A Dynamic Transmission Opportunity Allocation Scheme to Improve Service Quality of Vehicle-to-Vehicle Non-Safety Applications

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***Abstract*— Similar to IEEE 802.11e, the Wireless Access for Vehicular Environment (WAVE) uses the Enhanced Distributed Channel Access (EDCA) to provide service differentiation. Nevertheless, WAVE does not make use of the transmission opportunity (TXOP) parameter, i.e., only one packet can be transmitted per channel access. This fits well most safety applications as they usually transmit individual short messages. Yet, non-safety applications can witness a decline in their performance as they often transmit multiple long messages. In this paper, we propose an innovative scheme, called DTAS, that dynamically assigns TXOP limits to vehicles to improve non-safety applications' efficiency. DTAS targets vehicle-to-vehicle (V2V) communications and updates periodically its functionality to reflect changes in both network circumstances and mobility pattern between vehicles. To the best of our knowledge, no existing work has proposed something similar for V2V non-safety applications. Simulation results demonstrate that DTAS generates higher throughput compared to the conventional IEEE 802.11p.**

I. INTRODUCTION

Vehicular ad-hoc network (VANET) is considered as a key enabling technology for Intelligent Transportation Systems (ITS). It accommodates two types of communications, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I), allowing for the support of different applications (i.e., safety and non-safety applications). With the expansion of mobile experience everywhere, researchers have started focusing on non-safety applications (e.g., traffic management, location-based service advertisement, Internet access and media sharing) to make VANET lucrative and more business appealing, accelerating therefore its deployment. These applications aim at making passengers' journey entertaining and comfortable. Most of them have stringent requirements in terms of delay and throughput. However, meeting these needs is not straightforward given VANET characteristics (e.g., high mobility, intermittent connectivity and channel fading).

In order to cope with these challenges, the WAVE [1] framework was released. It operates on the Dedicated Short Range Communication (DSRC) band, a 75 MHz licensed spectrum in the 5.9 GHz band [2], that is partitioned into seven 10 MHz channels: one is referred to as the control channel (CCH) and is dedicated exclusively for safety and control messages transmission; the remaining channels are referred to as service channels (SCH) and are used to transmit data packets of non-safety applications. WAVE deploys the IEEE 802.11p [3] standard, a modified version of the legacy IEEE 802.11, at the physical and MAC layers and makes use of the IEEE 1609.4 [4] to enable coordination between CCH and SCHs. Indeed, based on the Coordinated Universal Time (UTC), each second is divided into 10 synchronization intervals (SI). Each SI consists of one CCH interval (CCHI) followed by one SCH interval (SCHI). Vehicles are compelled to monitor CCH during CCHI not to miss safety messages and can switch to one of SCHs to exchange non-safety data messages.

WAVE enables non-safety data messages to be transmitted within WAVE Basic Service Sets (WBSS), which are akin to BSS in legacy IEEE 802.11 without the need for authentication and association procedures. WBSS can be established by any WAVE device [2], [5], (i.e., RSU or OBU), and can be of two types: 1) persistent: WBSS is announced at every CCHI during the WBSS lifetime; and 2) non-persistent: WBSS is announced only when it is established [6]. A vehicle with data packets to transmit, labeled *provider*, starts establishing WBSS by broadcasting a Wave Service Advertisement (WSA) message during CCHI. WSA contains the provider's identifier, a description of the service provided and the service channel to be used [7]. When receiving WSA, vehicles interested in the service, labeled *users*, will join WBSS. Both users and the provider will switch to the advertised SCH at the start of the subsequent SCHI. The provider will then initiate data packet transmission.

IEEE 802.11p uses the Enhanced Distributed Channel Access (EDCA) mechanism to provide service differentiation. It defines four access categories (ACs) (i.e., AC_{BK}, AC_{BE}, AC_{VI} and AC_{VO}), each having its own parameter list: arbitration inter-frame space (AIFSN), minimum contention window (CW_{minc}), maximum contention windows (CW_{max}), and transmission opportunity (TXOP). TXOP is defined as the time interval during which providers can send one or multiple consecutive frames when accessing the channel. It can be regarded as the maximum time a provider is allowed to hold the channel after winning a contention. According to the IEEE 802.11p standard, each AC is allowed to transmit only one packet per channel access, (i.e., TXOP = 0). This suits perfectly safety applications as they usually transmit individual small-size messages. Yet, given that non-safety applications generate multiple large-size packets, this can lead to inefficient channel utilization, hindering therefore their performance.

In [8], we studied the impact of considering TXOP on the throughput of non-safety applications. We simulated a highway segment where an RSU is placed at its center and vehicles passing by contend to transmit fixed-size UDP packet. We fixed TXOP values for AC_{VI} and AC_{VO} to 3.008 ms and 1.504 ms respectively, according to the IEEE 802.11e standard [9]. Simulation results showed that using TXOP generated higher throughput for both ACs compared to the conventional IEEE 802.11p standard. Still, we believe that by dynamically allocating TXOP values according to traffic conditions, we can improve further the performance of V2V non-safety applications. Little work to date has been done in this regard. Indeed, the work proposed by Harigovirdan et al. [10] is the only study that we could find in the literature. They proposed a stochastic model for tuning TXOP limits according to vehicles' speed to provide bit-based fairness for vehicles with high velocities when trying to communicate with nearby RSUs. Nevertheless, the model is based on the Distributed Coordination Function (DCF), which does not support service differentiation.

In this paper, we propose a novel approach, called DTAS, that allows providers to dynamically adjust TXOP limits considering links lifetime, number of packets to be transmitted and number of contending providers in their vicinities. This is to enable prioritisation of real-time non-safety applications (e.g., video streaming, VoIP) with respect to best-effort and background applications (e.g., location-based service advertisements).

The rest of this paper is organized as follows. Section II describes the network model. Section III presents our proposed approach. Section IV describes simulation settings and results, while Section V concludes the paper.

II. Network Model

In this paper, we are interested in situations where vehicles can provide services for other vehicles in the absence of road side units (RSU). For instance, vehicles with 4G/LTE connections can supply their neighbors (i.e. without 4G/LTE connection) with traffic information and/or weather conditions [7]. In addition, nearby vehicles can share multimedia files (e.g., music, movies) to make passengers' journey more enjoyable. Such a capability is crucial for highway scenarios to avoid the often very high costs of RSU deployments.

The network considered consists of a multi-lane highway segment with obstacles (e.g., houses and trees) on its sides, as illustrated in Figure 1. Vehicles arrive at the starting point of the highway segment following a Poisson process, with an average rate of α_a. They travel with different speeds, uniformly distributed between V_{min} and V_{max}. Vehicles are equipped with single WAVE transceivers to enable V2V communications. Beacon messages are generated at a rate of α_b, enabling vehicles to transmit information regarding speed and location. We adopt the alternating access mode,(i.e. CCHI followed by SCHI), to enable coexistence between safety and non-safety applications. We assume that providers support only one traffic type (i.e., they have packets for only one AC); hence, internal collisions are not considered

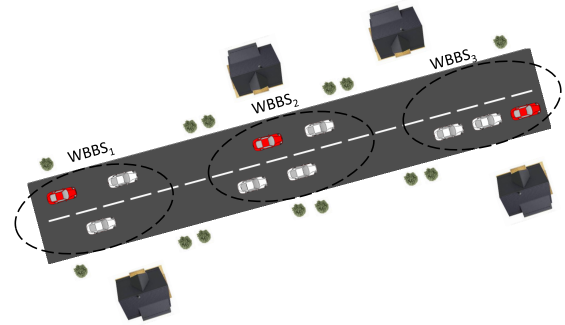


Fig. 1. Network model.

in this work. A provider P_i, with $i = \{0, 1, 2, 3\}$ denoting its service priority (i.e., 3 having the highest priority), will contend for the channel only if they have packets to transmit; otherwise, they keep silent. We assume that fragmentation is not deployed at the MAC layer and we use channel 176 to transmit data packets. We set channel 174 as the default service channel for vehicles that did not join any WBSS. In this way, we can only focus on the impact of TXOP allocation on the performance of V2V non-safety applications.

III. Dynamic TXOP Allocation Scheme (DTAS)

In this section, we describe our DTAS scheme, proposed to enhance the performance of V2V non-safety applications. DTAS has two procedures: link lifetime estimation and dynamic TXOP allocation. They are described in details in the following subsections.

A. Link Lifetime Estimation

Since association is not required for WBSS establishment, providers have no means of identifying interested users. To mitigate this issue, several handshake mechanisms [11]–[16] have been proposed. They can be carried over either CCH or SCH. Yet, most of these schemes incur high signaling overhead. While handshakes carried over CCH (e.g., [11]–[13]) can reduce the transmission opportunities of safety messages, those carried over SCHs (e.g., [14]–[16]) can cause inefficient service channel utilization, deteriorating therefore the performance of non-safety applications.

In order to enable providers to identify potential users, we make use of beacon messages, which are considered as a key element of VANET. Vehicles exchange beacon messages to acquire information regarding their neighboring vehicles (e.g., speed, position and direction).Apart from this information, we added a new 8-bit field, labeled *providerID*, to permit vehicles to show their interest in joining a particular WBSS. Indeed, when receiving WSA messages, users first set the *providerID* field in their beacon messages to the identifier of the provider offering the service in which they are interested; then, they broadcast these messages. Note that for this mechanism to operate properly, WSA messages have to be transmitted before beacon messages. Thus, we assigned them higher priority.

When receiving beacon messages, providers construct user tables (UT). UTs have four fields: user identifier, user position, user speed, and link lifetime (LLT) which estimates the time to elapse before a disconnection occurs and is computed as follows.

Let S_u be the set of P_i's users, with $U_j \in S_u$. Let V_{P_i} and V_{U_j} be the speeds of P_i and U_j, respectively. In case P_i is in front of U_j, we have:

$$LLT_{i,j} = \begin{cases} \frac{R-d}{V_{U_j}-V_{P_i}}, & \text{if } V_{P_i} > V_{U_j} \\ \frac{R+d}{V_{P_i}-V_{U_j}}, & \text{if } V_{P_i} < V_{U_j} \end{cases} \quad (1)$$

In case P_i is behind U_j, we have:

$$LLT_{i,j} = \begin{cases} \frac{R+d}{V_{U_j}-V_{P_i}}, & \text{if } V_{P_i} > V_{U_j} \\ \frac{R-d}{V_{P_i}-V_{U_j}}, & \text{if } V_{P_i} < V_{U_j} \end{cases} \quad (2)$$

where *R* is the transmission range and *d* is the distance between P_i and U_j. UTs are updated after every beacon interval to reflect changes in speed, position and eventually LLT.

B. Dynamic TXOP Allocation

Vehicles maintain occupancy tables (OT) to keep track of providers in their vicinities. OTs have three fields: provider identifier, provider priority and provider TXOP. They are updated when receiving WSA messages or periodically via beacon messages (i.e., to reflect changes in TXOP or to indicate WBSS termination). Once P_i establishes its WBSS, it checks whether all of its users can benefit from the service. Indeed, it computes the service completion time, T_{sc}, as follows:

$$T_{sc} = \frac{NL}{r} \quad (3)$$

where N and L are the number of packets to be transmitted and size of each packet, respectively, and r designates the data rate. P_i then computes the service period (T_{sp}), defined as the maximum time during which all P_i's users can benefit from the service. Let $B_{S_u} = \{LLT_1, ..., LLT_m\}$ with $m = |S_u|$ be the set of the estimated link lifetimes for P_i's users. T_{sp} can be expressed as:

$$T_{sp} = \frac{min(B_{S_u})}{2} \quad (4)$$

The minimum link lifetime is divided by 2 to account for the time that P_i and its users need to spend over CCH.

Next, P_i compares T_{sc} to T_{sp}. If $T_{sc} > T_{sp}$, P_i broadcasts a *PARSERV* message, just after switching to SCH, to inform the user with the shortest link lifetime that it cannot get the full service. This latter will leave WBSS and try a different provider as we believe that partial services are useless. P_i updates its UT and selects a new T_{sp} as per Equation (4). Note that by notifying users of the possibility of getting incomplete services, we can prevent users' disappointment. This is to avoid situations where unsatisfied users may mark their providers as unreliable and might decide not to join any of their WBSS in the future.

In case $T_{sc} < T_{sp}$, P_i computes its TXOP limit. To do so, it checks its OT. If it is empty, (i.e. there is no other provider in its vicinity), P_i is entitled to use SCH alone and therefore, sets its TXOP limit to the entire SCHI. The rational behind this is twofold: 1) we assume that all users are eager to benefit from the provided services and want to be served as soon as possible; and 2) by allowing P_i to transmit its packets faster, we make the service channel quickly available to be used by new providers .

In case OT is not empty, P_i classifies the existing providers according to their service priority. Let n denotes the number of providers having similar service priority as P_i and let n' designates the number of providers having different service priorities. In this paper, we mainly focus on services with priority 2 and 3 (i.e., AC_{VI} and AC_{VO}, respectively). Then, P_i sets its TXOP limit as follows:

$$TXOP_k = min\left(SCHI, \frac{L(N-N')A}{\rho r}\right) \quad (5)$$

where k represents the k^{th} SCH interval while N' designates the number of successfully transmitted packets. ρ is the number of SCH intervals in T_{sp} and is expressed as follows:

$$\rho = \left\lfloor \frac{T_{sp}}{SCHI} \right\rfloor \quad (6)$$

while A is expressed as follows:

$$A = \begin{cases} i=3 \begin{cases} 1+\dfrac{1}{\beta n + n'}, & \text{if } k=1 \\ 1+\dfrac{1}{\beta\left(\dfrac{n_k}{n_{k-1}}\right)+\left(\dfrac{n'_k}{n'_{k-1}}\right)}, & \text{otherwise;} \end{cases} \\ i=2 \begin{cases} 1+\dfrac{1}{n + \beta n'}, & \text{if } k=1 \\ 1+\dfrac{1}{\left(\dfrac{n_k}{n_{k-1}}\right)+\beta\left(\dfrac{n'_k}{n'_{k-1}}\right)}, & \text{otherwise;} \end{cases} \end{cases} \quad (7)$$

$\beta \in (0, 1]$ is a tuning parameter that allows for the adjustment of DTAS aggressiveness. This is because providers of different service priorities do not have the same probability of accessing the channel due to differences in EDCA parameters. For instance, if P_i has a service priority $i = 3$, more weight is given to providers with the same service priority, whereas if P_i has a service priority $i = 2$, more weight is given to providers with higher service priority. The ratios n_k/n_{k-1} and n'_k/n'_{k-1} in Equation (7) account for the dynamic changes in the number of contending providers and are included to allow for prompt TXOP adaptation in case of new traffic load situation or WBSS termination.

Observe that the first term of Equation (5) accounts for the average TXOP limit allocated for P_i in each SCHI to meet the service time constraint (i.e.,T_{sp}). This implies that when accessing the channel during a high contention period, providers should be able to transmit as many packets as they can. Observe also that when vehicles are assumed to move with the same speed, TXOP limit is expressed in terms of the number of packets to be transmitted and the number of contending providers. Consequently, by removing ρ only, Equation (5) can be easily adapted to such a scenario .

Once TXOP is computed, P_i piggybacks it into its beacon message. This is to inform nodes, including providers, about how long they should abstain from accessing the channel when P_i gets hold of it. When all data packets are transmitted, P_i terminates its WBSS. To quickly notify their users about WBSS termination, providers use the mechanism described in [7], which consists of adding a T-bit flag to beacon messages. Indeed, when P_i terminates its WBSS, it sets T-bit flag to 1. When received, nodes, including P_i's users, can update their OTs by deleting P_i's entry (i.e., P_i's users will switch back to SCH 174). This can help reduce the waiting time to access the channel for other providers and can assist them in adjusting their TXOP limits accordingly.

IV. Performance Evaluation

In this section, we present a simulation-based evaluation of DTAS, which is compared to FTXOP, denoting the IEEE 802.11p standard with fixed TXOP values set according to IEEE 802.11e, and NTXOP, designating the conventional IEEE 802.11p standard (i.e., no TXOP).

A. Simulation Settings

We have implemented DTAS and FTXOP using OMNET++ [17] and Veins [18] based on the IEEE 802.11p (i.e., NTXOP) in [18]. Substantial changes at the physical and MAC layers were made to accommodate for TXOP inclusion. We deployed SUMO [19] to generate realistic mobility traces for our VANET scenario. The simulation setup is a 4000 meters one-direction highway segment with two lanes. Vehicle speed is uniformly distributed between 80 and 120 km/h, which is typical for a highway scenario. The Nakagami-m propagation model was adopted with the fading factor m set to 1.5 for short distances between transmitters and receivers ($d \leq 80$) and 0.5 for longer distances ($d > 80$) [17]. Other simulation parameters are listed in Table I.

In our simulation, providers contend to transmit fixed-size UDP packets. These providers are randomly selected and their service type (i. e. AC_3 or AC_2) is arbitrarily chosen once they traveled 500 meters. When receiving WSA, vehicles decide at random whether to join WBSS or not. Once SCHI starts, providers start transmitting their data packets. Two metrics were used to assess the performance of these schemes:

- Average throughput: the number of data bits transmitted over a time period.
- Number of incomplete services (NIS): the number of services that were not completed successfully (i.e., all packets were received by users before T_{sp} expires).

B. Simulation Results and Analysis

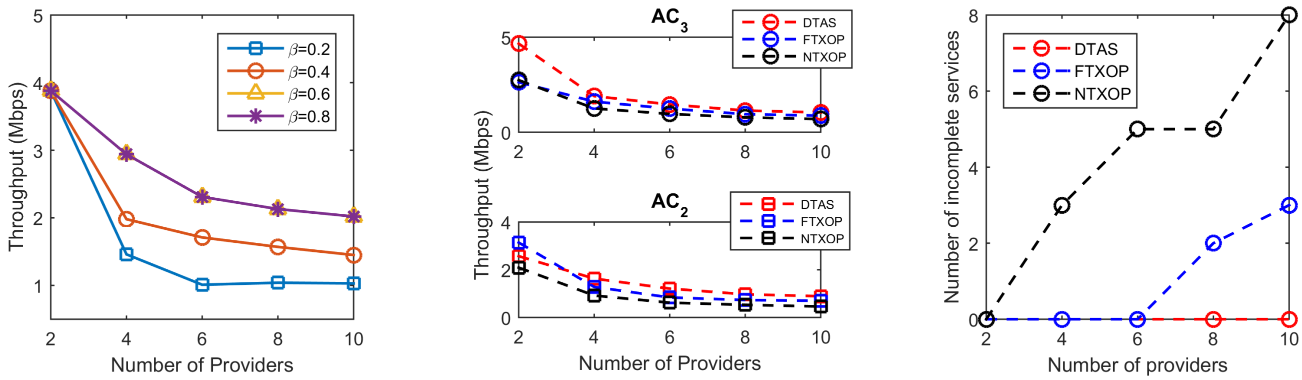
Fig. 2(a) depicts the average throughput for AC_3 for different values of β as a function of the number of providers in the network. Fig. 2(a) shows that the throughput recorded for all β values decreases with the increase of the number of providers. This is mainly because providers contend continuously for the channel to transmit their packets. Fig. 2(a) shows also that DTAS generates the highest throughput for AC_3 when $\beta = \{0.6, 0.8\}$. The same values generate the highest throughput for AC_2 as well, but due to space constraint, results were omitted. Therefore, in the subsequent simulations, we set β to 0.8.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Frequency	5.9 GHz
Data rate	6 Mbps
Vehicles arrival rate	1 vehicle/s
λ_b	10 beacons/s
Packet size (Bytes)	512
Header size (Bits)	80
Transmission power	20 mW
Beacon and WSA priorities	1,3
CCHI, SCHI	50 ms
$N_{AC_2} = N_{AC_3}$	1200

Fig. 2(b) shows the average throughput with respect to the number of providers in the network. In our simulations, traffic types are divided evenly among providers (i.e., up to 5 providers have AC_3 traffic while the remaining providers have AC_2 traffic). We observe that the throughput of all schemes decreases and has the tendency to stabilize as the providers' density increases. NTXOP generates the lowest throughput for both AC_2 and AC_3 as it allows ACs to transmit only one packet per channel access, which generates high contention periods that might lead to packet loss. DTAS achieves the highest throughput for both AC_2 and AC_3. For instance, when the number of providers in the network is set to 10, DTAS generates a throughput that is 20% and 27% higher than FTXOP for AC_3 and AC_2, respectively. The reason is twofold: 1) unlike FTXOP, DTAS considers the link lifetime between providers and their users as well as the number of contending providers, and adapts rapidly TXOP limits to reflect network conditions changes; and 2) by considering the number of packets to be transmitted when computing TXOP, DTAS mitigates the problem of assigning a large TXOP to providers that would not use it entirely, enabling better channel utilization.

Fig. 2(c) shows NIS as a function of the number of providers in the network. We observe that except for DTAS, NIS of all schemes increases with the increase in the number of providers. As expected, NTXOP generates the highest NIS since it does not support TXOP. FTXOP incurs a higher NIS compared to DTAS. For instance, in a network with 10 providers, the number of incomplete services for FTXOP is 3 while the number of incomplete services for DTAS is 0. This is because: 1) by estimating the transmission time and comparing it to the link lifetime, DTAS discards users that would not receive the entire service; and 2) by periodically adjusting TXOP, DTAS strives to complete services within their time constraint (T_{sp}). Note that DTAS might generate NIS > 0 when the number of providers is very high. Indeed, accessing the channel is dependent on $AIFS$ and CW_{min}.



(a) (b) (c)

Fig. 2. Simulation results as a function of the number of providers in the network. (a) β; (b) throughput; and (c) NIS.

This may deprive low priority providers from accessing the channel for entire SCHIs during high contention periods. Therefore, we believe that NIS can only be optimized by combining TXOP with adaptive schemes for other EDCA parameters (e.g., CW_{min}).

V. Conclusion

In this paper, we propose DTAS, a dynamic TXOP allocation scheme that enhances service quality of V2V non-safety applications. First, it describes a beacon-based mechanism that helps providers identify potential users before switching to the service channel. Then, it computes TXOP limits considering various aspects such as the number of packets to be transmitted, link lifetime between providers and their users, and number of contending providers in the vicinity. TXOP values are piggybacked in beacon messages to inform nearby providers about the time during which they need to refrain from contending for the channel.

Simulation results show that DTAS outperforms the legacy IEEE 802.11p standard in terms of throughput. For future work, we will examine the performance of DTAS in scenarios where traffic loads have different characteristics (e.g., number of packet to transmit, size of packets). We are also planning to study the performance of DTAS when combined with other EDCA parameters, as mentioned in Section IV.

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