Optimised CSMA Protocol to Support Efficient Clustering for Vehicular Internetworking*

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***Abstract*—Vehicular ad-hoc networks (VANETs) that support communication among vehicles can facilitate a wide range of road-safety applications. To deal with network fragmentation for low vehicular density, clusters of neighbouring vehicles can be formed. Clustering techniques also require timely communications among vehicles. Despite the stringent performance requirements for the safety and clustering applications, the IEEE 802.11p standard still employs the carrier sensing medium access/collision avoidance (CSMA/CA) protocol that has a fixed contention window (CW) range for backoff. This results in significant inefficiency as vehicular density changes. This work investigates how the maximum CW size can be optimised to enhance performance based on vehicular density by exploiting the equivalence between the CSMA/CA and Aloha performance models. Simulation shows a great reduction in transmission delay for the proposed protocol when compared with the standardised one. Thus, with the low latency, the new protocol is useful to the vehicle clustering and road-safety applications.**

***Index Terms*—Vehicular Ad-Hoc Networks, Clustering, Contention Window, MAC layer, 802.11p, CSMA/CA.**

I. Introduction

Vehicular ad-hoc networks (VANETs) consist of highly mobile vehicles communicating with each other through a multi-hop ad-hoc connection without relying on permanent infrastructure. VANETs can support many applications, amongst others improve road safety, by exchanging safety information to be constantly aware of potential imminent threats. In light of this, based on the IEEE 802.11p standard, the cooperative awareness messages (CAMs) are designated to contain relevant information for safety applications (e.g., vehicle speed and position) and are to be broadcasted in a single hop with low latency of 100 ms [1].

Network fragmentation for low vehicular density can be addressed by employing clustering techniques to form hybrid networks. In this case, clusters of neighbouring vehicles are formed and only cluster heads are allowed to interconnect with unmanned aerial vehicles (UAVs) or cellular base stations, as shown in Figure 1. CAMs can support such vehicle clustering techniques. In [2] we proposed a clustering algorithm that can reliably support hybrid networking. The effectiveness of clustering techniques is strongly influenced by the timeliness and accuracy of the information collected from neighbouring, mobile vehicles.

The rapid vehicular density changes play a major role in determining network performance [3]. It is especially so because CAMs are broadcasted using the standardised protocol CSMA/CA. This is characterised by the lack of acknowledgment (ACK) packets and a fixed CW size from which the randomised backoff counter is selected. In light of this, the CSMA/CA broadcast has been investigated and it has been found that the medium access control (MAC) protocol in IEEE 802.11p tends to behave like the Aloha protocol, diminishing the benefits of the sensing mechanism [4]. In [3], we presented an approach to choose the optimal transmission probability p_t for the slotted Aloha based on the vehicular density in networks.

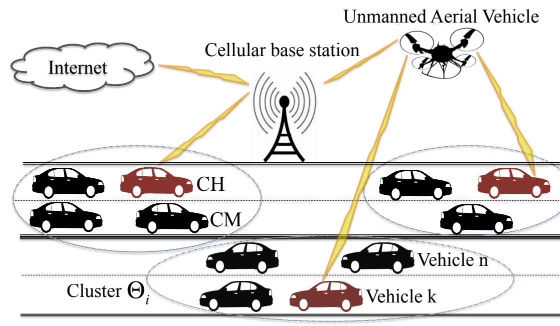

Fig. 1. Clustering scenario: vehicle cluster (circle dashed line) with cluster head (red), grouping all cluster members (black) within range. Only cluster heads are allowed direct communication with UAVs or cellular base stations.

In this work, after establishing the relation between the (fixed) maximum CW and the transmission probability, the Aloha performance behaviour of the broadcast CSMA/CA is exploited to adopt and integrate the optimal p_t value from [3] into the CSMA/CA protocol to support efficient vehicular clustering. Finally, simulation results confirm the low latency of the new protocol to support vehicle clustering mechanisms for internetworking and other road-safety applications. Key contributions of this work are:

- Using the parallel between CSMA/CA and Aloha protocols, derive the optimal CW size based on estimates of vehicular density, while considering the signal-to-interference ratio (SIR) and capture at receiving vehicles.
- Integrate the optimal maximum CW with the CSMA/CA protocol to enhance the delay performance for CAMs.

II. System model

A. CSMA/CA broadcast model

Using the broadcast CSMA/CA protocol, to fulfil the low latency requirements, CAMs are sent over the control channel (CCH) during the CCH interval (CCI) of 100 ms long. Figure 2

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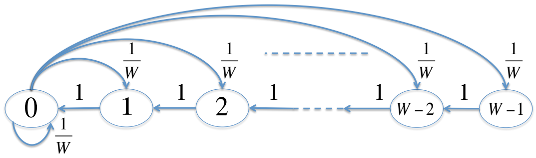

Fig. 2. Markov model of CSMA/CA broadcast in 802.11p for one CCI

depicts the states associated with the channel contention protocol over a single CCI. Each vehicle generates a new CAM as CCI starts and a random backoff is selected in a fixed CW range of 0 to (W - 1) slot times. In each slot time the channel is sensed idle, the backoff counter is decremented, otherwise (i.e., busy channel) it stays unchanged. The vehicle can transmit its CAM when the counter reaches 0. Under the assumption of a proper backoff process (i.e., no hidden node problem), as shown in the Markov model in Figure 2, the CW size can be expressed as

$$W = \left\lfloor \frac{2}{b_0} - 1 \right\rfloor . \tag{1}$$

The flooring operation assures that CW is an integer value, as in the protocol standards, and b_0 is the probability that a vehicle starts transmitting in an arbitrary idle slot time. Consequently, by focusing only on the idle slot times, the CSMA/CA for CAMs behaves in the same way as slotted Aloha, where a transmitter has a corresponding probability $p_t = b_0$ to transmit in an arbitrary slot time.

B. Optimal contention window

By following the stochastic model we developed in [3], the optimal value for p_t to maximise the slotted Aloha throughput T_h given the number of transmitting vehicles is estimated. The expression for T_h, after the introduction of the vehicle size c for a more realistic constraint, can be obtained as

$$T_h = \prod_{k=1}^{\infty} \left[1 - p_t \left(1 - \sum_{n=0}^{k-1} \frac{(\lambda(R_f - kc))^n}{n!} e^{\lambda(R_f - kc)}\right) \right]^2 \cdot \frac{(p_t - p_t^2)(1 - e^{-\lambda(R_c - c)})}{(1 - p_t) + p_t e^{\lambda(R_f - c)}}, \tag{2}$$

where λ is the vehicular density, R_c and R_f denote the communication and interference range, respectively. All variables in (2) are known constants for a given network apart from p_t that is the only control variable and as such can be derived as a function of estimated number of neighbours.

Due to the aforementioned equivalence argument, b_0 can be set equal to p_t and (1) is applied to evaluate the optimal maximum CW, W-1, to maximize the CSMA/CA throughput.

III. Numerical Results

To validate the proposed CSMA/CA protocol and compare it to the existing standard, a one-lane, single-direction road of 5 km length is simulated for 1500 s. Vehicles are assumed to be able to estimate the number of neighbouring vehicles in the range R_f. The values used for the model are identical to those in [3] while the parameter values for the broadcast CSMA/CA are specified in the 802.11p standard.

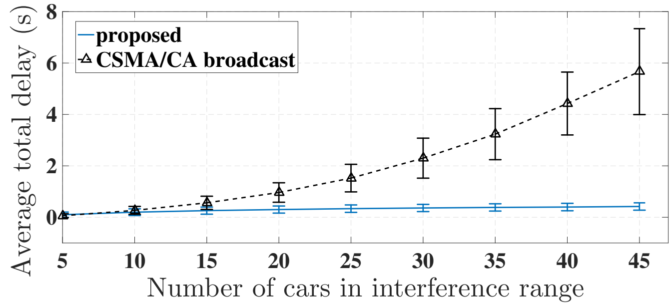

Fig. 3. Average total delay for a vehicle to collect all CAM messages from its neighbours as a function of the average number of neighbouring vehicles within the interference range R_f.

Figure 3 depicts the average total delay for the proposed (optimised) and standard protocol as a function of the average vehicular density. The vertical bars in the figure represent one standard deviation around the average delay. The total delay metric is defined as the average amount of time that a vehicle waits before CAMs from all its neighbours are received. As shown in the figure, the proposed protocol offers much lower delay than the standard protocol because the CW is optimally selected according to vehicle density by the new protocol to avoid transmission collision. In fact, each time a collision occurs, the packets involved are not received and new transmissions can be possible in the next CCI. This increases the total delay to receive all CAMs packet from the neighbours. Vehicle clustering mechanisms for internetworking and road-safety applications strongly rely on the timely reception of accurate status information from neighbouring vehicles. Hence, by offering low latency, the optimised protocol can support such real-time applications.

IV. Conclusion

As a step toward the design of efficient MAC protocol to support clustering mechanisms for VANET internetworking with UAVs or cellular base stations, we have established the relation between the (fixed) maximum contention window size and the transmission probability p_t. By exploiting the Aloha performance behaviour of the broadcast CSMA/CA, the optimal value for p_t derived in [3] is adopted and form a new, optimised CSMA/CA protocol. Simulation experiments have revealed a significant delay improvement to receive status information for neighbouring vehicles needed for efficient clustering mechanisms and other road-safety applications.

References

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