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A Survey on MAC Protocols for Vehicular Ad-Hoc Networks

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Abstract**—**Vehicular Ad-hoc Network (VANET) is an emerging and very promising technology that has great demand on the access capability of the existing wireless technology. VANETs help improve traffic safety and efficiency. Each vehicle can exchange their information to inform the other vehicles about the current status of the traffic flow or a dangerous situation such as an accident. To achieve these, a reliable and efficient Medium Access Control (MAC) protocol with minimal transmission collisions is required. High speed nodes, absence of infrastructure, variations in topology and their QoS requirements makes it difficult for designing a MAC protocol in vehicular networks. There are several MAC protocols proposed for VANETs to ensure that all the vehicles could send safety messages without collisions by reducing the end-to-end delay and packet loss ratio. This paper gives an overview of the several proposed MAC protocols for VANETs along with their benefits and limitations and presents an overall classification based on their characteristics.

Keywords**—**MAC Protocols, QoS, VANET, V2V, V2I.

I. Introduction

VEHICULAR Ad-hoc Networks known as VANETs are important component of Intelligent Transportation Systems (ITS). They aim to improve the efficiency in transportation, traffic management conditions and driver's safety on road. VANETs help to exchange the messages between the vehicles and infrastructure which provides comfort to drivers and passengers. Each vehicle is equipped with a communication unit called the On-Board unit (OBU). The vehicles communicate using Dedicated Short-Range Communication (DSRC) radio to advertise their traffic-related and location information to all the nearby nodes using data broadcast mechanism. This communication [2] can either be inter-vehicle communications V2V (Vehicle to Vehicle), vehicle-to-roadside communications V2I (Vehicle to Infrastructure) and inter-roadside communications I2I (Infrastructure to Infrastructure) which is explained in Fig 1.

The IEEE has standardized WAVE communications especially for vehicular use by introducing the IEEE 1609.1-4 and the IEEE 802.11p standards. As IEEE 802.11p is contention-based, it has its own limitations. Therefore MAC protocols are designed to share the channel fairly between the homogeneous and heterogeneous nodes. These protocols can be classified into three broad categories: Contention-based, contention-free and hybrid protocols [3]. In contention-based protocols, each node uses the carrier sensing mechanism to access the channel to transmit the data.

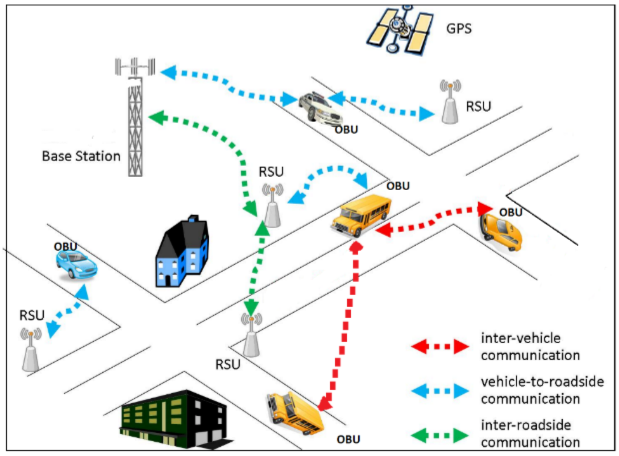

Fig. 1 Vehicular communications

When the other neighboring nodes sense a free channel, and decide to transmit the data at the same time it results in the collision between them. Contention-based protocols do not follow any pre-defined schedule; each node will access the channel access without the guarantee for success. In real-time applications, problems like packet loss, high access delay can occur. To avoid these problems, contention-free MAC protocols assigns the medium to one node at a given time. These protocols provide bounded-delays for real-time applications, but require periodic exchange of control messages that help to maintain a schedule table and synchronize the time between all nodes within the network. Due to the problems such as dynamic topology, channel interference, collision effects faced by contention-based and contention free protocols independently, hybrid MAC makes use of the characteristics of two channel access schemes and improves the performance when traffic load increases. It is a combination of both contention – based and contention free scheme. The diagrammatic representation of the classification is given in Fig. 2.

The rest of the paper is organized as follows: Section II deals with the related work explaining the various MAC Protocols for VANETS based on its characteristics and working, Section III concludes the paper.

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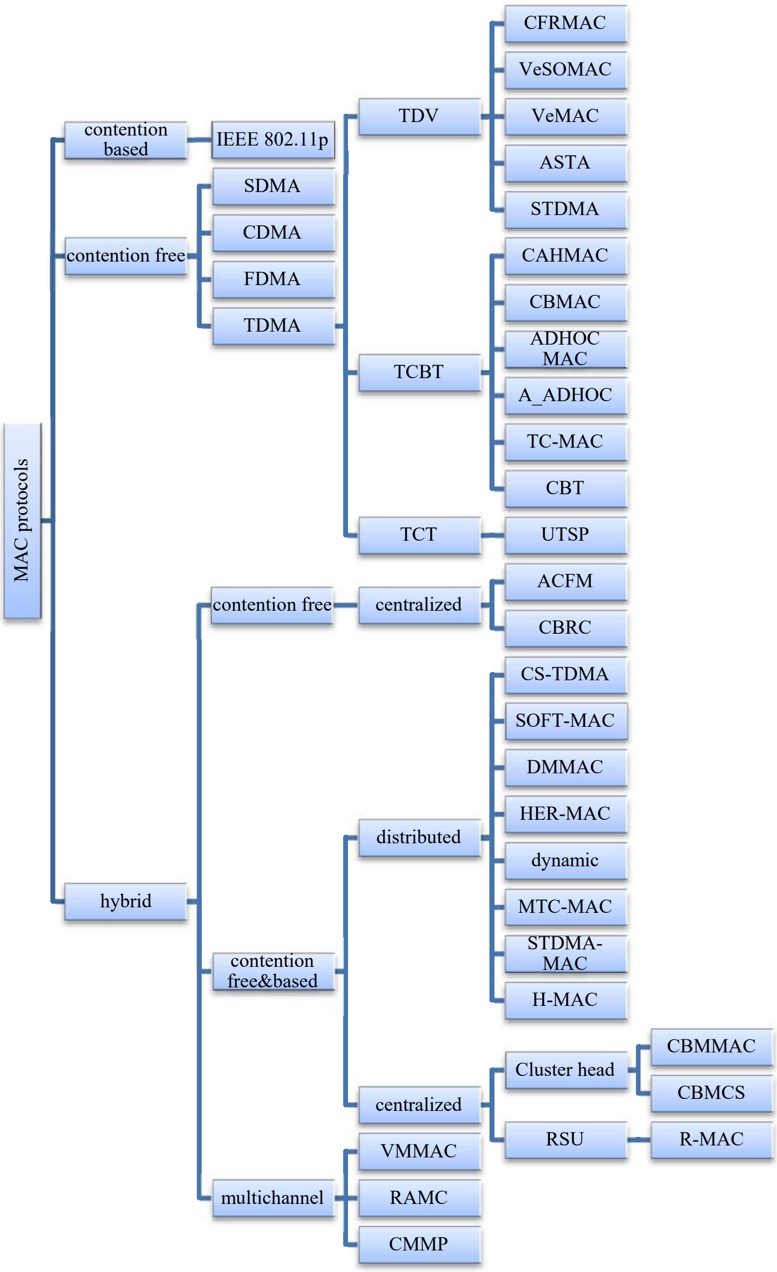

Fig 2 Classification of MAC Protocols

II. MAC Protocols for VANETs

A. Contention-Based MAC Protocols

1. WAVE (802.11p)

Wireless Access in Vehicular Environments (WAVE) do not have a predetermined schedule and allows the vehicles to access the channel randomly which results in transmission collision at high load conditions. IEEE 802.11p [5] is based on CSMA/CA. This protocol is contention-based and does not assure any QOS requirements for the safety critical applications. Important parameters like physical carrier sense threshold, the minimum contention window, and the transmission power control must be considered to improve the scalability of contention-based MAC protocols under heavy load conditions.

In WAVE protocol, all vehicles are equipped with DSRC radio which is synchronized using Global Positioning System (GPS). The sync interval (SI) is split into CCH interval (CCHI) and a SCH interval (SCHI) which is separated by a guard interval. During CCHI, the radios are tuned to the CCH to broadcast updates and listen to the messages from the neighboring vehicles and RSUs. During SCHI, vehicles are tuned to SCH based on the services offered. As WAVE communicates safety and non-safety applications through a single DSRC radio, reliability of either of these applications are compromised at high traffic densities.

B. Contention-Free MAC Protocols

Contention free MAC protocols possess a predetermined channel access schedule. The various contention-free MAC protocols proposed for intervehicle communications are Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA) and Space Division Multiple Access (SDMA). The channel is accessed by the vehicles whose protocols allow each vehicle to access the channel in a predetermined time slot, frequency band or code sequence. The major advantage of such protocols is that there are no message collisions between vehicles in the same two-hop neighborhood.

1. TDMA Based MAC Protocols

TDMA based MAC protocols are used to control channel access in wireless networks like cellular GSM network, Mobile Ad hoc Networks, VANETs, Wireless Sensor Networks, Mesh Networks. The TDMA principle allocates the bandwidth to all the vehicles by dividing time into different frames and the frames being further divided into many timeslots. In each frame, vehicles can access one or more dedicated timeslots to send data but receive data only in the slot allocated for other vehicles. This has a great advantage when compared to IEEE 802.11p standard. These protocols can be classified as protocols operating on a distributed VANET, protocols operating on a cluster-based topology, protocols operating on a centralized topology.

C. TDMA Based MAC Protocols in a Distributed VANET (TDV)

TDV protocols coordinate channel access in a distributed way. They assume that each vehicle only needs to communicate with its one-hop neighbors to access the channel.

1. CFR MAC

Near Collision Free Reservation based MAC protocol [6] addresses the merging collision problem to provide near collision free channel access. The scheduling mechanism is based on the VeMAC protocol which considers the traffic flow and the relative speeds of each vehicle. Each frame is split into two sets of time slots namely the Left and Right which are assigned to vehicles moving to the left and right. To overcome the merging collision problem due to vehicles moving at different speeds each slot set is further divided into three subsets based on the three speed intervals: High, Medium and Low. The number of time slots reserved for each direction and speed level are adjusted by the CFR MAC protocol dynamically.

2. VeSOMAC

VeSOMAC is a self-Organizing MAC Protocol for DSRC in VANETs [7] which is used in multimedia applications. An in-band control mechanism exchanges the TDMA slot information during distributed MAC scheduling. This achieves fast TDMA slot reconfiguration without relying on roadside infrastructure to deliver improved throughput in highway scenarios. VeSOMAC operates in both synchronous and asynchronous modes. In the synchronous mode, all the vehicles are assumed to be time-synchronized with the help of GPS and share the same frame and slot boundaries. In the asynchronous mode, each vehicle maintains its own frame boundaries. VeSOMAC has fixed frame length which leads to inefficient channel utilization when the vehicle density increases.

3. VeMAC

VANETs MAC [8] is a totally contention-free multichannel MAC protocol which supports efficient one-hop and multi-hop broadcast services on the control channel and reduces access collisions and merging collisions caused by node mobility. In VeMAC, disjoint sets of time slots are assigned to vehicles moving in opposite directions (Left, Right) and to road side units (RSUs) to reduce the merging collision rate. Each node has two transceivers tuned to the control channel and service channel and synchronized using the 1PPS signal provided by the GPS in each vehicle. There are four major fields in each frame transmitted by the control channel namely the header, service announcement (SAn), service acceptance (SAc) and high priority short applications.

To overcome the hidden terminal problem each header field transmits the time slots of the vehicles within its one-hop neighborhood along with the message. Thus, each vehicle can acquire a free time slot without any collision. The time slots are assigned to the nodes on the service channels by the providers which announces a service offered on a specific service channel in the AnS field on the control channel. The user is a vehicle which receives the announcement for a service and makes use of it. The provider assigns the time slots to all the users and announces this slot assignment on the service channel in a specific time slot called the provider’s main slot. After receiving the acceptance of the service in the AcS field, the provider tunes its second transceiver to offer services in the time slots announced in the AnS field. VeMAC uses seven DSRC channels to support the same broadcast service on the control channel and on the service channels.

There is a considerable overhead due to the size of the control frame transmitted on the CCH. In a highway scenario where the vehicles move in high density, merging collisions occur when the moving vehicles could not access a time slot from the reserved set of slots in its direction. Therefore the vehicle accesses any available time slot which is reserved for vehicles moving in the opposite direction. This can be overcome by adjusting the size of the slots based on the number of vehicles.

4. ATSA

Adaptive TDMA Slot Assignment [9], [10] is an enhancement of a MAC protocol named Decentralized Adaptive TDMA Scheduling Strategy DATS [11]. Like VeMAC, ATSA divides the frame into two sets of time slots Left and Right and balances the traffic. In ATSA, a vehicle chooses a frame length and competes for one of the time slots available for its direction to access the network. The frame length is dynamically doubled or shortened to solve merging collisions under unbalanced traffic conditions using a binary tree algorithm. The slot management mechanism is based on a binary tree structure. The set of vehicles on the left sub-tree is regarded as the Left set of slots and those on the right sub-tree are taken as the Right set of slots.

In general, the ATSA protocol reduces the number of collisions and time delay along with maximum channel utilization. But the use of single channel results in lower performance when compared with the ADHOC and VeMAC protocols.

D.TDMA-Based MAC Protocols in a Cluster-Based Topology (TCBT)

TCBT protocols assume that one vehicle in each group is elected to act as a local channel access coordinator called the Cluster-Head which performs the process.

1. CAH-MAC

Cooperative ADHOC MAC [12], [13] enhances the throughput of non-safety applications based on distributed TDMA. It helps to overcome the transmission failure problems which occurs due to poor channel conditions. On the detection of transmission failure, the neighboring nodes called the helper nodes offer cooperation to relay the failed packets to its destination during an idle time slot. The main disadvantage is the use of free time slots by the helper nodes which may lead to access collision problems with the vehicles which tries to obtain the available time slot.

2. CBMAC

In Cluster Based MAC Protocol [14], [15], the cluster head of each cluster assigns the bandwidth to the members of its cluster. They mainly reduce the hidden node problem and provide a fair medium access. The access time is divided into time slots which are grouped into several time-frames. The cluster head (CH) always uses the first slot to periodically broadcast a HELLO message (CH-HELLO) to its cluster members which indicates the start of a frame and the second slot is used by the CH to announce a control message which is a vector that specifies the status of each slot and the identifier of the vehicle that transmits during the slot. CBMAC has two phases, the data link phase where each vehicle uses its slot to send data messages to any of its one-hop neighbors and the random-access phase the vehicle sends a reservation request to the CH to access the network. The length of this phase depends on the number of slots reserved for the data link phase. To avoid collisions during the random-access phase a minimum length value is fixed which is 10% of the frame.

CBMAC uses spatial reuse algorithm which determines how vehicles can use the same channel in the same time slots. But this concept is not very clear for communications between vehicles and RSUs. Moreover CBMAC uses single channel protocol which makes it unsuitable for a DSRC architecture.

3. ADHOC MAC

In ADHOC MAC [16] restricted number of vehicles which are one-hop away are grouped into a set of clusters without a CH. They provide QoS provisioning and solve hidden and exposed terminal problems in inter-vehicle communications. Each vehicle accesses the channel at least once in each frame and randomly selects a time slot as its basic channel (BCH). The vehicle broadcasts an additional frame to its two-hop neighbours called the Frame Information (FI) during its BCH to know whether the node is free or busy thereby solving the hidden node problem. ADHOC MAC uses multi-hop broadcast service and parallel transmissions with minimum set of relaying terminals to cover the whole network.

4. A-ADHOC

Adaptive Real-time Distributed MAC [17] is based on the ADHOC MAC protocol. The A-ADHOC protocol is meant for real time applications in large-scale wireless vehicular networks which offer adaptive frame length. A-ADHOC has exceeded the performance of ADHOC MAC in both channel resource utilization and response time and avoids network failure irrespective of traffic density.

5. TC-MAC

TDMA Cluster-based MAC [18] is a multichannel MAC protocol which possesses stable CHs to manage the slot reservation schedule. They provide efficient time slot utilization for the participating vehicles and each vehicle can tune either to the Control Channel (CCH) or to the specific service channels (SCHs) in the time cycle. A cluster formation algorithm provides a stable clustering architecture with less communication overhead caused by CH election and cluster maintenance procedures.

In the cluster formation process, a local ID is allocated for each cluster member by its CH which is generally the local ID 1 and the ID 0 is held in reserve for a virtual vehicle. The access time in the SCH is split into many periodic frames of length 100 ms and each frame is divided into Nmax/k times slots where Nmax is the maximum number of vehicles in the cluster and k is the number of slotted service channels. In the CCH, also the access time is divided into periodic frames and each frame has Nmax/k time slots which are further split into k mini-slots of size $\tau/6$ ms to broadcast safety messages. When a new vehicle joins the cluster, it communicates with the CH by transmitting in the mini-slot number 0 reserved for the virtual vehicle.

TC-MAC performs intra-cluster management and safety message delivery within the cluster with the help of CH for broadcasting safety messages and cluster members to exchange non-safety data in unicast or multicast communication mode. The main drawback of this protocol is that it was designed for simple highway traffic in which all the vehicles move in the same direction, and thus resulting in high collision rate in bidirectional traffic due to the merging collision problem. Moreover, this protocol is intensely dependent on the local IDs which must be periodically updated along with the cluster members by each CH resulting in high overhead.

6. CBT

Cluster Based TDMA Protocol [19] focusses on V2V communications to control collisions during intra-cluster and inter-cluster communications. They use the Transmit-and-Listen scheme to elect the VANET Coordinator VC. In CBT each vehicle is equipped with GPS positioning system to synchronize the vehicles. The slot 0 in Frame 1 has the SYN signal indicating the start of the frame. The remaining slots from 1 to n-1 are used for VC election process. The first slot in the other frames are used by the elected VANET Coordinator VC to broadcast a Slot-Allocation Map (SAM) and the other slots are used to send data messages. The randomly elected vehicle which acts as the VC transmits a Compete-For-VC (CFV) message to all the other vehicles during the inter-cluster and intra-cluster communications. The main drawback in CBT is that the lifetime of the VC is short resulting in unstable clusters and problems in allocation of time slot when a vehicle joins or leaves the cluster.

E. TDMA-Based MAC Protocols in Centralized Topology (TCT)

TCT protocols assume that there are central points (RSUs) which are used to coordinate channel access for the vehicles in their coverage area.

1. UTSP

Unified TDMA-based Scheduling Protocol [20], [21] is mainly used for V2I communication to increase the throughput for non-safety applications in VANETs. The RSUs collect the information such as channel state information and the speed of the vehicles within its communication range and allocates the time slots based on the above factors. The channel-quality weight factor maximizes the network throughput, the speed factor ensures equality between all vehicles moving in varying speeds and the AC factor determines the priorities of the slot reservation requests. The RSU serves the vehicle with the highest weight value. As the vehicles in the overlapping regions experience an interference problem, UTSP is mainly used for road safety issues.

2. CDMA Based MAC Protocols

In Code-Division Multiple Access, multiple nodes use the communication channel simultaneously at the same radio frequency. At the receivers' end the messages are distinguished based on the respective nodes. The concept of cell reuse (using CDMA as a cell) helps to overcome the hidden terminal problems and increases the capacity of the system which will lead to the increase in bandwidth efficiency. Though CDMA is good for real-time medium access and gives high bandwidth efficiency, there is no synchronization of messages sent by the network nodes. CDMA introduces two problems in VANETs namely the near-far problem and collision problems. These problems make it challenging to do simulation-based research about CDMA in VANETs.

3. SDMA Based MAC Protocols

Space Division Multiple Access uses the concept of space division multiplexing in which the road is divided into pieces called spaces and TDMA scheme is mapped to each space. Each vehicle uses different time slots depending on the location of the vehicle at that time. This scheme is good when the traffic density is high but in a highway scenario where the traffic density is sparse the overall network utilization becomes low due to many unused slots.

4. FDMA Based MAC Protocols

FDMA-based MAC protocols require a transmitter and the receiver which must be synchronized in the same channel frequency. Frequency synchronization mechanism is essential for matching the communicating vehicles. The synchronization algorithm creates CCH frequency for the vehicles for the exchange of frequencies through control messages. This adds high complexity and communication overhead to the FDMA mechanism. In TDMA, several different frequencies are required which increases the demand for bandwidth.

F. Hybrid MAC Protocols

Hybrid MAC protocols are the combination of contention based and contention free protocols which makes use of TDMA and CSMA/CA [4]. Two channel schemes are used to improve the performance at high traffic loads. They can be classified as contention free access scheme: ACFM (Adaptive Collison – free MAC) and CBRC (Cluster Based RSU Centric Channel Access) and a combined approach of contention free and contention based access scheme: CSTDMA (CSMA and Self-Organizing TDMA MAC), SOFT-MAC (Space Orthogonal Frequency-Time MAC), HER-MAC (Hybrid Efficient and Reliable MAC), DMMAC (Dedicated Multichannel MAC with Adaptive Broadcasting), CBMMAC (Clustering Based Multichannel MAC), CBMCS (Cluster Based MAC Protocol) and R-MAC (Risk-Aware Dynamic MAC), hybrid TDMA/CSMA MAC (HTC MAC), STDMA MAC Protocol, Dynamic MAC, H-MAC.

G. Contention Free Access Scheme

1. ACFM

Adaptive collision free MAC [22] is a TDMA based protocol with dynamic slot assignment mechanism. Ad hoc subnet is formed for each RSU surrounding the mobile vehicles present in that RSU slots are dynamically allocated for each vehicle. ACFM protocols adjust the slot assignment cycles based on the traffic to avoid unused slots during sparse traffic and additional slots when the traffic is dense.

2. CBRC

Cluster based RSU centric channel [23] present across the roadside units possesses the centralized control in a cluster.

This reduces the channel allocation time and helps to manage the overheads. CBRC is implemented on both RSU's and vehicles. The RSU acts as the CH and divides the road into many clusters. It broadcasts beacon messages with ID number and locality to the vehicles entering that cluster. After receiving the beacon message in the RSU range, the vehicle responds with a registration request. RSU's categorizes the message based on the priority such that the safety/alert messages are given higher priority access than data messages. The channel allocation matrix stores the information about the free and assigned channels which solves the hidden and exposed node problems. The main drawback in this protocol is that it fails to address the inter cluster communication at the junctions of the RSU range.

G.Contention Free and Contention Based Access Scheme

1. CS-TDMA

CS-TDMA, known as CSMA and self-organizing TDMA MAC protocol [24], [1], makes use of the channel access scheduling and channel switching mechanism to reduce the utilization of available resources. As per multichannel operations, the vacant access time can be split into control channel intervals (CCI) and service channel intervals (SCI). The ratio between CCI and SCI varies based on the quantity of traffic present which will ultimately result in the efficient use of resources, reduced delays and packet collision. The main drawback of CS-TDMA is that it is limited only to medium density of traffic.

2. SOFT-MAC

SOFT-MAC [25] is a combination of SDMA, OFDMA, TDMA, CSMA techniques. In SOFT-MAC the road is divided into cells of radius R and the sub-carriers present are assigned to every cell. Sub-carriers are shared between vehicles in the same cell. Preinstalled maps give information about the vehicles and sub-carrier location is the road vehicles make use of the GPS system to find the sub-carriers in its location. This protocol consists of two periods namely the reservation period (RS) and the transmission period (TS). RS is accessed using CSMA mechanism to transmit short messages and reserve the channel for TS period. TS period gives the information about the number of slots, status of slots either busy of free, ID of vehicle transmitting data. SOFT-MAC is highly complex due to the involvement of SDMA, CSMA, OFDMA. Vehicles which are not equipped with digital road maps cannot ensure its operability using SOFT-MAC.

3. HER- MAC

The Hybrid Efficient and Reliable MAC [26] protocol is a contention free multichannel MAC which performs adaptive broadcasting. It is assumed that each vehicle has a half-duplex transceiver to transmit safety/alert messages in the CCH without collision. The non-safety messages utilize the service channel (SCH). Each SI in CCH is split into Reservation period (RP) and contention period (CP). RP contains emergency slots (Emgslots) for communicating emergency messages. CP is used to transfer the control message between the vehicles using 3-way handshake protocol. In SCH, the SI is partitioned into M service transmission slots (Serslots) for sending nonsafety messages. HER-MAC requires high level of coordination during broadcast of messages.

4. HTC-MAC

To overcome the high collision rates of HER-MAC, a new protocol called hybrid TDMA/CSMA multichannel (HTC) MAC [27] was introduced. HTC-MAC eliminates unnecessary collisions and improves the throughput in CCH. An Announcement Packet (ANC) is broadcasted along with the Reservation Period (RP) to reduce its duration. Markov chain is used to analyse the HTC-MAC performance. HTC-MAC outperforms HER-MAC at high traffic roads.

5. DMMAC

DMMAC is a dedicated multichannel MAC [28] protocol which witnesses adaptive broadcasting. Coordination scheme in DMMAC is like WAVE MAC. The channel access time is split into SIs which in turn consist of CCHI and SCHI of equal lengths. CCHI is again split into Adaptive Broadcast Frame (ABF) and Contention-based Reservation Period (CRP). ABF contains many time slots reserved for vehicles for message distribution without collision. The number of slots present in ABF is called ABF Length (ABFL) which ranges from ABFL min to ABFL max.

The length of CRP depends on the ABFL value. To prevent collision additional slots called virtual slots are allocated which can be used after entering CRP. Similarly, SCHI is split into several time slots which are grouped into Non-Safety Application Frame (NSAF). Performance of DMMAC decreases where there is re-reservation of BCH during the random slot assignments due to changing topology.

6. STDMA MAC Protocol

Self-organizing Time Division Multiple Access protocol [29] was developed for real-time communications. They are employed in automatic identification systems. STDMA is a decentralized scheme where the synchronization between the nodes is done through GPS. STDMA MAC protocol exhibits the advantages of both CSMA and TDMA. CSMA segment is used to provide synchronization and reserve time slots on TDMA. Based on the simulation results this protocol proves to be more efficient when compared to pure CSMA and TDMA.

7. Dynamic MAC

Dynamic MAC [30] splits the frame between CSMA/CA and STDMA based on the traffic load. MAC end to end delay and packet drop probability are the main parameters of utility maximization frame work. Larger CSMA/CA fraction minimizes the channel access delay in sparse traffic conditions and larger STDMA ensures minimal delay and packet loss ratio for dense traffic.

8. H-MAC

H-MAC [31] is the combination of reservation and competition schemes to avoid sudden burst of data. The frame cycle is divided into reservation period which has a reserved slot for each node to send stable data and a competition period where the data burst competes to be transmitted. Hence the excess data do not compete with the stable data thereby improving the channel utilization and reducing the delay.

9. CBMMAC

Clustering Based Multichannel MAC (CBMMAC) [32] is the communication scheme used for infrastructure-free VANETs. CBMMAC performs three mechanisms namely cluster configuration, intra-cluster and inter-cluster coordination communication. Cluster configuration organizes the vehicles into clusters based on their direction and assigns a cluster coordinator for each cluster. Intra cluster coordination and communication manages the reservation schedule and communication between the CH and its members. Inter cluster communication combines the safety messages from one cluster and forward it to the neighboring clusters.

10. CBMCS

In cluster based MAC protocol [33] the vehicles are formed into clusters. The medium is divided into several CCHs using CSMA/CA and single data channel using TDMA/CDMA. The cluster members periodically update their location and speed to the CH. CBMCS has vehicle accident avoidance mechanism (VAAM) to inform the nearby vehicles about the accident. In CBMCS the CCHs are divided into five units, more the number of channels results in smaller bandwidth leading to slower transmission.

11. R-MAC

Risk aware dynamic protocol, R-MAC, [34] is a collision avoidance system which is the extension of ACFM protocol [22]. In R-MAC the access time is split into number of frames and each frame is subdivided into uniform time slots. Each frame has a CSMA segment for the transmission of alert messages and TDMA segment for beacon transmission. During transmission, high priority is given to the alert messages, so the CSMA segment is allocated prior to TDMA segment. Based on the number of positive vehicle collisions, CSMA slots are determined and the remaining slots are used by the TDMA segment which results in the fairness in channel access. R-MAC is a single channel protocol and its evaluations are limited only for vehicles moving in the same direction in a simple highway with one lane. It does not assure collision free transmission of non-safety messages.

H.Multi-Channel MAC Protocols for VANET

Initially multichannel MAC protocols were developed for adhoc networks [35], later it was introduced in VANETs. There are several Multi-channel MAC protocols for VANET to reduce the contention for channel access in MAC layer. The workload distribution of Multichannel MAC is comparatively better than Single-channel MAC protocols.

1. VMMAC

VANET Multi-channel MAC [35] is a directional antenna based adaptive multi-channel MAC protocol for dense VANET. Every vehicle has a Beam Table (BT) which displays the current state of beams in all seven DSRC channels. This table contains either 1(blocked) or 0(unblocked) for every beam. The vehicles exchange their BT with each other before the channel reservation. The Channel Selection Request to Send (CS-RTS) signal has the IDs of both the sender and receiver and is transmitted in a predefined direction. After a certain time, it transmits the same CS-RTS to all beams around it.

VMMAC protocol uses two methods for directional handshake in CCH. In lane-based directional antenna method, the CS-RTS packets are transmitted to all the beams in a circular manner. This transmission continues till the end of the timer ends and changes on the arrival of a new CTS packet. This method is appropriate in sparse traffic environment with lane limits, such as highway etc. The other method is an omni-directional RTS which solves the problem of contention in dense traffic environment by sending RTS in Omni-directional way.

2. RAMC

Road Side Unit-Assisted Multi-Channel Coordination MAC [36] protocol provides safety and non-safety communications using the DSRC channels. Vehicles can change to any service channel based on the transmission range of a roadside unit (RSU). These RSUs monitor all the safety messages transmitted by the control and service channels and periodically broadcasts the traffic view report to all its neighbors. The channels are parallely accessed by the vehicles and RSUs for transmission. Time is equally divided, called as SI, and the length of the interval is measured by the maximum tolerable delay of safety messages. A vehicle should send at least one safety message by using either control or service channel in each SI. Thus, high throughput is achieved by the vehicle in the service channel for non-safety applications. To increase the delivery ratio of safety messages a two-step approach was proposed for different traffic densities. In the first step, a vehicle broadcasts a warning message. After rebroadcasting the message in both control and service channel the RSU sends an acknowledgement to the sender. This message is retransmitted when the sender does not receive the message within the limited time. In the second step, the duplicate messages for the same event are filtered by the RSU.

3. CMMP

Clustering-Based Multi-Channel MAC [37] Protocol separates the channels into control and data channels. A vehicle in the cluster transmits the information to the other vehicle by sending a Request Channel Assignment (RCA) packet using CSMA/CA method to the cluster header of the data channel. It checks the Channel Usage List which contains the number of channels, data channel used by each vehicle and time information of when the nodes using this channel changes to use other channel. This list is periodically broadcasted by the CH. When a data channel is available the vehicle sends its data to the destination, otherwise it retransmits its RCA packet. This protocol has decreased transmission delay, packet loss ratio and has provided quality of service in VANET.

There are three core schemes in this protocol namely Cluster Configuration protocol, Inter-cluster Communication and Intra-cluster communication protocol. In Cluster Configuration Protocol, a vehicle is elected as a CH from each cluster of vehicles moving in the same direction. The Inter-Cluster Communication Protocol transfers the safety and non-safety messages between the clusters over two separate IEEE 802.11 MAC-based channels. Intra-Cluster Coordination and Communication Protocol collects and delivers the safety messages from and to the cluster-member vehicles using the upstream time-division multiple-access and downstream-broadcast method using the multichannel MAC algorithms for each CH.

III. Conclusion

Improving road safety in VANETs requires efficient and reliable MAC protocols. This paper presents an extensive overview of MAC protocols for Vehicular Networks. These protocols make use of various channel access schemes to transmit safety and non-safety messages. The contention based protocol WAVE incorporates several protocols in conjunction with the family of the IEEE 1609 standards. These include IEEE 1609.1 WAVE resource manager, IEEE 1609.2 WAVE security services for applications and management messages, IEEE 1609.3 WAVE networking services and IEEE 1609.4 WAVE multi-channel operation. The main drawback in WAVE is both safety and non-safety applications are communicated through a single DSRC radio resulting in low reliability during high traffic. The contention free protocols can communicate the safety and non-safety messages in separate channels and has no message collisions between vehicles in the same two-hop neighborhood. The contention free TDMA-based MAC protocols help to reduce interference between overlapping areas whereas the other access techniques such as CDMA and FDMA based protocols make use of more complex and expensive techniques. The Hybrid protocols makes use of the various combined channel access schemes of contention based and contention free protocols. These protocols provide Qos support for the problems due to high mobility, improve multichannel operation, GPS locations and reduce access and merging collisions. All these proposed solutions allow VANETs to work well under different scenarios to perform reliable, efficient and collision-free transmissions.

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