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An Efficient and Fast Broadcast Frame Adjustment Algorithm in VANET

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***Abstract*—Designing MAC protocol for VANETs is challenging because of quick topology changes, high vehicle mobility, and different quality of service requirements. One promising approach is to employs both TDMA and CSMA hybrid access schemes in the control channel interval. These protocols can adjust the length of TDMA frame (also called broadcast frame) to adapt itself to different vehicle conditions and provide efficient non-safety message transmission. To improve the efficiency of hybrid MAC mechanism in VANET, we propose an efficient and fast broadcast frame adjustment algorithm, called EFAB based on the three-hop neighbor information. By adjusting the broadcast frame length quickly, MAC protocol using EFAB can support efficient broadcast services on the control channel. Simulation results show that hybrid MAC protocol using EFAB can provide faster broadcast frame adjustment and higher packet delivery ratio of safety packets on the control channel than using the existing algorithms.**

***Keywords*—VANET, MAC, broadcast frame adjustment.**

I. INTRODUCTION

Vehicle Ad Hoc Network (VANET) is considered to be an important part of Intelligent Transportation System supported to improve the quality, effectiveness and the safety of future transportation system. In a VANET, each vehicle is equipped with an On-Board Unit (OBU) and RoadSide Units (RSUs) are distributed along the road to connect to Internet. VANETs focus on two main communication types: Vehicle-to-Vehicle (V2V) and Vehicle-to-RSU (V2R) transmissions. The Medium Access Control (MAC) protocol is designed to provide efficient and reliable broadcast services for VANETs. In 1999, the United States Federal Communications Commission (FCC) allocated 10-MHz channels in the 5.9 GHz band, including one Control CHannel (CCH) and six Service CHannels (SCHs) for safety and non-safety applications. The MAC protocol using Time-Division Multiple Access (TDMA) [1] [2] is fair, has predictable delay, and supports reliable and efficient packet without collision. However, it needs strict synchronization. On the other hand, the MAC protocol using Carrier Sense Multiple Access (CSMA) [3] [4] can support variable packet sizes and does not require strict synchronization. Nevertheless, it has unbounded time delay and consecutive packet drops. In VANET safety applications, vehicles have to be constantly aware of the events in the surrounding environment to prevent dangerous situations. To ensure that safety messages can be received timely and reliably, one hybrid approach employs both TDMA and CSMA in the control channel [5] [6]. On the one hand, the high-priority safety packet is broadcast by each vehicle during its time slot using TDMA to avoid collision. On the other hand, the control packet or Wave Service Announcement (WSA)/ACKnowledgment (ACK)/RESponsibility (RES) will be transmitted during the CSMA period.

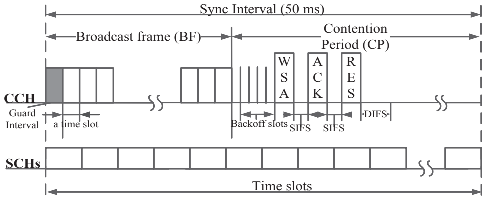

Fig. 1: The considered multi-channel MAC protocol.

In this paper, we focus on the hybrid MAC protocol combining TDMA and CSMA. In this protocol, each Sync Interval (SI) is divided into Broadcast Frame (BF - using TDMA) and Contention Period (CP - using CSMA). This MAC protocol allows every vehicle to send collision-free and delay-bounded transmission for safety applications. One of the special advantages in this MAC protocol, such as [5] [6], is that the length of BF is not uniform over the entire network. Each vehicle dynamically adjusts the BF length according to its neighbors. Each node will broadcast control packet or WSA/ACK/RES packet after one-hop neighbor length from the beginning of the broadcast frame. Hence, the Packet Delivery Ratio (PDR) of safety packets during the SI will be increased.

However, the existing broadcast frame adjustment algorithms in [5] [6], are designed based on two-hop neighbor information. Therefore, only one vehicle in Two-Hop neighbors (TH) which occupied the last time slot in the broadcast frame, denoted by node x, can adjust the length of BF by broadcasting its switching information. In [6], node x will broadcast its switching information in its reserved time slot in BF. On the other hand, node x will broadcast SWITCH packet including its switching information in CP [5]. The rate of adjusting BF length affects the PDR because the safety packet will be transmitted after the last time slot in the BF. In this paper, we propose an Efficient and Fast Algorithm to adjust the Broadcast frame length, called EFAB based on three-hop neighbor information. In our scheme, a head node in One-Hop neighbors (OH) can suggest a new time slot for possible switching nodes. Hence, in each SI, more than one node can switch to new time slots. The proposed algorithm is

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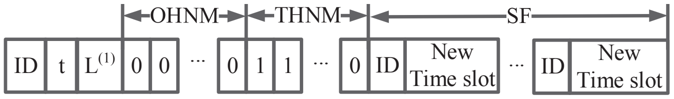

Fig. 2: Format of each frame broadcast in BP.

shown to be more efficient and achieves faster broadcast frame adjustment than the existing algorithms.

II. A Novel BF Adjustment Algorithm

A. Preliminaries

In this scheme, we assume that each vehicle (now called a node) has one half-duplex transceiver which can either transmit or receive but cannot do both simultaneously. All nodes are time-synchronized using the Global Positioning System (GPS). The CCH and SCHs are defined according to Fig. 1. Each vehicle has to occupy one time slot in the BF according to HTC-MAC protocol [7]. When a node successfully occupies a time slot, it will keep accessing the same slot in all subsequent frames without collision. Each vehicle transmits a packet during its time slot. For a certain node x, IDs of x's OH (IDOHN) is defined N_x and a packet is divided into six main fields. A packet is shown in Fig. 2 and defined as follows:

1) The IDentifier (ID): x.
2) The reserved time slot: t_x.
3) Length of time slots used by its OH (LOHN): $L_x^{(1)}$.
4) The bit map of time slots used by OH (OHNM): $B_x^{(1)}$.
5) The bit map of time slots used by TH (THNM): $B_x^{(2)}$.
6) Suggestion Field (SF): S_x. There consists of set of possible switching nodes ($P_x : P_x \subseteq N_x$) and a new time slot for each node $t_j^x, j \in P_x$ if node x is a head node of its OH. Otherwise, if it receives packet transmitted from a head node, it will update a set of possible switching nodes (Z_x) and a new time slot for each node $\tau_j, j \in Z_x$.

Similar to [7], we use the access time slots in the BF. However, different from HTC-MAC [7], the broadcast packet in Fig. 2 contains bits to represent status of time slots for OH and TH. The neighbors implicitly detect the node ID from the broadcast packet in each time slot and save them. The information in the IDOHN and OHNM fields is necessary for a new node to decide which time slots it can access or successfully occupy. The information in THNM and SF fields is used to adjust the length of BF as to be described in next Section II.B.

B. EFAB Algorithm

After each node has occupied exactly one time slot, according to [7], each node will consider to adjust its length of BP to improve the PDR of safety packets. Firstly, we define the OH and TH information following Rules 1-3. Note that in EFAB algorithm, the bits i^{th} in $B_x^{(1)}$ and j^{th} in $B_x^{(2)}$ to represent status of time slots given by

$$b_i = \begin{cases} 1, & \text{if } i^{th} \text{ is used by a node y} \in N_x, \\ 0, & \text{otherwise.} \end{cases}.$$

$$b_j = \begin{cases} 1, & \text{if } j^{th} \text{ is used by y} \in N_x \text{ (or) y} \in N_k, \text{ k} \in N_x, \\ 0, & \text{otherwise.} \end{cases}.$$

TABLE I: Node *h*'s NIT at the end of SI

N	t	$LOHN$	$OHNM$	$THNM$	STL
h	1	12	100000001000	100001001000	
g	9	12	100001001000	110101001000	3, 5, 7, 8

Rule 1: For a node x, its packet contains the value $L_x^{(1)} = \max_j\ [L_j^{(1)}], \forall j \in N_x$.

Rule 2: For a node x, it receives all packets including their OHNMs transmitted by its OH. The length of THNM (LTHN) is given as $L_x^{(2)} = \max_j\ [L_j^{(1)}], \forall j \in N_x$.

Rule 3: Considering OH, if a node x is the first node transmitting packet in the BF, it becomes a head node.

Secondly, according to [1] [2], nodes in TH cannot use the same time slots. In addition, OH information is built reliably by each node because it receives all packets transmitted in its transmission range on a time slot of BF. Since three-hop and TH information are build from OH information, they are also actually reliable. When a head node x wants to suggest a new time slot for possible node j, it has to consider j's TH information. To avoid collision in TH, we propose the Rules 4 and 5 as follows.

Rule 4: For a head node x and each node j, $\forall j \in N_x$, the length of suggestion bit map of node j is given as $L_{xj}^{(3)} = \max\ \{L_x^{(1)}, L_j^{(2)}\}$. This field is called Suggestion Bit Field ($B_{xj}^{(3)}$). A bit i^{th} in $B_{xj}^{(3)}$ is given by

$$b_i = \begin{cases} 1, & \text{if } i^{th} \text{ is used in } B_x^{(1)} \text{ (or) in } B_j^{(2)}, \\ 0, & \text{otherwise.} \end{cases}.$$

Rule 5: For a head node x and a node $j \in N_x$, the current time slot of node j is t_j and a set of index of bits **0** in $B_{xj}^{(3)}$ is I_{xj}. A set of Suggestion Time Slot (STL) is given as $T_{xj} = \{k \in I_{xj} : k < t_j\}$.

Node x maintains Neighbor Information Table (NIT) defined as N_x, reserved time slots $\{t_j, j \in N_x\}$, LOHN $L_x^{(1)}$, OHNM $B_x^{(1)}$, THNM $B_x^{(2)}$, STL $\{T_{xj}, j \in N_x\}$. According to Rules 1-5, we build the NIT for each node in the considered topology for vehicles, as shown in Fig. 5. We assume all nodes in considered topology acquired time slots successfully according to [7]. Following Rule 3, we have three head nodes *h, d* and *a* for this topology and Tables I shows an example for node *h*.

Thirdly, after a head node builds STL for possible switching nodes, it will choose a new time slot for each possible node to broadcast during its reserved time slot. To do that, a head node will follow Rule 6.

Rule 6: Consider the case where there exists a head node x and a set of possible switching nodes P_x. Node x sorts the IDs of P_x in decreasing the order of their occupied time slots, P'_x. Node x chooses the information for S_x according to Alg. 1. In Alg. 1, the first node k in P'_x will choose the lowest time slot in T_{xk}. And then, node x will delete both this node in P'_x and this time slot in all STL of its NIL. Then, this will be repeated until no possible node remains in P'_x.

However, when a possible node receives packets transmitted by more than two head nodes, a possible node will choose only one switching information to transmit in its reserved time slot following Rule 7. In another case, when more than two nodes in OH receive the same time slot in suggestion field, only one node can switch to a new time slot following Rule 8.

Algorithm 1 Selecting S_x for a head node x

```
Input: $P'_x$ and $T_{xj}, \forall j \in P'_x$
Output: $S_x$
while $length\ of\ P'_x \neq 0$ do
    $k = P'_x(1)$
    $t^x_k \leftarrow T_{xk}(1)$
    $P'_x = P'_x \setminus \{k\}$
    $T_{xj} = T_{xj} \setminus \{t^x_k\},\ \forall j \in P'_x$
end while
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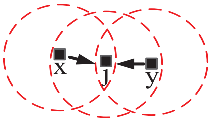

Fig. 3: Scenario for Rule 7.

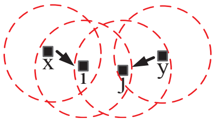

Fig. 4: Scenario for Rule 8.

Rule 7: Assume that node *j* receives t^x_k and t^y_k transmitted by two head nodes x and y, where $k \in N_x, k \in N_y$, as shown in Fig. 3. The τ_k in S_j transmitted by node *j* is given as

$$\tau_k = \begin{cases} t^x_k, & \text{if } t_x < t_y, \\ t^y_k, & \text{otherwise.} \end{cases}.$$

Rule 8: Assume that node *j* receives t^x_j transmitted by a head nodes x and node *i* receives t^y_i transmitted by a head nodes y, where $t^x_j = t^y_i$, $i \in N_x, j \in N_y, i \in N_j, j \in N_i$, as shown in Fig. 4. The τ_j in S_j and τ_i in S_i transmitted by nodes *j* and *i* are given as

$$\text{if } t_j < t_i\text{:} \begin{cases} \tau_j \leftarrow t^x_j,\ Z_j = Z_j \cup \{j\} \setminus \{i\} \\ \tau_i \leftarrow t^x_i,\ Z_i = Z_i \cup \{j\} \setminus \{i\} \end{cases}.$$

$$\text{if } t_j > t_i\text{:} \begin{cases} \tau_j \leftarrow t^y_i,\ Z_j = Z_j \cup \{i\} \setminus \{j\} \\ \tau_i \leftarrow t^y_i,\ Z_i = Z_i \cup \{i\} \setminus \{j\} \end{cases}.$$

Rule 9: If a node *j* receives all packets transmitted by all nodes in its OH including its ID and new time slot in their suggestion fields, it will change to new time slot in next SI.

A node *j* switches successfully to a new time slot if and only if it satisfies Rule 9. Now, we apply EFAB algorithm to a considered topology as shown in Fig. 5. In the first time slot, node *h* is a head node of its OH set, nodes {*h, g*}. Node *h* broadcasts a packet suggesting node *g* moving to a new time slot #3 following node *h*'s NIT. Similarly, a head node *d* broadcasts a packet suggesting *f* moving to a new time slot #3 and *c* moving to a new time slot #1. A head node *a* broadcasts a packet including *b* moving to a new time slot #1. Once node *e* receives packet transmitted by a head node *d*, node *e* will include i) *f* and a new time slot #3 and ii) *c* and a new time slot #1 into its suggestion field. Node *e* broadcasts its packet in its reserved time slot. Notice that in nodes {*a, b, c*}, nodes *c* and *b* receive the same suggested time slot. According to Rule 7, when node *b* receives packet transmitted by node *c*, node *b* will delete both its ID and a new time slot. Then, node *b* updates the fact of *c* moving to a new time slot #1 into node *b*'s suggestion field. Comparably, node *g* deletes both its ID and a new time slot and then updates *f* moving to a new time slot #3 into its suggestion field to broadcast. When nodes *c* and *f* receive all packets transmitted of their OH, they will change to a new time slot and their OH will update a new information in next SI.

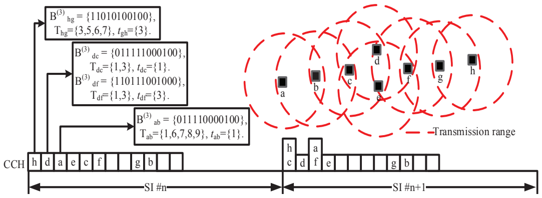

Fig. 5: Considered topology for vehicles.

III. PERFORMANCE EVALUATION

A. Protocol overhead

In Fig. 2, the size of packet transmitted by a node x is approximated as follows. The number of nodes in one-hop neighbor set of node x is defined as N_x and we need at least $\lceil \log_2 N_x \rceil$ bits to represent a node ID, where $\lceil . \rceil$ denotes the ceiling function. Similarly, the number of time slots is defined as s and $\lceil \log_2 s \rceil$ bits identify time slots in a BF. We set the maximum number of nodes in SF $\lceil N_x/4 \rceil$ for each broadcasting packet. Therefore, the total packet size S (bits) is

$$S = (1 + N/4) \cdot \lceil \log_2 b_{\text{ID}} \rceil + (2 + N/4) \cdot \lceil \log_2 s \rceil + 2 \cdot s$$

where b_{ID} is the number of bits to represent a node ID. As in [1] [2], we make the following assumptions: N_{max} = 100, data rate R = 12 Mbps supported by the IEEE 802.11p OFDM physical layer for the 5-GHz band, b_{ID} = 1 byte, s = 100 time slots. The estimated packet size of N_{max} is S = 571 bits ≈ 72 bytes. A packet requires a transmission time of 0.05 ms. After adding the guard period and physical layer header, we assume a slot duration of 0.1 ms. Consequently, with s = 100 time slots, the duration of one complete BF on the control channel is T = 10 ms. Similar to DMMAC [6] and HER-MAC [5], the maximum packet size and duration of one complete BF are S_{DMMAC} = 835 bits, T_{DMMAC} = 12 ms and $S_{\text{HER-MAC}}$ = 478 bits, $T_{\text{HER-MAC}}$ = 9 ms, respectively. The maximum packet size and duration of one complete BF in EFAM are higher than those of HER-MAC because EFAB uses three-hop information. However they are lower than those of DMMAC since EFAB does not transmit IDs of one-hop neighbor. Despite this, all of them are compliant with the 100 ms maximum delay requirements for most of the safety application [4].

B. Simulation results

To validate our algorithm, we use NS-2 [8] and model in [9]. The values of the parameter are summarized in Table. II. Before using broadcast frame adjustment algorithm, we perform some setups for a fair comparison. For a given topology, all algorithms require that each node has to acquire time slot successfully in BF. This is achieved using HTC-MAC protocol [7]. After that, we run separate algorithms as follows:

1) For HER-MAC, when a new node wants to acquire a time slot in BF, it has to broadcast HELLO packet in CP. When a node wants to change the time slot, it broadcasts SWITCH packet in CP.
2) For DMMAC and HTC-MAC, when a node wants to change the time slot, it broadcasts its switching information in its reserved time slot. Note that, these two algorithms allow a node which occupied the last

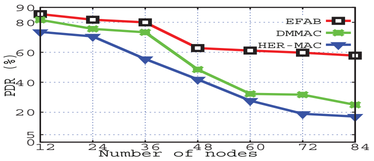

Fig. 6: PDR with $\lambda = 5$ pkts/SI.

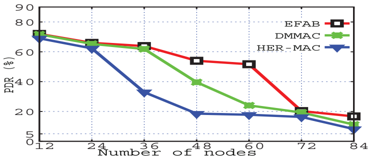

Fig. 7: PDR with $\lambda = 10$ pkts/SI.

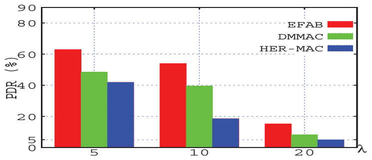

Fig. 8: PDR with $N = 48$ nodes.

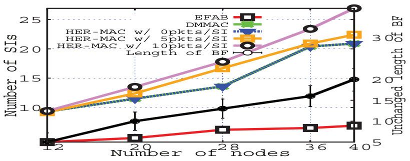

Fig. 9: Average number of SIs.

time slot in the broadcast frame to adjust the length of BF.

3) For EFAB, a head node announces switching information in its reserved time slot.

Assume that a node has to successfully transmit a WSA packet. We analyze two values to compare EFAB with DMMAC and HER-MAC algorithms: a) Average number of SIs (AnS) that have successfully adjusted the length of BF, and b) Packet Delivery Ratio (PDR) of WSA packets defined as:

PDR = total successful transmission of WSA packets / total transmission of WSA packets.

Considering the same topology, the WSA packet arrival rate (λ packets/sync interval (pkts/SI)) is set to 5 pkts/SI and 10 pkts/SI, the contention window for WSA packet and SWITCH packet are set to $W_{ow} = 32$ and $W_{os} = 8$. In HER-MAC algorithm, when the WSA packet arrival rate increases, the collision also increases and then, SWITCH packets can be dropped. Hence, the AnS using HER-MAC algorithm with 5 pkts/SI and 10 pkts/SI is greater than using DMMAC or EFAB algorithm. Particularly, when AnS using HER-MAC algorithm with 0 pkts/SI, the AnS equals to using DMMAC algorithm. On the other hand, EFAB algorithm allows more nodes to adjust the length of BF by suggestion field. Consequently, AnS in EFAB algorithm is faster than both of DMMAC and HER-MAC algorithms. Although the networks apply different schemes to adjust the length of BF, the final length of BF will converge to the same value (see Fig. 9). Nonetheless, the EFAB algorithm is faster than both DMMAC and HER-MAC algorithms in all typologies as shown in Fig. 9.

The exchanging of WSA/ACK/RES packet begins after the last time slot occupied in two-hop neighbors. When the length of BF decreases, the exchanging of WSA/ACK/RES packet has more chance to transmit and hence, the PDR of WSA packets will be increased. In HER-MAC algorithm, WSA and SWITCH packets can collide because they use CSMA access scheme and it makes PDR of WSA packets the lowest, as shown in Figs. 6-8. The smaller the node density is, the smaller a switching node is. Consequently, PDR using the EFAB algorithm approximates to using DMMAC algorithm. However, with 5pkts/SI in Fig. 6, the length of BF is adjusted quickly. Hence, the length of period using to exchange WSA packets is increased. The PDR using EFAB algorithm is higher than using DMMAC or HER-MAC algorithm when node density increases. Similarly, with 10pkts/SI in Fig. 7, when a node density is in interval (36 to 72 nodes) node density, the PDR using EFAB algorithm is higher than using DMMAC or HER-MAC algorithm. Nonetheless, when the node density is high, the collision because of CSMA access scheme increases; thus, PDR using the EFAB algorithm approximates to using DMMAC algorithm. With the node density of 48 nodes, we set the WSA packet arrival rate to 5, 10 and 20 pkts/SI. PDR of EFAB is clearly higher than that of both DMMAC and HER-MAC as shown in Fig. 8.

TABLE II: PARAMETER SETTINGS

Parameters	*Value*	*Parameters*	*Value*
Street length	1 km	Propagation model	Nakagami
# lane/direction	2	Speed mean value	100km/h
Speed standard deviation	20 km/h	Transmission range	150m
Data rate	12Mbps	WSA	100 bytes
Slot duration	1 μs	Simulation time	20 seconds

IV. CONCLUSION

In this paper, we propose an efficient and fast algorithm to adjust the length of broadcast frame in MAC protocol using hybrid TDMA/CSMA, called EFAB algorithm. Based on three-hop neighbor information and NIT, a head node can suggest the new time slot for each possible node. Simulation results show that average number of SIs that have successfully adjusted the length of BF using EFAB algorithm is lower than using DMMAC or HER-MAC algorithm. In addition, the MAC protocol using EFAB algorithm has higher PDR of WSA packets than using DMMAC or HER-MAC algorithm.

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