Application-Based Congestion Control Policy for the Communication Channel in VANETs

Miguel Sepulcre, Javier Gozalvez, Jérôme Härri, and Hannes Hartenstein

Abstract—**This letter proposes a novel proactive congestion control policy for vehicular ad-hoc networks, in which each vehicle's communication parameters are adapted based on their individual application requirements. Contrary to other approaches, where transmission resources tend to be assigned based on system-level performance metrics, the technique proposed in this paper aims to individually satisfy the target application performance of each vehicle, while globally minimising the channel load to prevent channel congestion.**

Index Terms—**Congestion control, VANETs, cooperative road safety applications, intelligent transportation systems.**

I. Introduction

VEHICULAR Ad-hoc Networks (VANETs) are expected to play an important role in the future improvement of road safety and efficiency through the real time exchange of information among vehicles and among vehicles and Road Side Units (RSUs). Based on the IEEE 802.11p technology at the 5.9GHz band [1], all vehicles and RSUs periodically broadcast 1-hop CAMs (Cooperative Awareness Messages) on the so called control channel, to provide and receive information about presence, movement and service announcements to/from neighbouring nodes [2]. The periodic exchange of CAMs would help each vehicle to support higher layer protocols, and cooperative applications, including road safety applications.

Given its reference status, the control channel can easily get congested, and thus congestion control protocols need to be applied to ensure its efficient operation. A significant portion of the control channel is likely to be occupied by CAMs, since they are periodically transmitted by all vehicles. As a result, many congestion control protocols focus on the dynamic adaptation of the transmission parameters of CAMs. Some of them propose the transmission power adaptation to fairly distribute the available bandwidth [3] or to control the number of neighbouring vehicles [4]. Other approaches demonstrate the benefits of assigning a different priority or bandwidth to vehicles with diverse operating conditions. The work in [5] proposes that each vehicle modifies its transmission parameters based on its own speed to reduce the global generated interference. Other studies like [6] propose the use of application-specific utility functions to adapt the channel access priority of each vehicle. However, the specific performance requirements imposed by CAM-based cooperative road safety applications are not considered. The transmission range and packet transmission rate requirements of these applications to warn the driver with enough time to react and avoid potential dangerous situations should be taken into account, since considering only the individual vehicle's speed does not take into account the relations between vehicles, which can be crucial for VANETs.

The need of taking into account the application requirements can be illustrated through the comparison of two different applications with the same speed for a given vehicle. For example, let's consider the lane change assistance application and the overtaking of a vehicle moving at $100km/h$ by another vehicle moving at $120km/h$. To avoid an accident if the vehicle moving at $100km/h$ starts a lane change manoeuvre, the two vehicles should communicate at a given distance, considering that the relative speed between the two vehicles is only $20km/h$. Now, let's consider a head-on-collision warning application where a vehicle moving at $100km/h$ starts an overtaking manoeuvre in a road with two lanes of opposite direction, and in the opposite direction there is another vehicle moving at $100km/h$. In this case, their relative speed is higher and so is the distance at which the two vehicles need to communicate to avoid the accident, which shows their different communication requirements, and the need of considering the applications in the transmission parameters adaptation.

In this context, this letter proposes a new proactive congestion control policy based on application requirements. The proposed policy aims to globally minimise the channel load generated to prevent channel congestion, while individually satisfying the target application requirements of each vehicle. To evaluate the proposed policy, traffic safety applications are considered due to their strict requirements, but it could be extended to e.g. traffic management applications.

II. Application-Based Congestion Control Policy

The proposed policy is based on the continuous adaptation of each vehicle's application requirements that could depend on its operating and driving conditions, such as the D_w Warning Distance. D_w represents the minimum distance at which two vehicles need to communicate to avoid a dangerous situation, and depends on the considered application and operating parameters such as the vehicle's speed. Once the D_w distance has been updated, each vehicle accordingly adapts its communications parameters so that at least one message can be received at D_w with certain reliability imposed by the application. Following the proposed policy, it is the transmitter's

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responsibility to adapt its transmission parameters so that those vehicles that might require its positioning information are able to receive it with enough distance to react and avoid dangerous situations. It is the receiver's responsibility to distinguish the relevant vehicles for the different applications.

With the proposed policy, the same application reliability can be provided to all vehicles, independently of their position, speed or traffic context. This approach differs from congestion control protocols based on the experienced channel load, which tend to assign similar transmission parameters to close vehicles, irrespective of their operating and driving conditions. This could be critical when there is a traffic jam in one direction of a highway, but free flow conditions in the other direction. The proposed approach differs from other per-vehicle or per-application congestion control policies in that the application requirements are satisfied considering the transmission range and packet transmission rate requirements needed to provide the driver with enough time to react and avoid potential dangerous situations. This is especially needed for safety applications given their critical nature.

III. Applications and Performance Metrics

To illustrate the proposed policy, the lane change assistance application has been considered, and its specific application requirements have been identified. This application informs the driver about whether a potential lane change manoeuvre can be performed in a safe way or not based on positioning and movement information received from surrounding vehicles through periodic CAMs. For example, following the illustration in Fig. 1, vehicle A would consider its lane change as unsafe if another vehicle B is approaching on the left lane and they are closer than a certain distance D_w. In this case, D_w represents the minimum distance between the two vehicles allowing vehicle A to change the lane without making vehicle B reduce its speed, and can be computed as:

$$D_w = -\frac{1}{2}\frac{(v_A - v_B)^2}{a_B - a_A} + L + D_s \qquad (1)$$

where v_A and v_B represent the vehicles speed in m/s, a_A and a_B their acceleration in m/s^2, L is the vehicle length in m, and D_s is the safety distance. D_w represents the application requirement, and the minimum distance at which the vehicles need to exchange at least one CAM to alert of each other's presence before considering the possibility to start a lane change manoeuvre[1]. It is important to note that neither of the two vehicles knows the speed of the other vehicle before receiving its first CAM. Consequently, they need to assume the worst case scenario in terms of speed to calculate their respective D_w. This corresponds to vehicle A calculating D_{wA} considering its real speed and that vehicle B is moving at the maximum speed allowed in the road ($v_B = v_{max}$), and vehicle B computing D_{wB} considering its real speed and vehicle A's speed as the minimum speed allowed in the road ($v_A = v_{min}$). Consequently, D_{wA} and D_{wB} can considerably differ, which highlights their different requirements. Vehicles with a speed outside the (v_{min}, v_{max}) limits would trigger a special application to warn about their abnormal state. Since only a few vehicles would be driving with a speed outside the limits, this results in a more efficient use of the radio channel than considering all vehicles calculating D_w based on speeds higher than v_{max} or lower than v_{min}. Considering a worst case scenario, D_s has been fixed to 30m, and $L = 4m$.

[1]The analysis of different particularities in the D_w calculation, such as the case in which $a_B = a_A$, have not been included in this letter to focus on the general aim and benefits of the proposed policy.

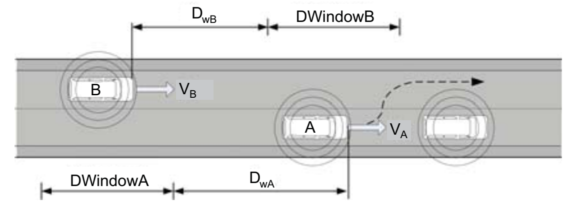

Fig. 1. Performance metrics for the Lane Change Assistance application.

In addition to the application requirement, D_w, an application reliability metric (p_{app}) needs to be defined, which in this case is equivalent to the probability of receiving at least one CAM before D_w. However, receiving a CAM at a distance slightly larger than D_w, and receiving it at a distance much larger than D_w produce the same application reliability. The p_{app} metric has been then confined to the probability of receiving at least one CAM before D_w in a given time window $TWindow$ (see Fig. 1, where $TWindow$ is mapped to the $DWindow$ distance according to the vehicle's speed); this metric contextualises the application reliability concept defined in [7] to the specific requirements of cooperative applications.

IV. Simulation Results

To illustrate the policy operation, a highway scenario with 6 lanes, 3 in each direction, with average vehicle densities of $\rho_1 = 30$, $\rho_2 = 15$ and $\rho_3 = 10$ vehicles/km/lane has been investigated with the network simulator ns2. In this general highway scenario, all vehicles are moving at the defined boundary speed limits ($v_{min} = 60km/h$ and $v_{max} = 120km/h$), considering a constant speed mobility model to produce potential dangerous lane change situations and constantly require the highest D_w, which corresponds to the worst case scenario in terms of transmission power requirements and channel load. The total duration of the conducted simulation has been 400s with confidence intervals below 5% for all the obtained results. CAMs are transmitted using the 6Mbps transmission mode with the transmission power and packet rate defined by the proposed policy.

Fig. 2 illustrates the combination of power and packet rate that allow meeting the application requirements (D_w) with the target reliability ($p_{app} = 0.99$ in this letter) for different $TWindows$ and payloads. For a given packet transmission rate and $TWindow$, the transmission power required to satisfy the application reliability at the D_w distance has been obtained following the work in [8]. The work reported in [8] calculates the minimum transmission power required to successfully exchange at least one message with p_{app} probability at a given distance, taking into account the propagation effects, and a compensation policy based on the increment of the transmission power to combat the negative effects of packet

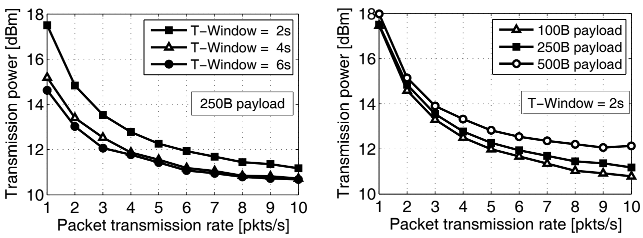

Fig. 2. CAM communications configuration that satisfies the application requirements with the target reliability (D_w and $p_{app} = 0.99$), for $\rho_2 = 15$.

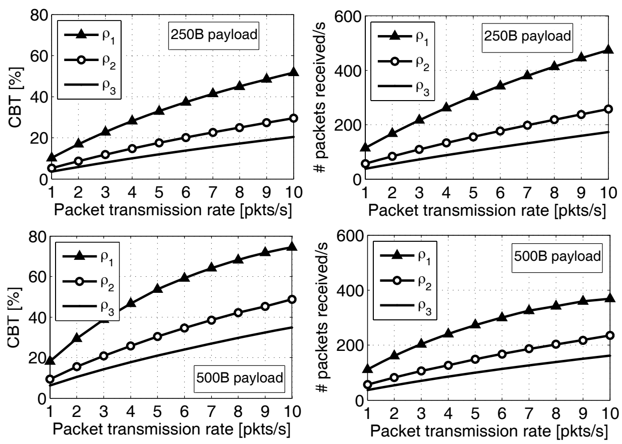

Fig. 3. Channel busy time (CBT) and number of packets correctly received per second for the CAM configurations that satisfy the application requirements with the target reliability (D_w, $p_{app} = 0.99$), considering $TWindow = 2s$ and varying vehicular density ρ.

collisions on the packet reception probability. The depicted results have been obtained considering the Nakagami radio model proposed for highway scenarios, with $m = 3$ [3]. As shown in Fig. 2, when increasing the packet rate, the transmission power can be decreased to maintain the same application reliability. It is then necessary to investigate the optimum communication settings.

Fig. 3 shows the resulting Channel Busy Time (CBT, i.e. the average fraction of time that the channel is sensed as busy) and the average number of packets correctly received per second by each vehicle for the communication configurations represented in Fig. 2. Although the x axis in Fig. 3 only represents the packet transmission rate, each point in the figure corresponds to the combination of packet transmission rate and power that satisfy the target $p_{app} = 0.99$, depicted in Fig. 2. When the packet transmission rate is increased, each vehicle receives more packets from each of its neighbours, but has a lower number of neighbours, because the increase of the packet rate reduces the transmission range (see Fig. 2). The reduction factor of the transmission range due to the power reduction is lower than the increase of the packet rate, and the CBT is increased as the packet rate is augmented (see Fig. 3).

The figure also shows that the traffic density increases the CBT, and therefore increases the need of efficiently sharing the radio channel. For high traffic densities, or high transmission rates and large payloads, the CBT can increase over 25%, which is a limit currently under discussions in standardization bodies [9]. These results show that a good option to prevent channel congestion in the proposed scenario and application is minimising the packet rate, despite that it would require a higher power to meet the traffic safety requirements. A limiting factor for the decrease of the packet rate could be the maximum power allowed by the standards (33dBm in Europe and 44.8dBm in the US), or the concurrent use of applications requiring a high packet rate. It is interesting to note that a traditional protocol design would result in a different communication setting of the CAMs, for example by increasing the packet rate to increase the number of packets correctly received (Fig. 3). However, the increase of the packets correctly received would not produce any safety performance gain, while significantly increases the channel load, creating unnecessary interferences.

V. Conclusions

This letter has proposed a proactive congestion control policy for VANETs that aims to satisfy the application requirements of vehicles, while preventing channel congestion. The obtained results demonstrate that different combinations of transmission power and packet rate could satisfy the application requirements. Considering the reference status of the control channel, the one minimising the channel load would be preferred to reduce the interference and increase the system capacity. The proposed policy has been evaluated considering the lane change assistance application. However, it could be used as the basis of advanced contextual congestion control policies, and congestion control protocols based on the experienced channel load, to efficiently distribute the available bandwidth. Moreover, the proposed approach could be extended to scenarios where multiple applications, each with different requirements, are simultaneously run by the same vehicle. While some applications could require a high packet rate, others could fix the minimum distance at which messages should be received. These requirements will need to be safely combined, which represents a challenging task for the future deployment of VANETs.

References

[1] IEEE P802.11p/D11.0, "Draft Part 11: WLAN MAC and PHY Specifications: Wireless Access in Vehicular Environments (WAVE)," IEEE Standards Association, 2010.

[2] ETSI TC ITS, "ITS; Vehicular Communications; Basic Set of Applications; Definitions," TR 102 638, 2009.

[3] M. Torrent-Moreno *et al.*, "Distributed fair transmit power adjustment for vehicular ad hoc networks," in *Proc. IEEE SECON*, pp. 479-488, 2006.

[4] G. Caizzone *et al.*, "A power control algorithm with high channel availability for vehicular ad hoc networks," in *Proc. IEEE ICC*, pp. 3171-3176, 2005.

[5] H. Ching-Ling *et al.*, "Analysis of aggregated power level and rate-power control designs for status update messages in VANETs," in *Proc. IEEE MASS*, pp. 615-620, 2009.

[6] T. Kosch *et al.*, "The scalability problem of vehicular ad hoc networks and how to solve it," *IEEE Wireless Commun.*, vol. 13, no. 5, pp. 22-28, 2006.

[7] F. Bai *et al.*, "Reliability analysis of DSRC wireless communication for vehicle safety applications," in *Proc. IEEE ITSC*, pp. 355-362, 2006.

[8] M. Sepulcre and J. Gozalvez, "Wireless vehicular adaptive radio resource management policies in congested channels," in *Proc. IEEE ISWCS*, pp. 380-384, 2007.

[9] ETSI TC ITS, "ITS; Harmonised Channel Specifications for Intelligent Transport Systems Operating in the 5 GHz Range," DTS-0040016, 2009.