduce the channel load and to ensure the required accurate and timely neighborhood awareness, by adapting the beacon generation frequency and transmission power [2]- [5]. Moreover, analytical models have been recently developed to investigate the performance of beaconing in VANETs [6]- [8].

To the authors knowledge, however, there is still lack of a work that studies the performance of beaconing on top of 802.11p/WAVE (Wireless Access for Vehicular Environment)-based vehicular networks. IEEE 802.11p [9], proposed as a draft amendment to the IEEE 802.11 standard [10], and the WAVE system [11], are currently working on a set of specifications to permit communications in the rapidly changing vehicular environment. Although they are properly designed to deliver both safety and non-safety applications to vehicles on the roadway, the envisioned multi-channel architecture [12] presents some inefficiences, which could strongly deteriorate applications performance, especially if they are *blindly* developed on top of the upcoming protocol stack intended for VANETs.

Therefore, in Section II we discuss the main 802.11p/WAVE features and capabilities, by also underlying the inefficiencies of the standard. Then, in Section III we evaluate the performance of beaconing on top of 802.11p/WAVE protocol stack. Finally, in Section IV we give conclusive remarks and hints for the future research.

II. The 802.11p/WAVE System

A. Main features

IEEE 802.11p [9] is releasing a set of physical (PHY) and medium access control (MAC) layer specifications to enable communications in VANETs in the 5.9 GHz spectrum. The 11p working group is cooperating with the IEEE 1609 team [11], which develops specifications to cover additional layers in the protocol suite intended for the provisioning of vehicular communications, and they collectively constitutes the WAVE stack. In the IEEE 1609 protocol family, the IEEE 1609.4 is an enhancement of the IEEE 802.11p MAC layer to allow for multi-channel operation [12]. In fact, the WAVE architecture supports one control channel (CCH) reserved for system control and safety messages delivery, and up to six service channels (SCHs) used to exchange non-safety data packets.

Apart from traditional IP (Internet Protocol) transactions, to accommodate high-priority and time-sensitive communications, WAVE also allows for the transmission of proprietary short messages (WAVE short message, WSM) on both CCH and SCH. As an example, beacons and safety messages are expected to be handled as WSMP packets, so that they can be exchanged directly among WAVE devices without the IP overhead.

As shown in Figure 1, the channel time is divided into synchronization intervals with a fixed length of 100 ms, consisting of a CCH interval and a SCH interval, each of 50 ms. According to the multi-channel operation, all vehicular devices have to monitor the CCH during common time intervals (the CCH intervals), and to (optionally) switch to one SCH during the SCH intervals. At the beginning of each interval, a 4 ms-long guard time is set to account for radio switching delay and timing inaccuracies in the devices.

The described operation allows the safety warning messages to be transmitted on CCH, while non-safety data applications may run over SCHs.

Coordination between channels exploits a global time reference, such as the Coordinated Universal Time (UTC), which can be provided by a global navigation satellite system.

The IEEE 802.11p PHY layer is an amended version of the 802.11a specifications, based on OFDM (Orthogonal Frequency-Division Multiplexing), but with 10MHz channels, with data rates ranging from 3 Mbps to 27 Mbps.

The IEEE 802.11p MAC layer has the same core mechanism of the Enhanced Distributed Channel Access (EDCA) specified in 802.11e [10], which is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme. The EDCA mechanism provides differentiated and distributed access to the channel using four different access categories (ACs). For each AC, an EDCA process will be started to contend for transmission opportunities using a set of distinct EDCA parameters, including AIFS (Arbitration Inter-Frame Space) and contention window parameters (CW_{min} and CW_{max}).

To better cope with the fast topology variations of VANETs, the procedure to set up a WAVE Basic Service Set (WBSS) in 802.11p is simplified; active scanning, association and authentication procedures are no longer necessary. To establish a WBSS, a *provider* has to periodically broadcast on the CCH a WBSS announcement message that includes the WAVE Service Advertisement (WSA). WSAs contain all the information identifying the WAVE application and the network parameters necessary to join a WBSS (e.g., the ID of the WBSS, the SCH this WBSS will use, timing information for synchronization purposes). A node should monitor all WSAs on the CCH to learn about the existence and the operational parameters of available WBSSs. After that, the node may join the WBSS by simply switching to the SCH used by this WBSS, on the subsequent SCH interval.

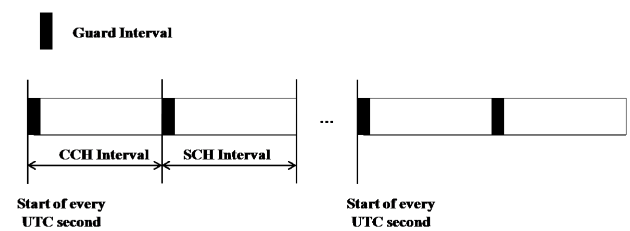

Fig. 1. The WAVE channel switching

B. WAVE multi-channel drawbacks

The main benefit of the IEEE 1609.4 is that it allows multi-radio, and also single-radio, devices to exploit the available channels, by providing access both to safety and non-safety services.

However, channel switching procedures unavoidably lead to some shortcomings.

The straightforward drawback of IEEE 1609.4 is the halved channel capacity: more than half of the bandwidth of service channels cannot be used during the CCH interval, and more than half of the bandwidth of the control channel cannot be used during the SCH interval.

Another shortcoming of WAVE channel switching is the effect of *synchronized frame collisions* at the beginning of a channel interval, as it is referred to in [13]. If an application generates packet regardless of the channel switching procedures, 56% of packets will be generated when they cannot be transmitted. This means that packets intended to be sent on the air during the CCH interval might be generated by the application, and buffered in the MAC queue, during the SCH interval, and vice versa.

Therefore, if several nodes accumulate packets during time interval where they cannot be transmitted, the probability of collisions, immediately following a channel switch, can be much higher than normal.

The probability of collisions after a channel switch increases with the number of devices that are contending for the same medium, especially if the packet generation rate per node is high enough to result in packet queuing actions. This condition will be more likely to occur for non-safety applications on the SCH interval, where vehicles may deal with bulk data transfer (e.g., file sharing).

However, the increase in collision probability upon channel switching could be an issue even if there is only one queued packet per device; this is what typically occurs on the CCH interval, since several devices may have a packet (e.g., beacon, WSA) ready to be transmitted at the beginning of channel interval.

To counteract the effects of syncronized channel switching, the IEEE 1609.4 draft suggests that a packet that is at the head-of-line of a queue at the end of a guard interval will undergo a random back-off before attempting to access the channel. This helps to avoid, but does not prevent, collisions between packets in different devices [12].

Moreover, the probability of having several nodes attempting to transmit at the beginning of the CCH interval can be reduced if the higher layer (i.e., application) becomes *aware* of channel switching and passes packets to the MAC layer only during the interval in which they are intended to be sent.

WAVE channel switching also results in a further negative issue: the *bandwidth wastage* at the end of a given channel interval. If a packet transmission is going to take place (after having waited for an AIFS and an additional backoff), but its estimated transmission delay exceeds the residual channel interval, that transmission would be useless due to the mandatory channel switching. If such an event occurs, the WAVE specifications recommend to postpone transmission to the next synchronization interval and queue the packet in the MAC sub-layer [12]. The missed packet transmission obviously leaves the residual bandwidth unused; we call it *vestigial bandwidth*. In [14] this issue is mitigated through the introduction of fragmentation schemes, which adapt the packet size in order to successfully utilize the residual time of the ongoing channel interval. However, some packets cannot be fragmented, e.g., beacons, WSAs, safety messages, this calling for new techniques to be deployed.

As also underlined in the IEEE 1609.4 draft document [12], broadcast transmissions, which lack of proper acknowledgements and contention window adaptation mechanism, are more prone to the above effects. Therefore, the main purpose of the following study is to show the impact of the above described WAVE shortcomings on a crucial broadcast applications for VANETs, namely beaconing, and to derive some hints for the design of *WAVE-compliant cross-layer* techniques.

The reader should notice that what we investigate for beaconing over the CCH interval, can be also useful for the analysis and design of non-safety applications, since although they are intended to be exchanged on the SCH interval, they may incur in similar channel switching drawbacks.

III. Performance Evaluation

In order to evaluate performance, we use the ns-2 [15] network simulator, that we modified to implement the multi-channel WAVE operational mode. MAC layer parameters are carefully configured according to IEEE 802.11p documents [9], as summarized in Table I. Each simulation lasts 200 seconds; the results are averaged over 20 independent runs.

Specifically, we modeled the behaviour of two kinds of beacon-generating applications: (i) *unaware* applications that pass beacons to the MAC layer in time instants randomly chosen during the Syncronization interval, regardless of the fact that the packet needs to be queued when generated during the SCH interval; (ii) *aware* applications that pass beacons to the MAC layer only on instants randomly chosen during the CCH interval, where they are intended to be actually transmitted.

The performance of beaconing has been assessed through the packet delivery ratio and the average access delay. The latter metric is the time spent in accessing the channel; it accounts for contention delay during the CCH interval and queuing delay during the SCH interval. In addition, to quantify the occurrence of *vestigial bandwidth* events, we compute the average percentage of packets which incur in this problem in proximity of the end of CCH interval.

To better track the successful delivery of beacons, we consider an idealistic scenario where nodes are in reciprocal radio coverage, and each of them has a beacon packet to transmit. The beacon generation frequency is set equal to 5 Hz and the beacon packet size equal to 500 bytes; this is a reasonable assumption, since a beacon typically includes a security-related overhead (signature plus a certificate) which has a maximum length of 300 bytes [16].

Since 802.11p/WAVE only mandates the use of the highest priority access category for safety packets, it will be expected that beacons use a lower priority. Thus, in this study, we vary the beacon access category between AC0, AC1 and AC2, by reserving the highest priority (AC3) to safety messages. AC parameters are reported in Table II.

Figures 2, 3, 4 compare the performances of aware and unaware beaconing applications for various ACs. We assume that beacons are transmitted at the basic data rate conceived by 802.11p, that is 3 Mbps. By looking at Figure 2 we can observe that, as expected, the use of the lowest priority (AC0), which provides for the largest contention window, leads to the highest packet delivery ratio, since the better time diversity in transmission attempts allows to strongly reduce collisions. However, this is achieved at the expense of an higher access delay in Figure 3. Such a trend is noticed for both aware and unaware beaconing.

As we can observe, whatever is the priority assigned to beacons, aware beaconing allows to achieve higher reliability and shorter delay as compared to unaware beaconing. In fact, the lack of coordination between WAVE devices and higher-layer operations exacerbates the congestion phenomenon for unaware applications, since additional packet collisions occur due to synchronized transmissions immediately following a channel switch.

Surprisingly, for large values of contention window as the number of nodes increases the differences between aware and unaware applications are smaller than for short contention windows. Specifically, if the contention window is large then there is a small difference between aware and unaware cases for a high number of nodes; if the contention window is small then the difference between aware and unaware cases is still large even for a high number of nodes (although smaller than for few nodes).

The reason for that lies in the fact that, being the beacon generation events all concentrated during the CCH interval and due to the large contention window, it will be more likely that several nodes attempt to transmit their beacon (after the backoff) near the end of the CCH interval incurring in a packet queuing action.

TABLE I
MAC PARAMETERS

Parameter	Value
Slot time	13 μs
SIFS time	32 μs
Header duration	40 μs
Packet size	500 byte

TABLE II
802.11P EDCA PARAMETER SET

Access Category	Contention Window	AIFSN
AC0	31	9
AC1	15	6
AC2	7	3
AC3	7	2

In fact, as shown in Figure 4, the percentage of *vestigial bandwidth events* for aware beaconing is not negligible and it significantly increases with the number of nodes deployed in the system. Such events are also responsible for the increasing access delay, which mainly accounts for the contention experienced at the beginning of the CCH interval by a large number of packets that were enqueued at the end of the previous CCH interval.

Such findings suggest that to design aware beaconing applications cannot be enough to cope with the shortcomings of the WAVE channel switching. In fact, although synchronized frame collisions can be reduced, the vestigial bandwidth unavoidably results in packet queuing at the end of the CCH interval, which on its turn leads to collisions at the beginning of the subsequent CCH interval.

As a further step, we repeat our study when considering 6 Mbps as transmission data rate for beacons. Figures 5 and 6 show that higher transmission rates lead to improved channel utilization, resulting in higher packet delivery ratio and shorter channel access delay, for both aware and unaware beaconing. However, we can notice that aware beaconing benefits of higher improvements both in terms of higher packet delivery and reduced delay, as compared to unaware beaconing. This confirming that synchronized collision events at the start of the CCH interval are the main reasons of the poor performances of unaware beaconing.

Furthermore, by looking at Figure 7 we can observe that shorter transmission times also allow the occurrence of vestigial bandwidth events to be reduced.

Although it seems tempting to increase the beacon transmission data rate, it should be mentioned that to increase the data rate of broadcast transmissions may have a negative impact on the probability of correct reception, since higher data rates are more prone to bit errors.

IV. CONCLUSION AND FUTURE WORKS

In this paper the main design issues related to beaconing in 802.11p/WAVE-based vehicular ad hoc networks have been investigated.

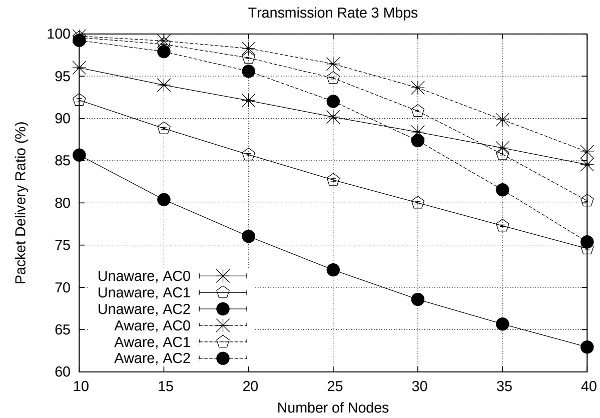

Fig. 2. Packet delivery ratio, data rate 3 Mbps

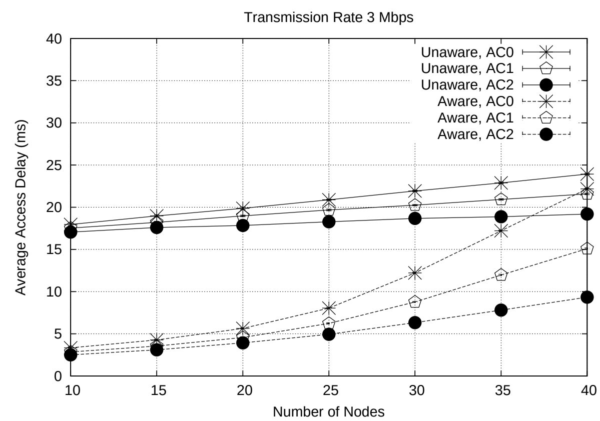

Fig. 3. Average access delay, data rate 3 Mbps

The main lesson we can draw from the conducted analysis is that, besides well-known collision events and contention, which affect the reliability of broadcast transmissions under high traffic load conditions, WAVE channel switching poses new issues: (i) synchronized frame collisions at the beginning of CCH interval; (ii) wasted bandwidth at the end of CCH interval resulting, on its turn, in packets queued at the end of the CCH interval. While the first issue can be reduced by letting the application exposed to the channel switching, the

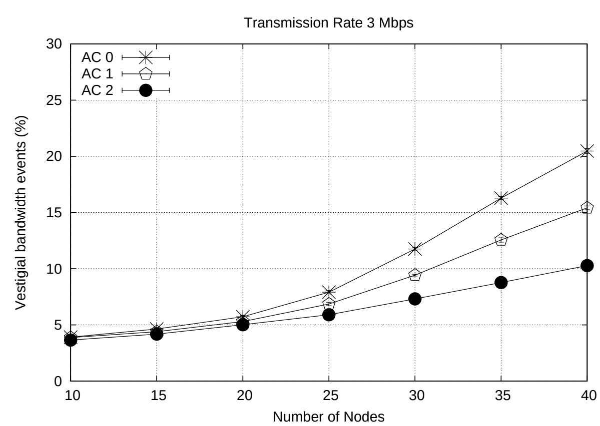

Fig. 4. Percentage of *vestigial bandwidth events* for aware beaconing, data rate 3 Mbps

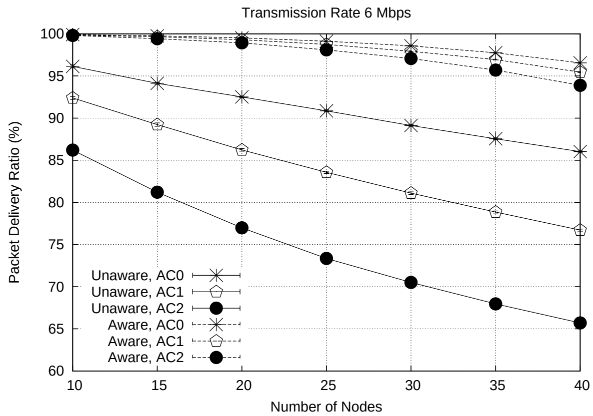

Fig. 5. Packet delivery ratio, data rate 6 Mbps

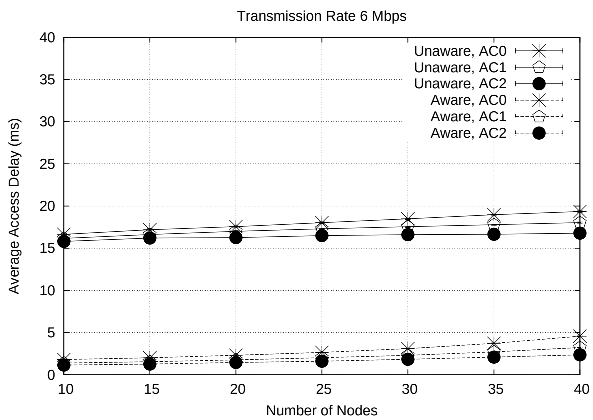

Fig. 6. Average access delay, data rate 6 Mbps

second one affects also aware applications.

Larger contention window and higher data rate help in improving beaconing delivery, however this may be achieved only at the expense of an increased channel access delay and a reduced useful transmission range, respectively.

New techniques which couple awareness with respect to channel switching and to CCH interval residual time with the dynamic tuning of contention window, data rate, or equivalently packet size, are strongly recommended to ensure the reliability of broadcast transmissions (e.g., beacons) and a better use of channel capacity.

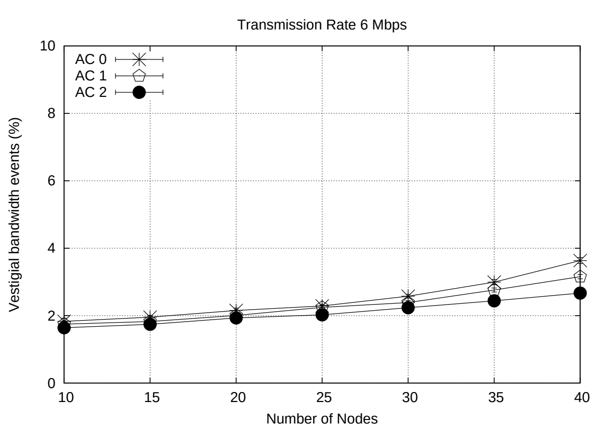

Fig. 7. Percentage of *vestigial bandwidth events* for aware beaconing, data rate 6 Mbps

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