

A Survey of TDMA-based MAC Protocols for Vehicular Ad Hoc Networks



Siman Emmanuel, Ismail Fauzi Bin Isnin, Mohd. Murtadha Bin Mohamad

Abstract— MAC design in a vehicle network is a challenging task due to high node speed, frequent topology changes, lack of infrastructure, and different QoS requirements. Several medium access control protocols based on Time Division Multiple Access (TDMA) have recently been suggested for VANETs in an effort to guarantee that all cars have sufficient time to send safety messages without collisions and to decrease the end-to-end delay and the loss ratio of packets. The reasons for using the collision-free media access control paradigm in VANETs are identified in this document. We then present a new topology-based classification and provide an overview of the MAC protocols suggested for VANETs based on TDMA. We concentrate on these protocols' features as well as their advantages and constraints. Finally, we provide a qualitative comparison and address some open problems that need to be addressed in future studies to enhance the efficiency of TDMA-based MAC protocols for vehicle-to-vehicle (V2V) and vehicle to infrastructural (V2I) communications.

Keywords: VANET, IEEE 802.11p, DSRC, MAC protocol, TDMA.

INTRODUCTION

Vehicular Ad hoc Networks (VANETs) are primarily designed to improve safety on roads. They can also be used to improve traffic management conditions and to provide on-board infotainment such as Internet access, video streaming, etc [1]. VANETs are an example of Mobile Ad hoc Networks (MANETs) but with their own specificities: high node mobility with constrained movements and the mobile nodes have ample energy and computing power. In VANETs, communications can either be between vehicles V2V (Vehicle To Vehicle) or between vehicles and road side units V2I (Vehicle to Infrastructure). The applications for V2V and V2I can be divided into the following three services: safety services, traffic management and user-oriented services. Safety services have special requirements in terms of quality of service. In fact, bounded transmission delays as well as low access delays are mandatory in order to offer the highest possible level of safety. At the same time, user-oriented services need a broad bandwidth. Medium Access Control will play an important

role in satisfying these requirements.

In VANETs, the nodes share a common wireless channel using the same radio frequencies, so inappropriate channel use can lead to collisions and bandwidth waste. Channel sharing is therefore the main problem in the quest for high-quality service. Medium Access Control (MAC) systems must be intended to effectively and fairly share the medium between the distinct nodes. However, traditional wireless MAC protocols are not suitable for use in VANETs due to the special characteristics of VANETs, which either leads to the adaptation of these traditional MAC protocols or to the design of new mechanisms, [5]. Generally, one of two wide classifications of MAC protocols is: contention-based and contention-free. Each node can try to access the channel when it has data to be transmitted using the carrier sensing mechanism in contention-based protocols. Several nearby nodes can sense a free channel and thus decide to simultaneously access and transmit their information, causing collisions at the target nodes, [6]. Contention-free MAC protocols attempt to prevent this by at any specified moment assigning access to the channel to just one node in a neighborhood. Contention-based protocols do not require a predefined timetable, each node will compete for access to the channel when it needs to be transmitted without any guarantee of achievement.

This can trigger issues such as packet loss or big delay in accessing apps in real time. Contention-free protocols, on the other hand, can provide limited delays for real-time applications, but require the regular exchange of control messages to maintain the schedule table and require time synchronization between all the network nodes. MAC protocols must give an effective broadcast service with predictable limited delays in order to provide QoS and decrease collisions in VANET networks. They also have to deal with frequent changes in topology, different node spatial densities and the hidden / exposed node issue. Multi-hop communication and nodes (cars) must be supported going in opposite directions. The significance of these problems was verified by developing a particular IEEE standard to support VANETs. The IEEE 802.11p, the emerging standard used to enable vehicle communication, is a contention-based MAC protocol, using a priority-based access scheme using Enhanced Distributed Channel Access (EDCA) and Carrier Sense Multiple Access with Collision Avoidance (CSMA / CA) mechanisms in [9]. The IEEE 802.11p standard does not provide limited communication delay with a reliable broadcast mechanism. In VANETs, which are specifically designed to improve road safety, this disadvantage is

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particularly important. It is therefore a particularly difficult job to design an effective MAC protocol that meets the QoS demands of VANET apps.

An evolving field of VANET studies is TDMA-based MAC protocols where time is split into slots and only one car can access the channel at each slot, in [10]. All cars in TDMA use the same frequency channel at a separate moment without any code sequence. This implies the transmitter and the receiver must be synchronized with the frequency. Unlike the FDMA system, the TDMA method guarantees that they will not experience interference from other concurrent transmissions in [4], which may suffer from interference between cars using the same frequency band and begin transmitting at the same moment. In addition, TDMA can support I2V communication effectively as it is possible to use fixed RSUs to generate and handle the TDMA slot booking timetable. Another significant characteristic of the TDMA system is that it enables allocation to separate cars of a distinct amount of time slots. This implies that, by concatenating or rescheduling time slots based on access priority, the bandwidth resources can be allocated on demand to separate cars. However, by offering collisions with TDMA, a collision-free transmission with limited access delay, can happen in essence, and TDMA is better adapted to VANET demands. MAC protocols have drawn a lot of attention recently, particularly those based on the TDMA method, and many protocols have been suggested in [11]. While these protocols can provide deterministic access time without collision, they must be conscious of the slot distribution of the neighbors in order to function effectively. Moreover, most of them use real-time systems that provide location and time data such as the Global Positioning System (GPS) that allows them to synchronize the cars that communicate. However, due to the high mobility of vehicles in VANETs that can affect the performance of these protocols in [13], many problems arise. Therefore, to avoid collisions, the scheduling mechanism in TDMA protocols should take into account the mobility features of VANETs.

LITERATURE REVIEW

This section presents in the vehicle ad hoc network a structured literature review related to the TDMA-MAC protocol. TDMA-based MAC protocol guaranteeing efficient broadcasting service and quality of service (QoS) for inter-vehicle communications and solving hidden / exposed terminal problems caused by random access in multi-hop network architecture [3][14]. Unlike the IEEE 802.11p standard, it is a single channel protocol that is not suitable for dedicated short-range communication (DSRC) using seven DSRC channels and assigning time slots based on vehicle direction to reduce vehicle-to-vehicle collisions in, [15][2]. However, for the control channel (CCH) and service channels (SCHs), it employs two half-duplex transceivers, respectively. Many contention-free TDMA MAC protocols have recently adopted cluster-based architecture because with the help of cluster head (CH) they can provide effective topology control, fair channel access within each cluster and minimize intra-cluster and inter-cluster transmission collisions in [16].

Clustering-based multichannel MAC (CBMMAC) protocol uses both contention-free and contention-based

access mechanisms and supports applications that are both safety-relevant and non-safety service. However, there are two half-duplex transceivers for each vehicle, [17][18]. A cluster-based MAC (TC-MAC) multichannel TDMA protocol combines a cluster-based centralized management method with a new dynamic TDMA slot booking mechanism. In contrast to the standard IEEE 1609.4 structure, its frames are not divided into two segments [8]. By using SCH during the CCHI, TC-MAC can improve the use of bandwidth. It is designed for simple one-way highway scenarios, however, and the likelihood of collisions with transmission is very high for bidirectional expressway scenarios and urban scenarios where collision problems can easily occur. The critical review of the literature providing the necessary background information and the basis for the material presented in the following sections.

1. Dedicated Short Range Communication (DSRC)

The Dedicated Short Range Communication Specification is based on the present IEEE 802.11p wireless connectivity standards, with modifications to the PHY and MAC layers to ensure reliable and low latency in car communication, 5 GHz Dedicated Short Range Communication (DSRC) and Wireless Access Vehicle Environment (WAVE) IEEE 1609 for safety and networking., [19]. The U.S. Federal Communications Commission (FCC) allocates 75M-Hz of bandwidth resources in the 5.9G-Hz band, specifically for inter-vehicle (i.e., V2V or V2I) communication in VANETs, commonly known as dedicated short-range communication (DSRC). DSRC splits the spectrum of 75M-Hz into seven frequency bands, including one control channel (CCH) for the transmission of safety or control texts and six service channels (SCHs) for the transmission of service texts in figure 1. Europe, Japan and China have suggested their own vehicle network norms and communication protocols. Based on the network of cellular LTE, S. Chen, Hu, Shi, & Zhao, S. In the VANET environment, [20] suggested LTE-V as an alternative for V2X. The program in China is considered to be a more appropriate vehicle communication network technology. Europe has assigned a dedicated 5855-5925MHz channel for DSRC, while Japan has selected 755.5-764.5MHz as a specialized communications band for smart transport systems. The aim of this Specification is to create Smart Transportation Systems (ITS) to enhance ITS communications architecture for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) traffic management, transportation safety and mobility.

The Dedicated Short-Range Communication Technology was developed for short distance mobile vehicle applications. More specifically, the short distant communication takes place between the on-board unit (OBU) on the vehicle and the beacon in the (fixed) road environment. This basic system shows all the elements described in the idea of the DSRC. DSRC packet messaging technique was created to operate at 5.8 GHz frequency using typically 10 MHz bandwidth with information rates of up to 2048 Mbps. This is the European standard accepted by the European Standards Committee (CEN), [15][21].

However, the separate requirements (used frequency, amount and length of channels, etc.) were used in separate nations and continents. For example, the U.S. DSRC protocol uses 5.9 GHz frequency split into seven 10 MHz bands. Dedicated Short-Range Communications (DSRC) is a collection of initially intended procedures for Intelligent Transportation Intelligent Communications, [22], figure 1. Intelligent Transportation Systems (ITS) was instrumental in reducing daily commute times and reducing congestion in intersection traffic. Traditional ITS uses, [23], smart intersections capable of detecting vehicles using loop detectors, magnetic detectors or cameras and adapting the decision on traffic light accordingly. Such solutions are very expensive and in most cities over the past three decades have therefore not scaled well. Dedicated short-range communication (DSRC) technology is a very attractive new technology.

According to [24], the DSRC system has two main operating modes: a broadcast mode and a peer-to-peer mode. A typical DSRC device includes two independent radios: one dedicated to receiving and broadcasting on the public safety broadcasting channel (i.e. channel 172) and one dedicated to peer-to-peer communications on the control and general service channels. Although different types of traffic safety related messages may be broadcast by the public safety channel, the BSM is considered representative of the size and frequency of most DSRC safety messages. The basic frame format for broadcast security related DSRC messages is similar, but the associated packet lengths will vary.

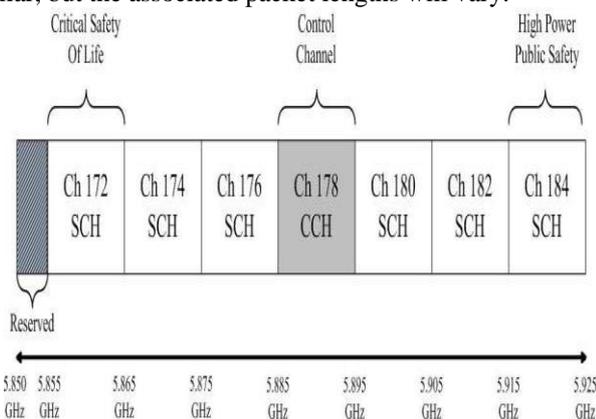


Figure 1: DSRC Framework

The IEEE 802.11p standard is a single channel protocol that is not suitable for dedicated short-range communication (DSRC) in multichannel scenarios. Haddad et al. (2015) Based on ADHOC MAC, VeMAC can use the seven DSRC channels and allocate time slots based on vehicle movement direction to significantly reduce transmission collisions between vehicles. However, it uses two half-duplex transceivers respectively for the control channel (CCH) and service channels (SCHs), Figure 1. For VANETs such as ADHOC MAC and VeMAC protocol, multiple access

(TDMA) based MAC protocols are suggested to solve the above problems. ADHOC MAC is a distributed MAC protocol based on TDMA that provides efficient broadcast and service quality (QoS) guarantees for inter-vehicle communication and solves hidden / exposed terminal problems caused by random access in multi-hop network architecture, [7].

2. Time Division Multi Access (TDMA)

According to [25], VANETs highlights the weaknesses of regional MAC standards. MAC protocol is responsible for the wireless resource distribution between vehicles. It must ensure that live critical safety messages are delivered with a limited delay. MAC standardization has a setback as the work is based on a contention-based mechanism due to unbounded delay in security messages. Less-based contention mechanism such as CDMA, SDMA and TDMA. TDMA-based MAC solves only a few problems by evaluating the basic idea, operation and performance of these protocols to outline the current status of MAC research for VANETs. Discussing and identifying the limitations of regional standards. It also develops important MAC protocols based on TDM, clearly stating their basic idea, operation and performance, followed by their comparison. VeSOMAC (Vehicle Self Organizing MAC): This protocol is proposed to contain free access technique that uses in-band control mechanism where each node shares a bit map with its neighbors, containing slot information. In both synchronous mode and asynchronous mode, it can operate. Improved TCP throughput in this protocol. The results of the simulation are based solely on the highway scenario. Based on [26] Originally, black-burst (channel jamming signal) was used in wireless networks to inform one-hop neighbors about the channel's use and to prevent collisions by forcing reference nodes. Using the redundancy time at the beginning of time slot, each vehicle sends a black burst after a random delay from the beginning of the reservation slot to inform its neighbors of the time slot's access will. By using the randomly shifted black-burst, a node can detect other nodes that reserve current slot in two-hop range in advance and decide to reserve current slot or re-select another idle slot. After successfully reserving the selected slot, the black-burst part in the subsequent frames will be removed. Black-burst is based on a novelty time slot acquisition scheme for the TDMA / CSMA multi-channel MAC hybrid in VANETs. In this scheme, all contending nodes broadcast a black burst at the beginning of the selected slots to inform others about the access of their selected idle slots within their two-hop range. The proposed access scheme can reduce the number of access collisions significantly. The results of the simulation show the superiority of the scheme in time slot acquisition. However, the performance of BB-MAC is much better than HTC-MAC when the density becomes higher, figure 2. The proposed slot acquisition scheme, called BB-MAC, can significantly reduce access collisions and speed up time slot acquisition compared to the above-mentioned protocols. This scheme was limited to a vehicle node medium density.

According to [27], provide a reason for the interactive and time-critical distance-bounding phase in which the prover is required to send the response to the verifier as soon as the challenge has been received to minimize the delay. In CSMA / CA, however, both RSU and cars must compete on the same channel for transmission opportunity, while at the same moment only one party is permitted to send packages.

For example, an RSU and a vehicle will run a distance bounding protocol and more specifically assume that they have already completed the slow phase and will do the bounding phase of the n-rounds distance, then the RSU will send a challenge and start its clock. It is difficult to ensure that the car will be able to send the reply in time as it could be in the queue to transmit data in order to prevent possible collision. The waiting time is not deterministic and can't be pre-measured. As a result, the challenge / response propagating round-trip time can not be correctly obtained from the recorded moment, which fails the range limitation. The implement TDMA to a suggested system in order to prevent this issue. In particular, TDMA operates in a time-slotted structure, i.e. a virtual frame with a set of time slots with the same time period (e.g. 1ms). When the node can send information without collision, each node is allocated at least one time slot in each frame, in figure 2. TDMA is a method used to enable multiple nodes to transmit on the same frequency channel based on the slot reservations as follows

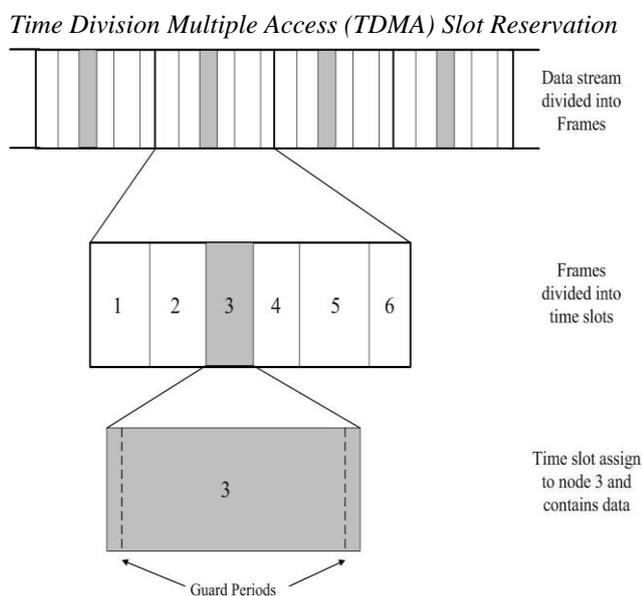


Figure 2: Time Division Multiple Access (TDMA) Slot Reservation

- Addresses scalability.

- It divides the signal into different time frames.
- Each frame is divided into several time slots, where each node is assigned to a time slot to transmit.
- The length of the time slot may vary, based on the needs of the node assigned to it.
- The main advantage of TDMA is reducing interference between nodes.

According to [13][28], the writer regarded the design of the MAC layer due to the progressively extensive application demands in VANETs, which one must consider the low-latency and high-reliability transmission specifications for security texts, as well as the high-throughput requirements for entertainment and service emails. The Author adopts a TDMA-based access system to provide vehicle contention-free transmission and guarantee message transmission reliability. Also embrace a system of contention-based negotiation to guarantee that cars using service channels are fair. There are few assumptions about the model before introducing the channel frame structure: First, each vehicle is equipped with a half-duplex transceiver that can only work on the CCH or SCHs simultaneously. Second, for inter-vehicle synchronization, GPS will provide an accurate UTC clock signal. [12], a channel frame structure shows a schematic diagram of one synchronization period channel frame structure. The CCH framework is split into the era of broadcasting and negotiation. The broadcast period consists of time slots of equal length, and the amount of slots will alter with traffic densities to enable the car to periodically broadcast status messages. The negotiation period is based on the system for back-off access to guarantee fairness between cars that access SCHs. The three-way handshake protocol is used during the negotiation period; the car can choose to access an accessible service channel each time a handshake protocol is finished. Therefore, the length of the SCHs will adapt to the results of the negotiations. When compared, the fresh system somewhat improves SCH's throughput. Existing MAC protocols based on TDMA may result in slot assignment collisions when multiple vehicle sets move with different speeds together. Contrary to this, intersections have the greatest need for reliable data communication to ensure the safety of driving.

TABLE 1: Qualitative comparison of TDMA-based MAC protocols in VANET

	HTC-MAC	CTMA C	TDMA-CS MA	PTMAC	RCMA C	FCM-MAC	EQM-MAC	APDM	MoMA C	ABC	VeSOM AC	BB-MA C
References	Nyojen et al	Haddad et al	Y. Nguyen et al	Jiang et al	N. Ngujen et al	Yao et al	Song et al	Song et al	Liu et al	Lyu et al	Hag & Liu	X. Zhang et al
Published	2016	2016	2016	2016	2016	2017	2017	2017	2018	2018	2019	2019
Channel	Multiple	Single	Single	Multiple	Single	Multiple	Multiple	Multiple	Multiple	Multiple	Multiple	Single
Pure TDMA	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Merging collision	Solved	Solved	Solved	Possible	Possible	Possible	Possible	Possible	Possible	Solved	Possible	Possible
Access collision	Solved	Solved	Possible	Solved	Solved	Solved	Solved	Solved	Solved	Solved	Solved	Solved

Mobility	High	High	High	High	Medium	High	High	High	High	High	High	Medium
Density (scalability)	High	High	High	High	High	High	High	High	Medium	Medium	High	Medium
Broadcast service	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mobility model	Highway	Highway	Highway/Urban	Highway	Highway	Highway	Highway	Highway	Highway	Highway	Highway	Highway
Vehicular traffic	Bidirectional	Bidirectional	N/A	Bidirectional	Unidirectional	Unidirectional	Bidirectional	Bidirectional	Unidirectional	Unidirectional	Unidirectional	Unidirectional
Data Traffic load	High load	High load	Medium	High load	High load	High load	High load	High load	High load	High load	High load	Medium
Control overhead	High	High	Medium	High	Medium	Medium	Medium	Medium	Low	Low	Medium	Medium
Transmission range	Medium	Medium	Medium	Medium	Medium	High	High	High	Low	N/A	High	High
Multimedia applications	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Real-Time applications	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Positioning System GPS	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Synchronization	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Simulator	MATLAB	MOVE/SUMO/NS234	MATLAB	SUMO/MATLAB	MATLAB	NS2	NS3	NS3	SUMO	SUMO	N/A	OMNET++

3. Cluster based Time Division Multi Access (TDMA)

VANET is based on the reliability of the Medium Access Control (MAC) protocol, according to [16], figure 3. VANET must provide reliable and timely delivery for a security application. Quality of service (QoS) requirement such as delivery delay and packet loss rate cannot be guaranteed under conventional MAC protocol, particularly under high vehicle mobility, heavy traffic conditions, frequent changes in network topology and high network density affecting timely delivery of critical safety applications [7]. Despite increasing vehicle density and transmission range, even if the CH moved out of the cluster without the need for cluster reconfiguration, the vehicles would still remain connected to the existing cluster for a long time. The approach enhanced the stability of the cluster. In addition, it significantly minimized the delay in broadcasting safety messages by using the worst-case scenario. Compared to the threshold-based approach, CH achieved a reduction of approximately 50 percent in the delay in transmitting safety messages to CMs. The process minimizes interference in adjacent clusters and delivered safety messages efficiently. It also provides stability to the cluster and minimizes overhead cluster. Only vehicles that move in the same direction and have the same road ID are considered to form a cluster group on a highway within a road segment. A message moving in a different direction from a neighboring vehicle is not considered and is ignored. The vehicles' arrival rate is supposed to be a Poisson process.

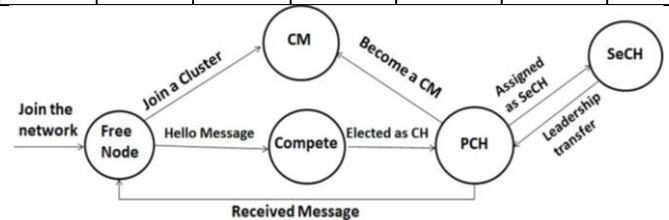


Figure 3: clustering Transition Model, [16].

According to [7][31], the standard IEEE 802.11p only provides VANETs with a contention-based MAC protocol while using an enhanced distributed channel access (EDCA) mechanism. However, due to the lack of request-to-send / clear-to-send (RTS / CTS) exchange, it does not provide an effective broadcast service with limited communication delay. Also, when the multiple nodes attempt to send their safety messages simultaneously, the probability of transmission collisions increases. MAC protocols based on Time Division Multiple Access (TDMA) such as ADHOC MAC and VeMAC protocol could solve the above problem. ADHOC MAC is a distributed TDMA-based MAC protocol that provides efficient broadcasting and service quality (QoS) guarantees for inter-vehicle communication and solves hidden / exposed terminal problems caused by random access in multi-hop network architecture. Unlike the IEEE 802.11p standard, it is a single-channel protocol, not suitable for dedicated short-range communication (DSRC), which uses seven DSRC channels and allocates time slots based on vehicle direction to reduce vehicle-to-vehicle collisions.



However, for the control channel (CCH) and service channels (SCHs), it employs two half-duplex transceivers, respectively. Many contention-free TDMA MAC protocols have recently adopted cluster-based architecture because with the help of cluster head

(CH) they can provide effective topology control, fair channel access within each cluster, and minimize intra-cluster and inter-cluster transmission collisions. This paper proposed an average time-based clustering algorithm for link expiration (ALET-CA), which takes into account multiple factors, such as relative distance and relative node velocity, and radius for transmission.

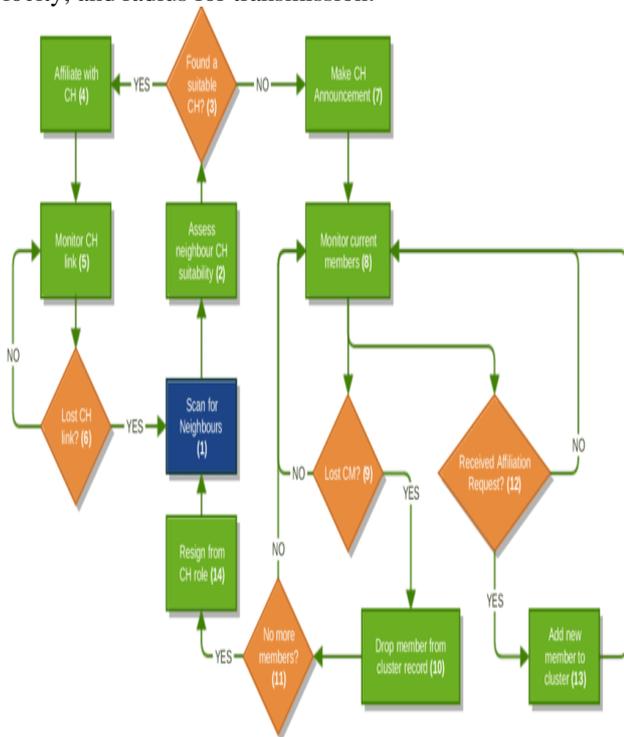


Figure 4: The basic flow of a clustering algorithm [32]

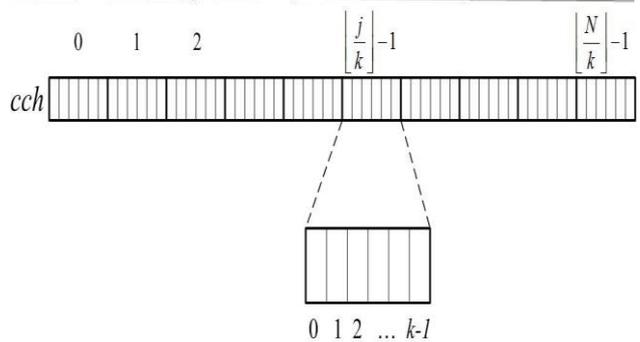
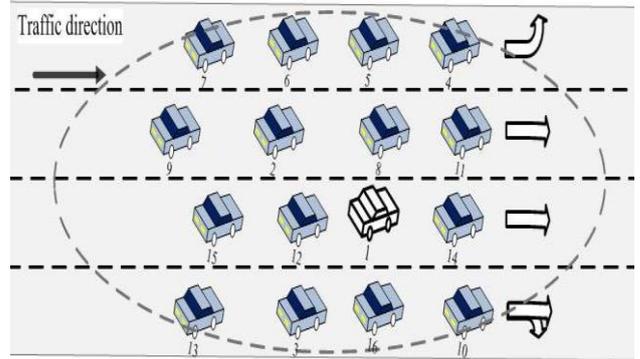
Network model is only for intra-vehicle clusters and inter-vehicle clusters. Because of its high speed and the dense building in the network, cluster structure is more suitable in VANET, according to [17][33]. Cluster algorithm is used to generate multiple clusters where the cluster head (CH) with a maximum connectivity clustering algorithm selects the node with the highest adjacent nodes, but is not suitable for stable cluster structure, figure 4. Modifications in topology change node connectivity. The nodes used by the ALM clustering algorithm's mobility and location do not consider the node's relative position in the cluster structure. The relative node movement is not considered by adopting weighted

clustering algorithm. The current traffic load is not considered by a stable algorithm based VMaSC, which calculates the neighboring node speed function. The SWC and AMA-composed AMAC protocol uses clustering and access information to solve clustering problems for high-speed vehicles. The VeMAC protocol combines random access with fixed allocation access, and uses the technique of random selection to select time slots to reduce transmission collisions and then achieve high network throughput.

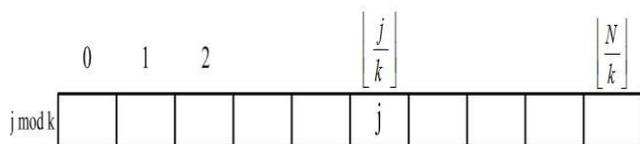
TDMA Assignment Algorithm

- Clusterhead based clustering scheme
- One transceiver on-board
- vehicles are equipped with GPS

- 1 CCH (cch)
- 6 SCHs (k)
- N vehicles
- τ is the slot size in SCHs
- a mini-slot on the control channel



- channel $j \bmod k$ during time slot $[j/k] j$; also, vehicle j owns the ordered pair (j and k, $[j/k] j$)
- The j-th mini-slot of slot $([j/k] - 1 \bmod [N/k])$ on channel cch



The Vehicle Ad-hoc Network (VANET) involves cars with specialized access points, according to [34]. It transmits and gets data from the Sensor Nodes (SNs) and environment to manage traffic loads. Destination routing, car velocity and direction management are therefore significant issues in VANETs. This document introduced the use of VANETS to hybridize Q-LEACH clustering based on FCM. The ideal CH was achieved from the group of SNs through this clustering. The data gathered by these CHs is transmitted to the near-CH highway side unit. The RSU-BS communication took place via the IEEE 802.11.p protocol. Based on the BS information, users know about the environment on the roadside. The performance of this FCM-Q LEACH-VANET was analyzed in terms of energy consumption, total packet transmission, network latency and performance. Results showed that the FCM-Q LEACH-VANET performs better than the IDVR protocol. The suggested technique has been introduced with distinct amount of SNs and 10 highway side units. The output of FCM-Q LEACH-VANET evaluated the VANET effectiveness with Dynamic VANET Routing Intersection (IDVR).



There is currently an intensive research on the problems of reliability and scalability of the routing protocol across large urban VANETs.

Clustering can be used to improve the scalability and efficiency of VANET routing as it results in the production of hierarchical network structures by grouping cars together based on correlated spatial distribution and relative velocity. These organisations, in relation to the benefits of routing, can serve as the grounds for collision detection or congestion detection, information dissemination and entertainment applications. The [32], reviews the design choices taken

when VANET-oriented clustering algorithms are created. It introduces a taxonomy of cluster head selection methods, cluster membership and cluster management issues, and identifies fresh directions and latest trends in the design of these algorithms. Also, methodologies for clustering performance validation are reviewed and a key shortcoming is identified as the lack of realistic modeling of vehicle channels. The significance of a strict and standardized performance evaluation system using realistic car channel models is demonstrated by [24].

TABLE 2: Qualitative comparison of TDMA-based MAC protocols in cluster-based network topology

	VMaSC-LTE	WCS-MAC	BEFM-MAC	STCM	SCMAC	CCFM-MAC	AMAC	EWCA	FCM-QLEACH	Adaptive IEE802.11p
References	Ucar et al	Xie & Li	Torabi & Gbahfarokhi	Shalin & Kim	Cao et al	Y. Zang	Chen et al	Bello et al	Engineering	Nguyen et al
Published	2016	2016	2016	2017	2017	2018	2018	2019	2019	2019
Channel	Multiple	Multiple	Multiple	Multiple	Multiple	Multiple	Multiple	Multiple	Multiple	Multiple
Pure TDMA	No	No	No	Yes	Yes	No	No	Yes	Yes	No
Access collision	Solved	Solved	Possible	Possible	Possible	Solved	Possible	Possible	Possible	Possible
Inter-cluster interference	Possible	Possible	Solved	Solved	Solved	Solved	Solved	Possible	Possible	Possible
Mobility	High	High	High	High	High	High	High	High	N/A	Medium
Density (scalability)	Medium	High	High	Medium	High	high	High	high	Low	Low
Broadcast service	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mobility model	Highway	Highway	Highway	Highway	Highway	Highway	Highway	Highway	Highway	Highway
Vehicular traffic	Unidirectional	Unidirectional	Unidirectional	Unidirectional	Unidirectional	Unidirectional	Unidirectional	Unidirectional	Unidirectional	Unidirectional
Traffic load	High load	Medium	Medium	Medium	Medium	High load	Medium	High load	Medium	Medium
Control overhead	Low	Low	Low	Low	Medium	Low	Low	Low	Medium	Medium
Transmission range	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Multimedia applications	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Real-Time applications	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
GPS System	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Time Synchronization	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Simulator	NS3/SUMO	N/A	SUMO, NS2 & MATLAB	N/A	NS2 & SUMO	MATLAB	SUMO, NS2 & MATLAB	SUMO&NS3	MATLAB 2015b	NS335

4. Hybrid TDMA/CSMA multi-channel MAC protocol

As in [24][35][36], many packet types like HELLO packet, SWITCH packet, and WSA / RES / ACK packet are broadcast during the contention period. Therefore, because of the number of packets transmitted, there is a higher

probability of collision. Thus, the overhead control will decrease the CCH throughput.

A Hybrid TDMA / CSMA multi-channel MAC (HTC-MAC) protocol for VANETs is presented to solve the disadvantages of HER-MAC. Not only does HTC-MAC remove unnecessary overhead control, but it also improves the control channel throughput. Simulation and analysis demonstrate that HTC-MAC outperforms HER-MAC in the average number of time-slot nodes. However, when the node density is large, HTC-MAC needs a bigger ANC's payload size to transmit data to its neighbours. A centralized TDMA-based MAC protocol called CTMAC that used RSU as a vehicle channel coordinator within its communication range [37][9]. The ways in which slots are assigned and reused among the coverage fields of the RSU are intended to prevent accidents triggered by the issue of vehicle interference in overlapping regions. When the results of ADHOC and VeMAC MAC protocols were compared, CTMAC was able to provide a lower rate of access and merging collisions as well as the overhead needed to create and maintain TDMA schedules. CTMAC does not promote multichannel operation and the control channel's secure multi-hop broadcasting service. The PTMAC protocol proposed to decrease the number of packet collisions, especially for encounter collisions. Potential collisions between cars could be identified, predicted, and then eliminated by intermediate cars before they actually happen [22]. The simulations show the protocol's effectiveness. Unbalanced traffic densities will not degrade PTMAC, [19], since no slot partition is used. PTMAC is also suitable for handling four-way traffic under different traffic densities,

unlike a few existing MAC protocols that work only for one way or two-way traffic scenarios. The results show that with the least number of collisions and the highest delivery rate, the PTMAC works best. Since ADHOC MAC enables a car to compete for any vacant slot without taking into account the nature of mobility of the cars, it is appropriate for only one-way traffic and its efficiency is significantly impacted by the enormous amount of crashes under such a four-way intersection situation. This is because not only does PTMAC eliminate collisions between vehicles from opposite directions, but it also prevents collisions from the same direction. Designing a new prediction-based TDMA MAC (PTMAC) protocol to reduce the likelihood of encounter collisions while maintaining high slot utilization and with very small additional overheads. Most collisions of the encounter can be predicted and potentially eliminated before they actually occur. The forecast is based on the data already supplied by the car to help apps related to safety.

- The freshly constructed PTMAC protocol is proven to be appropriate for two-way traffic and four-way junctions in metropolitan areas. Unbalanced densities of traffic will not degrade PTMAC's efficiency.
- By evaluating and comparing our PTMAC protocol to ADHOC MAC and even odd TDMA MAC, PTMAC demonstrates improved efficiency with lower collisions and greater shipping rates for two-way and four-way intersection situations.

Table 3. Different adaptive IEEE 802.11p-based multi-channel MAC protocols.

Reference	Protocol name	Interval divisions	Optimized object	Advantages	Disadvantages	Published
V. Nguyen et al	RCMAC	Safety interval WSA/ACK interval	Safety Interval WSA/ACK interval	Improves time slot acquisition through RSU coordination	All nodes in constant speed. Not suitable for multi-hop	2016
Nguyen et al	HTC-MAC	Safety interval	Safety interval WSA/ACK interval	Supports the various QoS requirements	Has a drawback in supporting throughput-sensitive non-safety application.	2016
Hadded et al	CTMAC	Safety interval Coordination control frame interval	Safety interval WSA/ACK interval	In a large area covered, it avoid collision by interference between vehicles in overlapping region.	Do not support multi-channel operation. The high are equip with RSU which are very expensive	2016
Y. Nguyen et al	TDMA-CSMA	WSA/ACK interval Safety interval	Safety interval WSA interval	The length of the BF is not uniform. Therefore, each vehicle dynamically adjust the BF length according to its neighbor	Collision between the two-hop neighbors attempt to access available time slot.	2016

Jiang et al	PTMAC	WSA/ACK interval Safety interval	Safety interval WSA interval	Potencial collision between two-hop communication range can be detected by immediate vehicle predicted and eliminated before it occur. Reduce number of collision and has the high delivery rate	Based on prediction instead of real world scenario. It do not eliminate collision totally	2016
Ucar et al	VMaSC-LTE	Safety interval WSA interval	Safety interval WSA interval	It forward efficient data with minimizing delay	Is not applicable to urban traffic scenario and path information of vanet	2016
Xie & Li	WCS-MAC	Safety Interval and WSA interval	Safety and Safety critical SCA interval WSA interval	It forward efficient data with minimizing delay	A time delay for CH election result in longer average total transmission time of an SCA session. Connection is set up only between CH and CM	2016
Torabi & Gbahfarokhi	BEFM-MAC	Safety interval, WSA interval	Safety and Safety critical SCA interval WSA interval	It has a better performance in terms of fairness and bandwidth utilization.	Inter-cluster communication is not addressed. The collision between nodes from different cluster occur and the hidden nodes collision	2016
Shalin & Kim	STCM	Safety interval, WSA interval	Safety and Safety critical SCA interval WSA interval	Enhance packet delivery in CCH and throughput in SCH	Limited to inter-cluster communication with limited nodes	2017
Cao et al	SCMAC	Safety interval, WSA interval	Safety and Safety critical SCA interval WSA interval	Enhance packet delivery in CCH and throughput in SCH. Achieves reliable and scalable periodic beaconing in vehicular environment. It solves hidden terminal problems.	The channel fading is ignored to focus on the MAC layer performance. The concurrent broadcasting will cause collision	2017
Yao et al. ⁴²	FCM-MAC	Coordination Control Frame interval WSA and safety message RES interval	WSA and safety message	High channel utilization. Supports the reliability for safety application. Allows safety and non-safety messages transmitted in a flexible way.	Considers WSA and safety messages with the same packet arrival rate.	2017
Song et al. ⁴¹	APDM	ORP interval Safety and WSA/ACK interval	Safety and WSA/ACK interval	Reduces the safety packet delay. Improves the system throughput in VANETs.	Once optimal node leaves the neighborhood, the channel access schedule is lost and collision between messages will occur.	2017
Song et al. ⁴⁰	EQMMAC	Safety interval Vehicle identification interval	WSA/ACK interval	Provide the high saturation throughput. Improves transmission delay for non-safety application	Vehicles require two transceivers.	2017
Y. Zhang et al	CCFM-MAC	Safety interval, WSA interval	Safety and Safety critical SCA interval WSA interval	No packet collision during the process of inter-cluster and inter-cluster	Limited to intra-cluster communication with limited nodes. Do not include RSU in the process	2018
Chen et al	AMAC	Safety interval, WSA interval	Safety and Safety critical SCA interval WSA interval	Reduces transmission collision and achieved high throughput	Uses half-duplex transmission and do not includes RSU in the process. In high way scenarios courses break in transmission	2018

Liu et al	MoMAC	Safety interval, WSA interval	Safety and Safety critical SCA interval WSA interval	It assign time slot according to road topology and lane distribution on road	In V2V communication every vehicle need to periodically broadcast their status and turn signal status to all neighbors within one-hop. There is no efficient slot assignment for uneven traffics	2018
Liu et al	ABC	Safety interval, WSA interval	Safety and Safety critical SCA interval WSA interval	Efficient beacon rate to avoid a rear-end collision based on individual estimates	TDMA must reduce energy waste in the contention protocol and with limited stability adaptability. Hard to dynamic change from frame size or slots assignment when new nodes join	2018
X. Zhang et al	BB-MAC	Safety interval, WSA interval	Safety and Safety critical SCA interval WSA interval	It reduces collision and speed-up time slot acquisition	Is only limited to medium density of vehicle nodes	2019
Engineering	FCM-Q LEACH	Safety interval, WSA interval	Safety and Safety critical SCA interval WSA interval	it enhances network performance, especially between CH and RSU	It do not work on selection of CH in cluster network because the choice is based on trust degree. Transport of packet using IEEE802.11p from RSU to BS i.e. contention based is not suitable for multi-hop	2019
Nguyen et al	Adaptive IEEE 802.11p	Safety interval WSA/ACK interval	Safety interval WSA/ACK interval	Improve saturated throughput, adapt to amount of traffic data and ensure safety package transmission	Not suitable for multi-hop communication. When CH move out of their cluster, channel access schedule is lost and collision between messages occur	2019
Bello et al.	EWCA	Safety interval, WSA interval	Safety and Safety critical SCA interval WSA interval	Minimize interference in adjacent clusters. Provide efficient delivery of safety messages. Provide cluster stability and minimizes cluster overhead, and maintenance	A messages from neighboring vehicles moving in different direction is not considered, due to merging amongst the adjacent cluster. Uses poison process to arrival rate of vehicle'	2019
Hag & Liu	VeSOMAC	Safety interval,	Safety and Safety critical SCA interval WSA interval	It can operate in synchronize and in asynchronies mode. Improve TCP throughput in this protocol	Vehicles require two transceivers. Unbounded delay in the delivery of safety messages.	2019

VANET: vehicular ad hoc network; MAC: medium access control; WSA: Wireless Access in Vehicular Environment Service Advertisement; ACK: Acknowledgment; SCHI: service channel interval; QoS: quality of service; CCH: control channel; RES: Reservation; CH: control head; CM: control member

CONCLUSION

The standard IEEE 802.11p only provides VANETs with a contention-based MAC protocol while using an enhanced distributed channel access (EDCA) mechanism. However, due to the lack of request-to-send / clear-to-send (RTS / CTS) exchange, it does not provide an effective broadcast service with limited communication delay. Also, when the multiple nodes attempt to send their safety messages simultaneously, the probability of transmission collisions increases. MAC

protocols based on Time Division Multiple Access (TDMA) such as ADHOC MAC and VeMAC protocol could solve the above problem. ADHOC MAC is a distributed TDMA-based MAC protocol that provides efficient broadcasting and service quality (QoS) guarantees for inter-vehicle communication and solves hidden / exposed terminal problems caused by random access in multi-hop network architecture. Unlike the IEEE 802.11p standard, it is a single-channel protocol, not suitable for dedicated short-range communication (DSRC), which uses seven DSRC channels and allocates time slots based on vehicle direction to reduce vehicle-to-vehicle collisions.



However, for the control channel (CCH) and service channels (SCHs), it employs two half-duplex transceivers, respectively. Many contention-free TDMA MAC protocols have recently adopted cluster-based architecture because with the help of cluster head (CH) they can provide effective topology control, fair channel access within each cluster, and minimize intra-cluster and inter-cluster transmission collisions. In table 5, gives detail analysis leveraging the applications of different TDMA protocols leveraging the VANET upto date. The advantages and disadvantages are clearly stated and uniquely presented in figure 1,2 and 3. The analysis suggested for VANETs to guarantee that all vehicle have sufficient time to send safety messages without collisions and to decrease the end-to-end delay and the loss ratio of packets.

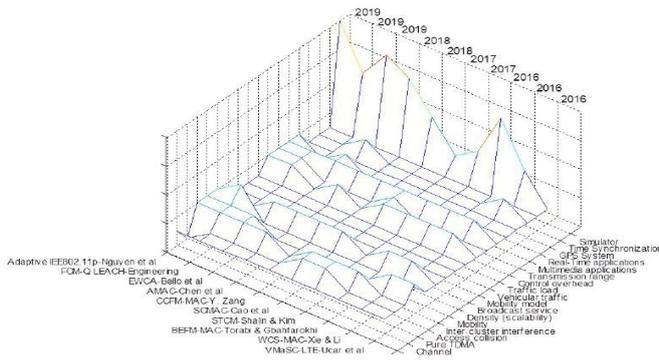


Figure 5: The number of TDMA-based MAC protocols proposed for each year.

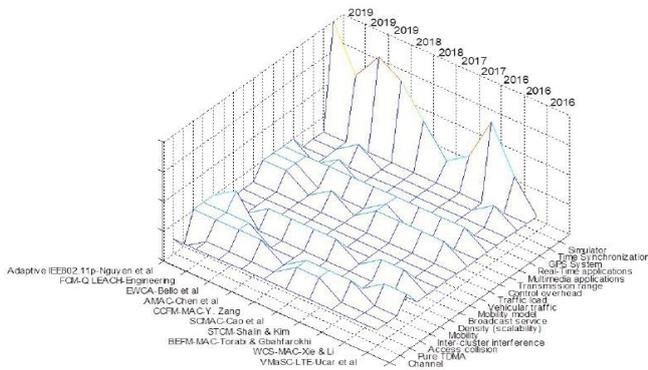


Figure 6: The number of TDMA-based MAC protocols proposed for each year

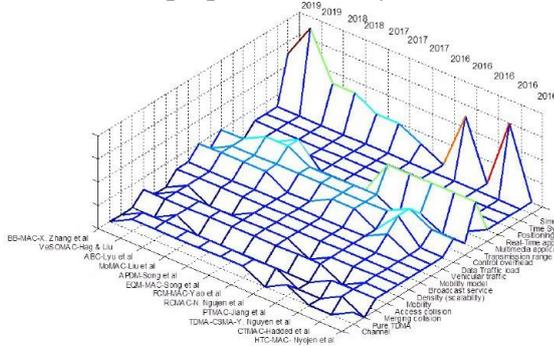


Figure 7: The number of TC-MAC protocols proposed for each year

Future work:

- Use multi-channel DSRC band to facilitate spatial reuse

of channel resources to develop a contention-less scheme based on TDMA that contains unbounded delay.

- The RSU capable of listening to all broadcast messages and doing traffic condition statistics on each segment of the road and then using their time slots to broadcast up-to-date slot allocation scheme.
- A CH in a cluster-based TDMA-MAC with the responsibility of allocating a slice of time to their CMs to reduce energy wasted.
- An average time-based clustering algorithm for link expiration, which takes into account multiple factors, such as relative distance and relative node velocity, and radius for transmission. Network model is only for intra-vehicle clusters and inter-vehicle clusters.

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Prediction..Mobile Adhoc Network; Robotic

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