A Cross Layered MAC and Clustering Scheme for Efficient Broadcast in VANETs

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Abstract

In this paper, we illustrate the design of a cross-layered MAC and clustering solution for supporting the fast propagation of broadcast messages in a Vehicular Ad Hoc Network (VANET). A distributed dynamic clustering algorithm is proposed to create a dynamic virtual backbone in the vehicular network. The vehicle-members of the backbone are responsible for implementing an efficient messages propagation. The backbone creation and maintenance are proactively performed aiming to balance the stability of backbone connections as well as the cost/efficiency trade-off and the hops-reduction when forwarding broadcast messages. A fast multi-hop MAC forwarding mechanism is defined to exploit the role of backbone vehicles, under a cross-layered approach. Simulation results show the effectiveness of the mutual support of proactive clustering and MAC protocols for efficient dissemination of broadcast messages in VANETs.

1. Introduction

In the last two decades, technology advances in portable devices and wireless networking have contributed to the introduction of new active safety systems assisting vehicle drivers to avoid congestion and road accidents [1,2,3,4,5,6]. Examples of such systems include Information Warning Functions (IWF) [1,13,14], real-time traffic monitoring applications [2], advanced driver assistance systems for co-operative Adaptive Cruise Control (ACC) [3] and intersection collision avoidance [1,2,3]. In this context, solutions based on inter-vehicle wireless communication (IVC) play a fundamental role. Since road-network coverage by wireless communication infrastructures is costly, distributed solutions are investigated in which neighbor vehicles will be able to communicate with each other by using dedicated short-range wireless technologies, enabling the vehicular ad hoc networks (VANETs) [5,6,7].

Road-safety applications based on IVC strictly rely on the assumption of cooperation and distributed coordination among vehicles, and pose new challenges on the nature and characteristics of inter-vehicular communication [15]. Security, identity and trust management issues, which are fundamental for these systems, have received attention from the research community [22], but are considered out of scope in this paper. When detecting a problem on the road, a single vehicle could send a broadcast alert message to a group of potential receivers in the Risk Zone (RZ). Since the risk zone may be larger than the transmitting range of wireless devices, the message should be relayed by the intermediate vehicles to extend the horizon of the message. The information exchanged by safety-related applications may determine strong communication requirements: few tenths of a second delay may have a significant impact on the effectiveness of a safety application (e.g. braking assistance). In particular, the viability of active safety applications is strongly based on the ability to broadcast information by guaranteeing i) as fast as possible dissemination, ii) highly effective message delivery ratio among the vehicles in the risk zone, iii) fair and scalable resources utilization.

Vehicle-to-vehicle communication for safety related applications has been recently addressed by several international consortium and research institutes [3,4,5,6]. Due to its wide adoption, many research works are currently based on the legacy IEEE 802.11 standard technology. The IEEE 802.11 DCF protocol [7] does not offer any specific support to the multi-hop broadcast communication. A flooding approach in IEEE 802.11 systems can be defined based on broadcast message retransmission upon reception by each vehicle. An efficient wireless multi-hop broadcast protocol should provide fast dissemination by limiting the number of retransmissions. Under ideal assumptions, this goal could be achieved by relaying broadcast messages only on nodes in the Minimum Connected Dominating Set (MCDS) [9] of vehicle-flows. As proposed in [9], the MCDS may be recursively obtained, but building a MCDS in a vehicular environment implies that all the vehicles must have a strong real-time knowledge of the vehicle positions and radio characteristics. For these reasons, most of the solutions in the literature for enabling fast

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broadcast in a VANET do not rely on the presence of a "pre-established" virtual structure in the network [10,11,12,13,14]. Each time a broadcast communication is started, the next relaying vehicle is dynamically determined, possibly as the farthest connected node with respect to current sender. Solutions based on contention-based channel access differentiation have been proposed at the MAC layer to statistically get the contention winner as the farthest nodes from the sender [10,11,12,13,14].

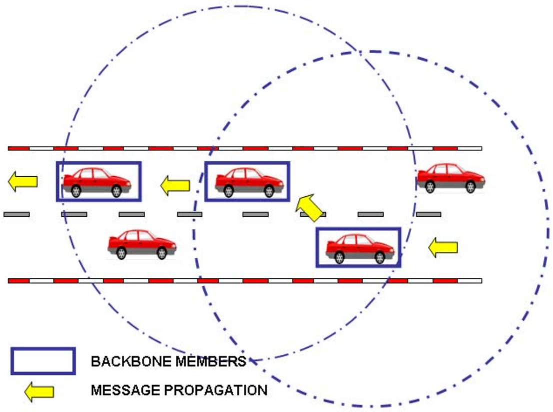

Figure 1: Virtual Backbone Infrastructure in a VANET

Cluster-based solutions may be a viable approach in supporting efficient multi-hop message propagation among vehicles [18]. A distributed cluster infrastructure may be defined by providing nodes with a distributed protocol to proactively form a backbone. We use the term backbone to identify a virtual chain of vehicles in a vehicular scenario (e.g. a highway). Each node of the backbone must be connected to previous and next hop of the backbone chain, as shown in figure 1. The backbone formation and management should be determined in a distributed way, by exploiting some characteristics of VANETs [17], like the "time-persistent clustering of vehicles" in common scenarios.

In this paper, we present a novel, cross-layered [19] scheme for fast propagation of broadcast messages in a vehicular environment. A distributed proactive clustering scheme is defined in order to dynamically establish a virtual backbone infrastructure, created by addressing robustness and lifetime of connections among backbone members. The backbone formation process works by taking into consideration i) the current distance among candidate backbone vehicles and ii) the estimated lifetime of the wireless connection among neighbor backbone members. In addition, we propose a forwarding scheme at the MAC layer, inspired to the IEEE 802.11 Distributed Coordination Function (DCF) basic access scheme, which exploits the existence of the backbone infrastructure. We called this scheme Dynamic Backbone-Assisted MAC (DBA-MAC). When an alert message is generated by a vehicle, it is relayed by the nodes of the backbone, as long as the backbone is present. In general, the advantages are twofold: i) transmissions among nodes of the backbone are impulses of unicast communications, that is, reliability could be improved by means of immediate Ack notification mechanisms, and ii) the effect of multi-hop MAC layer contention-delays is reduced, since each backbone node receiving a message immediately re-sends it to the next backbone node, with implicit contention resolution. If the transmission among vehicles of the backbone fails (e.g. due to collisions or hidden terminals), or if a backbone disruption is caused by mobility effects, then a fast multi-hop broadcast scheme like the one proposed in [10] is used as a background (worst case) solution.

The paper is structured as follows. Due to space limitations, the illustration of related works can be found in [23]. In section 2 we illustrate the target system model and general assumptions. In section 3, we describe the structure of the cross-layered scheme, with details of the distributed algorithm for backbone creation (section 3.1) and the solutions adopted at the MAC layer (section 3.2). Section 4 illustrates simulation results of the DBA-MAC scheme, compared with other multi-hop broadcast solutions in a highway scenario. Conclusions and future works are summarized in section 5.

2. System Model and Assumptions

In this work we consider the information propagation in a multi-lane highway scenario, with vehicles travelling in both directions. In general, the values for model factors will be defined in the simulation Section 4. The extension to urban scenarios will be included in our future works. We assume vehicles to be equipped with sensing, wireless communication, computation and storage capabilities. IEEE 802.11 devices are considered the target wireless technology. Vehicles collect data provided by on-board sensors (acceleration and speed) and by GPS devices (location). When a vehicle senses a critical condition on the road, it broadcasts an alarm message to inform vehicles in the risk zone (RZ). In general, the content of a message is application-dependent. We assume that each alert message includes : *i)* a direction of propagation (in our model, without loss of generality, we assume backward message propagation with respect to the vehicle flow direction), *ii)* a maximum time-to-live (TTL) limiting the temporal validity of the message and *iii)* a RZ limiting the space horizon of the message. Only nodes in the RZ are allowed to relay the message.

3. Cross-layered Protocol Scheme

In [24], we investigated the mutual support between MAC and clustering schemes in a MANET. In this paper, we show the effectiveness of the mutual support between customized clustering and MAC protocols in providing efficient forwarding of broadcast messages in a VANET.

3.1. Backbone Creation and Maintenance

A clustering structure to support the information dissemination of alert messages in a VANET should take into account the following issues: *i) backbone stability*: a minimum connectivity-duration threshold is required for a node to become part of the backbone, *ii) fairly high nodes distance*: for hop reduction, relaying nodes should be as much distant as possible, *iii) management overhead*: the backbone creation should be distributed and based on light communication, and *iv)* the overhead due to vehicle mobility and backbone disruption should be under the control of parameters, like the frequency of backbone refresh procedures.

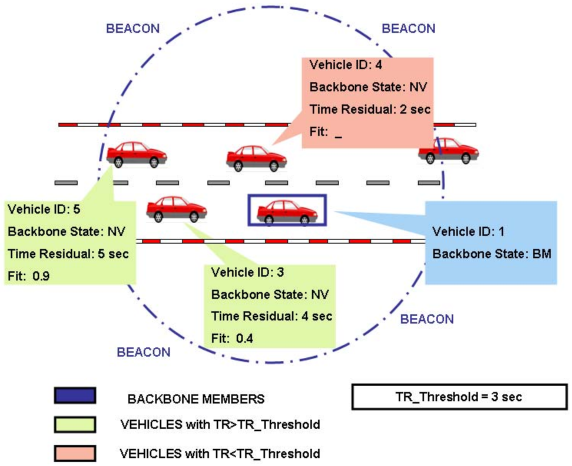

Figure 2: Backbone creation process

We propose a fully distributed clustering algorithm, whose implementation requires cross-layer interactions among MAC and clustering schemes. A backbone is not required to be monolithic. In general, the target backbone might be composed by multiple non-overlapping chains of interconnected backbone vehicles. Each vehicle device has a unique ID (as an example, a MAC address). Each chain member has at most two neighbors (*prev_hop, next_hop*) and a sequence number (*chain_seq*) obtained as the vehicle hop-count in the chain itself. Under a clustering viewpoint, vehicles can be in two states: normal vehicle (NV) or backbone member (BM). Each backbone member has a backbone-record (BR) information with the following structure:

<ID, state, prev_hop, next_hop, chain_seq> .

A backbone creation process starts whenever a vehicle does not receive backbone beacons for a time interval *RefTim* (defined in the following). In this case, it elects itself as a backbone member, and it broadcasts a BEACON message. The BEACON message has the effect to propagate the impulse of a backbone creation process. The BEACON message contains the following sender's information:

<ID, (x,y), R, speed, dir, horizon>

where *ID* is the unique sender identifier, *(x,y)* are the GPS coordinates, *R* is the transmitting range (or, equivalently, the transmission power in dBm), *speed* is the average speed, *dir* is the direction of the vehicle, and *horizon* is the space limit of the risk zone, respectively. Figure 2 shows the process of a backbone creation after vehicle with *ID=1* has broadcast a BEACON message. Vehicles receiving the BEACON message from node 1 (and travelling in the same direction) are potential next-hop candidates of the backward backbone creation. A distributed, contention-based MAC access phase is implemented by receiver nodes to select the candidate that *i)* is expected to stay connected with previous backbone node for at least a backbone refresh (*BB_REFR*) interval, and *(ii)* is expected to be the farthest node from *prev_hop* node after a *BB_REFR*.

Without loss of generality, we assume node A is following node B. We use the notion of *Residual Time (RT)* of a connection between two nodes A and B to indicate the time A will remain in the transmitting range of B (without overtaking B). The RT of a connection between two nodes *RT(A,B)* could be computed (under some assumptions) from the information about current positions, relative speed and transmitting range *R*. In detail, in this work we define:

$$RT(A,B) = \frac{[\max(0, sign(\Delta v))]R - dist(A,B)}{\Delta v}$$

where R is the transmission range of the sender vehicle, v_A and v_B are the average speed of vehicles A and B, *dist(A,B)* is the current estimated distance, $\Delta v = v_B - v_A$ is the relative speed between nodes B and A, and *sign()* is the function returning +1 if Δv is positive (that is, distance between B and A increases) and -1 otherwise.

Upon reception of a BEACON message from vehicle B, vehicle A computes the *RT(A,B)* of the connection: if the residual time is lower than the duration threshold (*BB_REFR*), then vehicle A is not a good candidate to be the *next-hop* of the backbone node B. This is because A is expected to move out of the range of node B within the next *BB_REFR* interval. Looking at figure 2, vehicles 3 and 5 are potential next-hop (backbone) candidates of vehicle 1, while vehicle 4 would be excluded by the backbone because it is overtaking vehicle 1 (to provide a numerical example, *RT(1,4)=2, BB_REFR=3*, that is, *RT(1,4) < BB_REFR*).

Vehicles with *RT(A,B) > BB_REFR* can join a contention phase whose winner will be the next backbone member. A generic vehicle A receiving a BEACON from B enters the contention phase, and performs the following actions: 1) it computes its own FF factor (see below); 2) after a random MAC backoff interval (see below), it sends a CANDIDATURE message to preceding vehicle B and it waits to receive an ACK_WINNER message from B; 3) if it receives an ACK_WINNER message from node B, then it changes its own state to backbone member (BM), it increases the *hop_count* value and it broadcasts a BEACON message in order to further propagate the backbone creation process.

The backbone member B receiving a CANDIDATURE message from candidate node A performs the following actions: 1) it checks the *next_hop* field in its backbone record: if the *next_hop* field is *null*, the vehicle B sets the *next_hop* to A and sends an ACK_WINNER message to A; if node B has previously acknowledged the CANDIDATURE message from another node, then no message is sent. This three-phases handshake protocol (BEACON-CANDIDATURE-ACK_WINNER) selects one single next-hop backbone member for extending the backbone. To select the best candidate, a cross-layer technique is used to reduce the number of CANDIDATURE messages generated in the contention phase. A local parameter named *Fit Factor (FF)* is calculated by every candidate node as a ranking metric to become the next backbone-hop. In this paper, the *FF* for candidate node A is defined as follows:

$$FF(A) = \frac{dist(A,B) + \Delta v * BB\_REFR}{R}$$

where $\Delta v = v_B - v_A$ is the relative average speed, *dist(A,B)* is the distance of node A with respect to backbone-node B, and R is the transmission range of B. The *FF* is an estimation of the distance between node A and backbone-node B after a *BB_REFR* interval, normalized with respect to *R*. The FF is used to dynamically control the contention window of the backoff scheme implemented at the MAC layer (IEEE 802.11), as indicated in the following formula:

$$CW = \max[0,(1 - FF(A))] * (CWMAX - CWMin) + CWMin$$

A node whose FF is near to the value one will obtain short backoff values, hence it would win the contention with limited delay, statistically. During the backoff phase, nodes perform carrier sensing: if a node C detects an early CANDIDATURE message from another vehicle A towards backbone-node B, than C aborts its own backoff phase and remains in the NV state.

Since the backbone creation process could be initiated in asynchronous way by multiple nodes, many virtual sub-chains may be created in the highway scenario. Virtual chains may remain disjoint or may be interconnected when a backbone member A with a backbone *chain_seq* equal to 1 (that is, the header node A of a sub-chain) receives a BEACON request from a front-head vehicle B (that is, the trailer node B of a sub-chain): in this case, the node A replies immediately (without backoff, after a SIFS interval) with a CANDIDATURE message to B, trying to realize a concatenation of two adjacent backbone sub-chains.

The high mobility of nodes in a VANET may produce frequent changes in the backbone topology. For this reason: *i)* links among nodes of the backbone may be broken and *ii)* the value of local connectivity factors (Residual Time) and node distance (Fit Factor) among backbone members may dynamically vary. A reactive scheme for repairing the backbone would need break-detection capability (and overheads), and would probably result in fragile patched backbones. To cope with these issues, our mechanism proactively refresh the backbone, under the control of a *refresh timer*. To limit the number of nodes re-starting the process of backbone-refresh, and to exploit the memory-effect of already existing backbone sub-chains, each node of the backbone maintains a refresh timer (*RefTim*) which is a multiple of the *BB_REFR* parameter, and it is defined as:

*RefTim =(chain_seq % Max_chain_size) * BB_REFR.*

The effect of the formula above is to randomize the distribution of backbone creation/refresh events, by increasing the frequency of refreshes coming from nodes ahead in the existing chains. This has the effect of reducing the occurrence of synchronous backbone creation processes activated by neighbor nodes.

3.2. MAC Layer Support

At the MAC Layer, we propose a cross-layered forwarding scheme that *i)* exploits the presence of a backbone structure in the VANET, *ii)* favors the fast propagation of multi-hop broadcast messages, and *iii)* dynamically adapts to network load and cluster variations. For these reasons, we called such scheme Dynamic Backbone Assisted MAC (DBA-MAC). The DBA-MAC protocol provides differentiated channel accesses reflecting two priority classes (Backbone Member, Normal Vehicle) determined in the backbone creation algorithm.

Backbone members (BM) have higher priority in accessing the channel and relaying the broadcast messages. This is supported by the MAC scheme called *Fast Multi-Hop Forwarding (FMF)*. In addition, we introduce a new mixed unicast and broadcast transmission concept to allow the fast advertisement propagation of alert messages in the risk zone. All messages relayed by backbone members are broadcast messages: in this way, every node will receive the advertised message information. On the other hand, by exploiting a cross-layered approach, backbone members (BM) react to broadcast messages in non-standard way defined in the following. As long as the backbone is working, when BM_{i+1} receives a broadcast information message from BM_i it immediately sends back and acknowledgment (as for unicast messages), after a SIFS, and then BM_{i+1} immediately broadcasts the message towards BM_{i+2} (if any) without releasing the channel control. If the ack is not received, the BM_i leaves the FMF scheme and enters the basic MAC scheme (see below). With the FMF approach, we achieve two important goals. *Enhanced reliability*: all the backbone-assisted transmissions are acknowledged (only by BMs) and re-transmission is possible if a message fails (e.g. due to backbone failure). The re-transmission will be forwarded with the help of normal vehicles NV (if any, see below). *Fast Multi-hop Forwarding:* as long as a backbone members receive a message, they forward it immediately after a SIFS. As a result, the medium control is inherited and propagated over pre-defined multi-hop nodes, without introducing backoff delays, as long as the multi-hop backbone is connected and no collisions occur.

In the following, we complete the illustration of the *basic MAC scheme*. This scheme is similar to the one defined in [10], and it is adopted as a background (worst case) scheme when the backbone assisted *FMF* fails: if a vehicle K receives an alert message from any node AND *i)* K is not a BM implementing the *FMF*, OR *ii)* K is a BM performing the second attempt (that is, no ack received after the first attempt), then K dynamically adjusts its contention window (CW) to control the MAC backoff. In particular, if the vehicle K is a backbone member (BM), the CW size is initialized to a low value (4). If the vehicle K is a normal vehicle (NV), the size of the contention window is inversely proportional to the distance from the sender, like in [10]:

$$CW = \max[0, (1 - dist(K,*)/R] * (CWMAX - CWMin) + CWMin$$

The vehicle K implements a standard IEEE 802.11 backoff scheme and broadcast the message. In the worst case, the MAC works like the mechanism in [10], by performing long-range broadcasts via a biased backoff scheme. In our scheme, if the message is received by a BM node, eventually, then the *FMF* re-starts by riding the multi-hop backbone of vehicles. A simple cancelation mechanism is introduced to limit the effect of broadcast storms: if one vehicle senses the transmission of its own alert message (with the same sequence number) from a vehicle ahead in the propagation direction, then the backoff is aborted and the packet eliminated.

To summarize, although all transmissions are broadcast, they work like unicast along the backbone, thanks to cross-layered definition of BM protocol stack. In this way the content of the message is potentially delivered to all the vehicles in the risk zone, and the efficiency and overhead reduction is obtained as long as the backbone is effective.

4. Performance evaluation

To analyze the performance of our solution, we consider the model of a 8 Km highway scenario with three uni-directional lanes. In our target application, a subset of vehicles broadcasts one alert message per second. Each alert message has a Risk Zone (horizon) covering a distance of 1 Km. Each vehicle is assumed to be equipped with 802.11 devices, with a homogeneous transmission range of 250 meters. We have considered different scenarios by varying the vehicle density (from 200 up to 600) and the percentage of vehicles generating alert messages (from 5% up to 50%). The tool used is the ns-2 simulator [20] with the extension provided by [21] to produce realistic mobility traces of highway scenarios.

Table 1. Simulation Parameters

Simulated Area	8 Km (3-lane highway)
Vehicles speed	[20,30] m/s
Vehicles density	200, 400, 600 vehicles
Transmitting range	250 m
Message size	100 Byte
Message Risk Zone	1 km (horizon)
Percentage of alert generating vehicles	5%, 25%, 50% (1 alert per second)
BB_REFR	5 sec

The parameters used in the simulations are shown in table 1. For each experiment we perform multiple runs, and we show average results whose confidence intervals (with 90% confidence level) are always below 5% of the average values (confidence intervals are not shown in the figures).

In the simulation analysis, we have compared our solution with three similar proposals. As a first reference, we have considered a simple 802.11 MAC flooding scheme: each vehicle receiving an alert message broadcasts it by using the standard IEEE 802.11 backoff scheme. The second scheme considered is the Fast Broadcast protocol [10]. The reason is that our DBA-MAC scheme may be considered an extension of the MAC scheme described in [10]. In practice, a scheme similar to the Fast Broadcast scheme is used when the backbone fails to propagate a message in our DBA-MAC scheme, hence the Fast Broadcast protocol can be considered the worst case behavior for our DBA-MAC (when the backbone fails). As the ideal reference scenario, we consider the static backbone, (like a roadside infrastructure system) whose nodes are placed at the maximum distance preserving the connectivity (250 m in our simulations), and resulting in a MCDS for this scenario. We call this scheme "Static Backbone-Assisted MAC", to emphasize the difference with our solution where a backbone is dynamically created in the VANET. Both Static and Dynamic Assisted MAC use the forwarding scheme described in section 3.2.

To compare the efficiency in forwarding the alert messages, we focus on parameters that may produce a direct impact on the communication performance, such as the delivery ratio and the average delay. In particular, we consider the following metrics: *i)* the total (average) number of retransmissions experienced by an alert message to cover the horizon distance, *ii)* the collisions percentage at the MAC layer, *iii)* the average end-to-end delay, *iv)* the percentiles of the end-to-end delay and, *v)* the overheads introduced by our clustering scheme.

4.1. Simulation Results

All performance figures refer to scenarios where the 25% of vehicles generate an alert message per second. Due to space limitations, we do not show the results obtained with other percentages since they are qualitatively equivalent for the analysis.

Figure 3 shows the average number of retransmissions needed by an alert message to cover the horizon of the risk zone (1 km), as a function of the vehicle density. As expected, the basic 802.11-based flooding protocol requires the highest number of retransmissions to propagate the message, in all the considered scenarios: this effect is emphasized when the vehicle density increases. The average number of flooding retransmissions in the scenario with 600 vehicles is five times the optimal value (roughly defined as 1000/250m = 4 hops). When the ideal static backbone is used, the alert message is often relayed by the backbone member vehicles, whose hop distance is the maximum transmission range (by construction, under our modeling choice). The performance obtained is still sub-optimal with respect to theoretical value 4, due to MAC collisions and hidden terminal effects, but the ideal scheme obviously outperforms all other schemes. When the backbone is dynamic, the DBA-MAC still produces a quite limited number of retransmissions, even if some more broadcasts are possible when the *FMF* backbone propagation fails. These results are slightly worse than the static backbone results. On the other hand, the DBA-MAC outperforms the Fast Broadcast protocol, which is not backbone-assisted. This is mainly due to the effect of the FMF scheme, which decreases the impact of contention during multi-hop backbone message propagation.

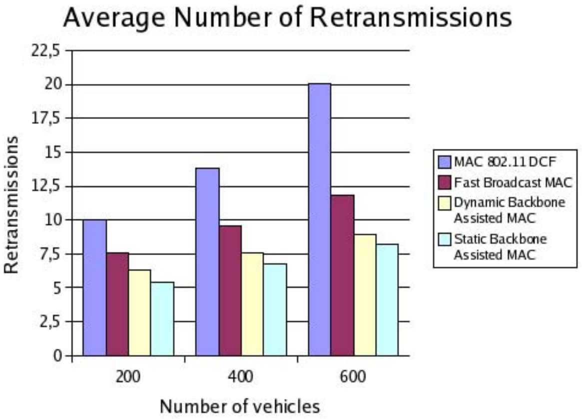

Figure 3: Average Number of Retransmissions

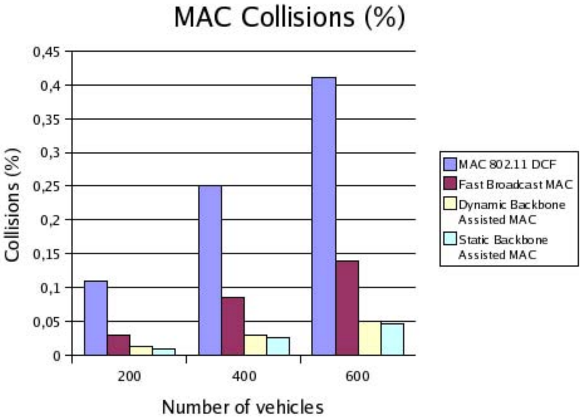

Figure 4: Average Percentage of Collisions

Figure 4 confirms this interpretation, by showing the average percentage collisions obtained at the MAC layer in the VANET, with respect to the total amount of message transmissions performed. The 802.11-based flooding scheme produces a significant 10% up to 30% collision risk, as a function of the vehicle density range and transmission message load (that is, the MAC access contention level). The collision probability is reduced by Fast Broadcast MAC thanks to the priority-based effect of the biased backoff scheme. The collisions are drastically reduced when the dynamic or static backbone assisted MAC is adopted, thanks to the reduction of contention-based accesses over multi-hop backbones.

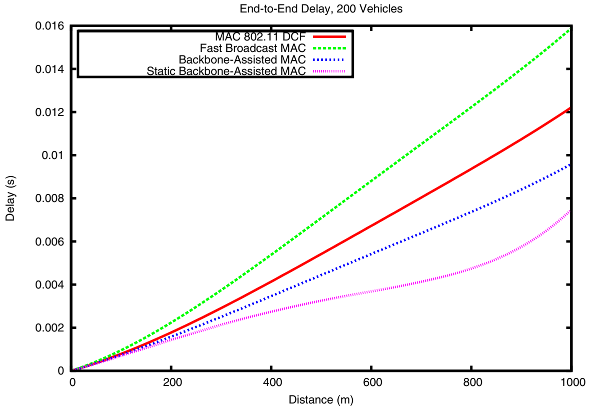

Figure 5: MAC End-to-end Delay, 200 Vehicles

Figure 5 shows the average end-to-end delay obtained by messages to cover a variable distance (x) in a low-density scenario (200 vehicles over 8 km). The Dynamic Backbone Assisted MAC falls in the range between the Static Backbone Assisted MAC and the 802.11-based flooding scheme. Surprisingly, the Fast Broadcast MAC protocol produces average delay worse than the flooding protocol. This problem is caused by the settings of the contention window. In the 802.11 DCF MAC protocol, the contention window size is set to the minimum value (CWMin) for the transmissions of broadcast messages (since no feedback is obtained by missing acks, to implement a binary exponential backoff). Given the low vehicle density, most of the flooding transmissions are successful. In the Fast Broadcast protocol, the contention window is dynamically managed, resulting equal to CWmin only for those forwarding nodes located at the maximum transmission distance from the sender. Hence, in a low density scenario, it may happen frequently that the (farthest) forwarding vehicle uses a contention window > CWMin, for each hop, resulting in high end-to-end delay.

Figure 6 shows the average end-to-end delay in a high-density scenario (600 vehicles over 8 km). In general, the effect of the increased message-load translates in end-to-end delay higher than the one in figure 5. However, the performance of the DBA-MAC scheme is close to the performance of the ideal static backbone assisted MAC.

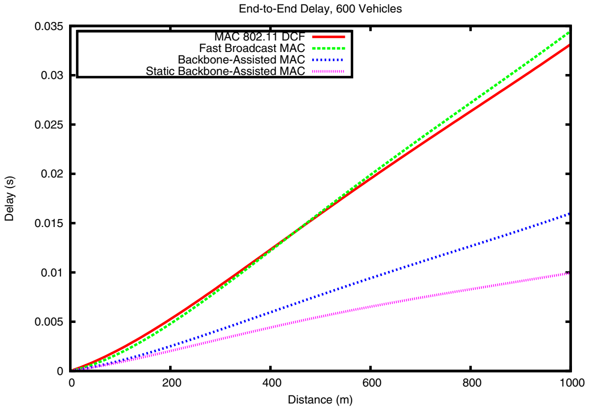

Figure 6: MAC End-to-end Delay, 600 Vehicles

Figure 6 demonstrates the advantage of using a cross-layered MAC and backbone solution to support fast propagation of broadcast messages. Both 802.11 and Fast Broadcast MAC protocols show high delays. By confirming previous comments, Fast Broadcast MAC has now performance similar to IEEE 802.11 DCF flooding, due to the increased vehicles' density (see comments above).

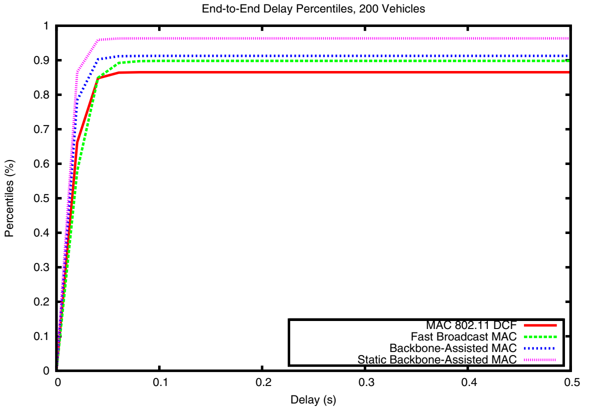

Figure 7: MAC Delay Percentiles, 200 Vehicles

Figures 7 and 8 show the MAC Delay Percentiles in a low density (fig. 7) and high density (fig. 8) scenarios, by taking into account the end-to-end delay of messages covering a risk zone of 1 Km. In the low-density scenario (200 vehicles) in figure 7, 85% of generated alert messages successfully cover the risk zone. The distribution of delays shows small differences among the considered schemes. Different schemes reliability is testified by the asymptotic values of the distribution, which could be interpreted as the asymptotic probability of message arrival. In figure 8, (high-density scenario, 600 vehicles) the most relevant effect is the different slope of the curves, which demonstrates the "resistance" of the system to message forwarding. The worst delay is obtained by flooding, as expected, while backbone assisted schemes outperform the Fast Broadcast scheme by delivering a high percentage of messages within short delay bounds.

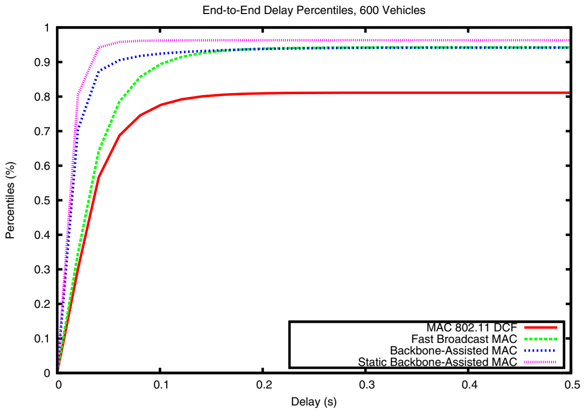

Figure 8: MAC Delay Percentiles, 600 Vehicles

5. Conclusions

In this paper we illustrated the design and analysis of a cross-layered MAC and clustering scheme for efficient broadcast of alert messages in VANETs, based on Dynamic Backbone-Assisted MAC protocol, and Fast Multi-hop Forwarding. The proposed scheme is compliant with IEEE 802.11 DCF systems, under the MAC layer viewpoint. The performance of the DBA-MAC has been compared with other schemes, by showing general advantages in performance, reliability, and overhead reduction.

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7. References

[1] J. Blum, A. Eskandarian, L. Hoffman, “Challenges of inter-vehicle ad hoc networks”, in IEEE Transaction on Intelligent Transportation Systems 5 (4), (2004), 347-351

[2] T. Nadeem., S. Dashtinezhad, C. Liao, L. Iftode, “TrafficView: traffic data dissemination using car-to-car dissemination”, in Proc of ACM Sigmobile Mobile Computing and Communication Review (3) (2004), pp. 6-19

[3] D. Reichardt, M.. Miglietta, L. Moretti, P.Morsink, W. Schulz, “CarTalk 2000: safe and confortable driving based upon inter-vehicle communication”, in Proc. of IVS’02, Versailles, France, June 2002, pp. 545-550

[4] NOW (Network On Wheels) Project, <http://www.network-on-wheels.de/>

[5] Federal Communication Commission, FCC Rep. and Order, Feb. 2004

[6] IEEE 802.11 TGp, Wireless Access for Vehicular Environment (WAVE)

[7] IEEE 802.11 WG, IEEE Std 802.11, 1999 Ed, Part II: Wireless LAN MAC and PHY layer specs, 1999

[8] C. J. Adler, “Information Dissemination in Vehicular Ad Hoc Networks”, in diplomarbeit thesis, Insititute fur Informatik, University at Munchen, April 2006

[9] A. Zanella, G. Pierobon, S. Merlin, “On the Limiting Performance of Broadcast Algorithms over Unidimensional Ad-hoc Radio Networks”, Proc. WMPC04, Sept 2004

[10] C.E. Palazzi, S. Ferretti, M. Roccetti, G. Pau and M. Gerla, “How do you quickly choreograph inter-vehicular communications? A Fast Vehicle-to-Vehicle Multi-Hop Broadcast Algorithm, Explained”, in Proc. of the 3rd IEEE CCNC/NIME 2007, Las Vegas, Jan. 2007.

[11] G. Korkmark, E. Ekici, F. Ozguner, U. Ozguner, “Urban Multi-hop Broadcast Protocol for Inter-vehicle Communication Systems”, VANET2004, 10/2004, pp. 76-85

[12] M. Torrent-Moreno, D. Jiang, H. Hartsenstein “Broadcast Reception Rates and Effects of Priority Access in 802.11-Based Vehicular Ad-Hoc Networks”, VANET 2004, 10/2004, pp. 10-18.

[13] C.F. Chiasserini, E. Fasolo, R. Furiato and alt., “Smart Broadcast of Warning Messages in Vehicular Ad Hoc Networks”, in Proc. of NEWCOM, Turin, Nov. 18, 2005

[14] Q. Xu, T. Mark, J. Ko, R. Sengupta, “Medium Access Control Protocol Design for Vehicle-Vehicle Safety Messages”, IEEE TVT, Vol. 56, N. 2, pp. 499-518

[15] L. Campelli, M. Cesana, R. Fracchia, “Directional Broadcast Forwarding of Alarm Messages in VANETs”, in Proc. of WONS’07, Jan. 2007, 72-79

[16] A. Benslimane, “Optimized Dissemination of Alarm Messages in Vehicular Ad-Hoc Networks”, in Proc. of HSNMC 2004, 2004, pp. 655-666.

[17] P. Fan, J. Haran, J. Dillenburg, P. Nelson, “Traffic Model for Clustering Algorithms in Vehicular Ad-Hoc Networks”, Proc. of CCNC 2006, Jan. 2006, Vol. 1, 168-172

[18] T..D.C. Little and A.Agarwal “An Information Propagation Scheme for VANETs”, Proc. of Intelligent Transportation Systems, September 2005, pp. 155.-160

[19] M. Conti. G. Maselli, G. Turi and S. Giordano, “Cross Layering in mobile ad hoc network design”, IEEE Computer, vol. 37, (2004) pp. 48-51

[20] Network Simulator, ns-2, http://www.isi.edu/nsnam/ns

[21] IMPORTANT Project, Mobility Generator Tool for ns2, http://nile.sc.edu/important/software.htm

[22] Secure Vehicular Communications, FP6 EU-funded project SEVECOM: http://www.sevecom.org/

[23] L.Bononi, M. Di Felice, “A Cross Layered MAC and Clustering Scheme for Efficient Broadcast in VANETs”, tech. report 2007, http://www.cs.unibo.it/~bononi/

[24] L.Bononi et al. “Design and Performance Evaluation of Cross Layered MAC and Clustering Solutions for Wireless Ad Hoc Networks”, *Performance Evaluation: An International Journal,* Elsevier CS, Vol 63/11, Nov 2006