A Survey on Medium Access Control Schemes for 5G Vehicular Cloud Computing Systems

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***Abstract*—Fifth generation (5G) vehicular systems support multiple services with strict Quality of Service (QoS) constraints. To fulfill the increased communication needs, 5G Vehicular Cloud Computing (5G-VCC) architectures with dense deployments of the access network infrastructures have been proposed. In such systems, the network resources manipulation is a critical task that could be addressed by the Medium Access Control (MAC) layer. MAC schemes that have been proposed for vehicular networks, can be applied to 5G-VCC systems in order optimal manipulation of communication resources to be accomplished. This paper makes an overview of available MAC schemes, while a comprehensive discussion about their implementation in 5G-VCC systems is performed leading to useful conclusions.**

***Index Terms*—5G Vehicular Cloud Computing (5G-VCC), Ultra Dense Networks (UDN), Medium Access Control (MAC), Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I), Survey**

I. INTRODUCTION

Fifth Generation Vehicular Cloud Computing (5G-VCC) architectures combine the operating principles of both Vehicular Networks and Cloud Computing. The vehicular environment consists of vehicles equipped with On-Board Units (OBUs) with computational, storage and communication resources. Vehicles communicate with each other as well as with Road Side Units (RSUs) which provide access to the core network. Specifically, the Vehicle to Everything or V2X model [1] is considered, where V stands for vehicle and X determines the entity that communicates with the vehicle. The most common V2X communication types include the Vehicle to Vehicle (V2V) [2][3] and the Vehicle to Infrastructure (V2I) [2][4] communications. V2V communication comprises a wireless network where vehicles exchange information with each other. Accordingly, V2I communication is performed between a vehicle and a network infrastructure (e.g. with RSUs). V2V and V2I communications could coexist in a 5G-VCC architecture. In this case, the entire communication between the architecture entities is called Hybrid Vehicular Communication (HVC) [5].

In a 5G-VCC architecture each RSU interacts with a Cloud infrastructure, which offers vehicular services with strict Quality of Service (QoS) requirements such as driver assistance and passengers entertainment services. Also, each vehicle could serve multiple passengers, namely vehicular users, with different services and various requirements. Thus, increased communication needs arise, requiring optimal manipulation of network resources. To address this issue, advanced Medium Access Control (MAC) algorithms are required to accomplish optimal manipulation of communication resources. A MAC scheme defines functionalities for the distribution of the available medium resources to the vehicles. Thus, the access of each vehicle to the underling physical layer is controlled through the appropriate resources scheduling, in order the utilization of the available spectrum to be maximized.

Several MAC schemes have been proposed to the research literature. Such schemes are being built upon well-defined multiple access mechanisms, including the Time Division Multiple Access (TDMA), the Orthogonal Frequency Division Multiple Access (OFDMA), the Space Division Multiple Access (SDMA) and the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). This paper makes an overview in MAC schemes that can be applied in 5G-VCC systems. The schemes are classified considering their multiple access mechanism. Also, scheme design characteristics such as the clustering of vehicles, the requirement of a positioning system, the control type (centralized or decentralized), the support of Cognitive Radio Networking (CRN) and the supported communication (V2V or V2I) are considered in order their design to be evaluated.

The remainder of the paper is as follows: Section II makes a brief overview of available MAC schemes that can be used in 5G-VCC systems. Section III discusses these schemes considering their design and, finally, Section IV concludes the survey.

II. MEDIUM ACCESS CONTROL (MAC) SCHEMES FOR 5G-VCC SYSTEMS

This section describes MAC schemes that can be applied to 5G-VCC systems. The schemes are organized considering their underlying multiple access mechanism. Since the vehicular environment often changes due to the high mobility of vehicles, while at the same time both V2V and V2I communications must be supported, sometimes in an ad-hoc manner, the most common multiple access mechanisms considered in vehicular MAC schemes include the TDMA and the CSMA/CA. Also, Hybrid schemes have been proposed in the literature combining more than one multiple access mechanism. Figure 1 presents the schemes that will be discussed in the following subsections.

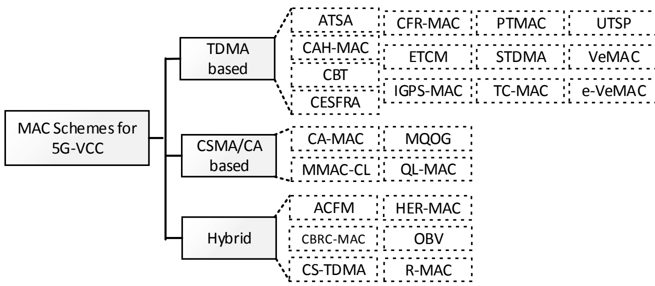

Fig. 1: The discussed MAC schemes for 5G-VCC systems.

A. TDMA-based MAC schemes

TDMA-based MAC schemes share the medium in the field of time. Indicatively, the Adaptive TDMA Slot Assignment (ATSA) [6] scheme defines that each vehicle selects a frame length, which is reduced to improve channel utilization when vehicle density becomes low, or increased when vehicle density becomes high to ensure that each vehicle can access the medium. Time slots are divided in two sets, namely the Left and the Right set. A slot management mechanism based on a binary tree model is used. The vehicles on the left sub-tree can compete for the Left time slots, while the vehicles on the right sub-tree can compete for the Right time slots. When a vehicle receives slot allocation information from its neighbors, it discovers which slots are in use. Thus, the remaining slots are available to compete for.

The Cluster Based TDMA (CBT) [7] scheme provides a mechanism for intra-cluster and inter-cluster communication to minimize the packet collisions that could occurre when two clusters are moving in close places. In each cluster, the vehicles are timely synchronized using their GPS devices, while one vehicle is elected as the Cluster Head (CH). A TDMA related technique is used where each frame consists of N time slots. The CH maintains a Slot Allocation Map (SAM) allocating time slots to vehicles. Moreover, the CH periodically broadcasts its SAM to its cluster's vehicles as well as a beacon frame. The cluster remains in intra-cluster communication state if beacon frames from CHs of other clusters are not received. However, if a beacon frame comes from an external CH, the two neighboring clusters' CHs exchange their SAMs in order inter-cluster interference to be prevented. The CH that successfully sends first its SAM is considered as the Winner, while the other is considered as the Looser and must reschedule its own SAM.

Another TDMA-based MAC scheme is the Cross-layer Extended Sliding Frame Reservation Aloha (CESFRA) [8]. It defines that safety information is disseminated up to the third hop neighboring vehicles without any routing scheme. The scheme divides each frame into N time slots. All the vehicles are considered to be timely synchronized using their Geographical Positioning System (GPS) devices. When a vehicle has packets to transmit, it senses the medium in order to find an idle time slot. Once an idle time slot is found, the vehicle starts transmitting its packets. Also, the time slot is reserved by the vehicle in the subsequent frames in order to transmit the remaining packets.

The Collision Free Reservation MAC (CFR-MAC) [9] is another mechanism that provides TDMA based medium access. It considers the vehicles' traffic flows as well as their velocities. Time slots are divided into two sets, the Left and the Right set. The Left set is assigned to vehicles that are moving to the one direction, while the Right set is assigned to vehicles moving to the other. In general, when multiple vehicles are moving on the same street with different velocities the interference levels on the wireless environment are constantly changing leading on unpredictable changes in the medium quality. CFR-MAC addresses this problem by dividing each slots set into three subsets, while each subset is associated to a specific velocity, namely the High, the Medium and the Low velocity. In this way the interference levels inside each subset become less variable and the medium quality more resistant.

The Vehicular MAC (VeMAC) [10] supports broadcast services. Similar to CBT and CFR-MAC schemes, two vehicles' moving directions are considered, namely the Left and the Right direction. A set of time slots is assigned to vehicles that move in the Left direction and the Right direction, respectively. Using these time slots, the vehicles of each direction communicate with each other, while vehicles time synchronization is performed using their GPS devices. Although VeMAC supports reliable transmission, it is not fully applicable in vehicular networks with parallel transmissions. In [11] an enhanced version of VeMAC scheme, the e-VeMAC, is proposed. The e-VeMAC scheme is based on the insight of the one-hop neighboring vehicles in order to improve the performance of the VeMAC scheme when parallel transmission occurs.

The Enhanced TDMA Cluster-based MAC (ETCM) [12], the Prediction-based TDMA MAC (PTMAC) [13] and the Unified TDMA-Based Scheduling Protocol (UTSP) [14] schemes also implement TDMA based multiple access. Specifically, the ETCM scheme defines that the vehicles are organized into clusters, while a vehicle of each cluster is defined as the CH. Subsequently, the CH applies a TDMA based method to assign time slots to cluster's vehicles.

The main operating principle of PTMAC is the packet collisions prediction. PTMAC consists of three parts, namely the collision prediction part, the collision detection part and the collision elimination part. According to the collision prediction part, data traffic and vehicles mobility information is used in order potential future collisions to be predicted. Furthermore, the collision detection uses time slots information to detect collisions that occurred in cases where two vehicles transmit data using the same time slot. Finally, the collision elimination part reschedules the slots considering the information obtained from both collision prediction and collision detection parts, in order the packet collisions to be eliminated.

The UTSP scheme implements a centralized resource allocation mechanism for V2I communication. Initially, the RSU collects information about the channel state, the vehicles' velocities and the priorities of the vehicles' services. Then, it uses a weighted function to compute a score for each vehicle. Finally, the RSU assigns TDMA time slots to each vehicle according to its score, where the amount of time slots assigned to each vehicle is proportional to the corresponding vehicle's score.

Similar to the aforementioned MAC schemes, other TDMA-based schemes include the Cooperative ADHOC MAC (CAH-MAC) [15], the Improved Generalized Prime Sequence Based MAC (IGPS-MAC) [16], the Self-organizing Time Division Multiple Access (STDMA) [17], and the TDMA Cluster-based MAC (TC-MAC) [18].

B. CSMA/CA-based MAC schemes

The schemes of this category share the medium by applying the CSMA/CA operating principles.

The Context Aware MAC (CA-MAC) [19] considers the network load status, in order to improve the medium access performance of 802.11p MAC. More specifically, CA-MAC consists of two parts, the Reasoning part and the Self-adaption part. Initially, the Reasoning part obtains the network load based on context information. Thus, the network is characterized as congested, idle or normal. Subsequently, the Self-adaption part considers the network load and dynamically adjusts the 802.11p Contention Window [20] size, which is used for channel reservation by the vehicles. Accordingly, if high network load is observed, the CW is incremented to reduce the collisions probability. On the contrary, if low network load is observed the CW is decreased to avoid unnecessary medium access delays. More specifically, if the Reasoning part indicates that the network is congested, the CW will be increased by 1, while if the Reasoning part indicates that the network status is idle, the value of CW will be halved. The CW will remain unchanged, if the Reasoning part indicates that the network status is normal.

Another CSMA/CA-based scheme called Multichannel MAC - Cross Layer (MMAC-CL) [21] aims to reduce the interference between vehicles at both MAC and Network layer considering two multichannel radio interfaces per vehicle. The proposed scheme maximizes the average Signal to Interference Ratio (SIR) between the source and the destination. Transmission channels are selected considering a SIR evaluation, in order to minimize the cochannel interference observed by the vehicles.

The Multichannel QoS Cognitive MAC (MQOG) [22] is multichannel scheme using a dedicated CCH for control information exchange and multiple SCHs for data transmission. It defines that each vehicle assesses the interference level in each channel and acquires the best one for transmission. Specifically, each vehicle tracks its neighbors' communications using a Channel Neighbor State Table (CNST). Vehicles obtain information from the CCH in order to update their CNST tables and select the appropriate SCHs for their data transmission.

Last but not least, the Q-Learning MAC (QL-MAC) [23] provides delay tolerant medium access, where neighboring vehicles exchange positioning information. A Contention Window (CW) is defined, while the best CW size is evaluated using a Q-Learning algorithm, in order to improve the contention efficiency. A positive reward is awarded to each vehicle when a data frame is successfully transferred. On the contrary, a negative reward is given when a data frame transmission is failed. The dynamic CW size adjustment reduces the packet collisions, while at the same time it succeeds low medium access delay. Furthermore, when the payload size is larger than a predefined threshold, the RTS/CTS mechanism is applied in order to avoid the hidden terminal and the exposed terminal problems, otherwise the position information is utilized in order to decide whether to start the transmission.

C. Hybrid MAC schemes

This category includes MAC schemes that use the operating principles of more than one of the aforementioned multiple access mechanisms. Indicatively, the Adaptive Collision Free MAC (ACFM) [24] scheme combines both TDMA and FDMA. It implements a time slot reservation mechanism located at each RSU. Each frame operates in a specific frequency and contains 36 time slots that can be used for data transmission and 1 slot that is called RSU Slot (RS). Furthermore, each RSU maintains a Slot Assignment Cycle (SAC) for the next 100ms of time, while each cycle can contain from 1 and up to 5 frames according to the vehicles density. Specifically, if vehicles density is low, the RSU uses few frames in order to avoid situations where a lot of slots remain unused. On the contrary, if vehicles density is high, the RSU uses more frames in order to support the increased needs for resources.

Similar to ACFM scheme, the Cluster Based RSU Centric MAC (CBRC-MAC) [25] combines both TDMA and FDMA for providing multiple access to vehicles. Firstly, the available spectrum is divided into a set of subfrequencies using FDMA and, subsequently, each subfrequency is divided into a set of time slots. Thus Resource Blocks (RBs) are created including a specific subfrequency in the frequency domain and a specific slot in the time domain. RSUs assign RBs to vehicles considering their communication needs.

Some schemes combine TDMA with CSMA/CA to accomplish the multiple access. Indicatively, in the Hybrid Efficient and Reliable MAC (HER-MAC) [26] scheme, vehicles are synchronized using their GPS devices. When a vehicle needs to transmit data, it uses the CSMA/CA to perform a 3-way handshake in Wireless Access for Vehicular Environment (WAVE) [27] called Service Announcement/Request for Service (WSA/RFS). During this handshake, the transmitter vehicle broadcasts a WSA message in order to reserve TDMA time slots for data transmission. Subsequently, when the slot reservation is complete, the transmitter vehicle sends a RFS message to the recipient vehicle. Subsequently, the recipient vehicle responses with an acknowledgement message (ACK) and then the transmitter vehicle can start the data transmission.

The Risk-Aware MAC (R-MAC) [28] scheme divides each frame into two segments, namely the RSU segment and the vehicle segment. RSUs broadcast control messages using the RSU segment, while the vehicle segment is further divided into two sub-segments, namely the CSMA/CA sub-segment and the TDMA sub-segment. The CSMA/CA sub-segment is used for warning messages transmission (e.g. in case of an accident) while the TDMA sub-segment is used for non-safety data transmission.

It should also be noted that in some Hybrid mechanisms, the TDMA or CSMA/CA are combined with the SDMA considering the geographic position of each vehicle. For example, the CSMA-based Self-Organizing TDMA (CS-TDMA) [29] combine TDMA, CSMA/CA and SDMA to support both safety and non-safety applications. A CCH channel is used for the safety applications data transmissions, while a SCH channel is used for the non-safety applications. The ratio between the CCH and SCH lengths is adjusted considering the vehicles density in each location. If the vehicles density is high, the CCH length is increased and the SCH length is decreased in order a maximum delay for safety applications to be guaranteed. On the contrary, if the vehicles density is low, the CCH length is decreased and the SCH length is increased in order the throughput for non-safety applications to be improved.

Finally, in the OFDMA-based MAC scheme for VANETs (OBV) [30] the CSMA/CA is combined with the OFDMA mechanism. During a resource negotiation phase, vehicles allocate resources using CSMA/CA. Thereafter, the data transmissions are performed using OFDMA, while at the same time the vehicles are synchronized using their GPS receivers in order the orthogonality between the OFDMA subcarriers to be guaranteed.

III. Discussion

Although most of the available MAC schemes have been designed for vehicular systems, but not necessarily for 5G-VCC systems, they could be easily applied to the vehicular part of a 5G-VCC architecture. The study of these schemes reveal the fact that different approaches have been proposed to the literature.

As mentioned in the previous sections, a main factor of the discussed schemes is the underlying multiple access protocol. The most common multiple access protocols used include the TDMA and the CSMA/CA. Additionally, some schemes apply hybrid solutions by combining more than one multiple access protocols. These schemes combine the FDMA with the TDMA (e.g. ACFM and CBRC-MAC), the CSMA/CA with the TDMA (e.g. HER-MAC and R-MAC), the OFDMA with the CSMA/CA (e.g. OBV) and so on. Furthermore, some schemes organize the vehicles into clusters (e.g. CBRC-MAC, CBT, ETCM, IGPS-MAC, R-MAC and TC-MAC), while the rest do not consider clusters of vehicles. In general, clustering could be considered as a useful methodology which offers improved use of the available spectrum. A positioning system is also required in some cases in order the vehicles positions to be monitored. The existence of a positioning system enables the vehicles to be timely synchronized with each other using their GPS receivers.

Another important factor that is considered is the control type applied from each scheme. Specifically, some schemes apply distributed control, while other schemes apply centralized control. Although the distributed control distributes the resource manipulation workload, the centralized control could be considered as more appropriate in some cases, since it simplifies the manipulation of communication resources. Indicatively, in 5G-VCC architectures where a centralized Software Defined Network (SDN) [31] controller supervises the manipulation of the entire system, centralized MAC schemes could be easily configured considering the complete view of system's resources. Besides, distributed schemes could also be configured in 5G-VCC systems considering the operating principles of the Fog computing [32].

Cognitive Radio Networking (CRN) [33] is another factor that is considered in 5G-VCC systems organizing the vehicles into two groups, namely the Primary and the Secondary vehicles. Primary vehicles obtain immediate access to network resources as determined in their Service Level Agreements (SLAs) [34]. However, sometimes Primary vehicles do not need the entire network resources provided according to their SLAs. In such cases, Secondary vehicles could use the free network resources, which are also called White Spaces. Furthermore, whenever a Primary vehicle requires the resources defined to its SLA, it immediately reserves them, while the Secondary vehicles should obtain access to other free network resources. Considering the CRN operating principles, some MAC schemes (e.g. MQOG) take advantage of free white spaces into the available spectrum in order more vehicles to be served. Finally, the communication type (V2V or V2I) that each scheme supports is considered. Table I presents the characteristics of the discussed MAC schemes considering the aforementioned factors.

TABLE I: The main characteristics of the discussed MAC schemes.

MAC Scheme	Multiple Access	Cluster based	Positioning System Required	Centralized /Distributed control	CRN Support	Communication
ACFM [24]	FDMA, TDMA	No	No	Centralized	No	V2I
ATSA [6]	TDMA	No	No	Distributed	No	V2V
CAH-MAC [15]	TDMA	No	Yes	Distributed	No	V2V
CA-MAC [19]	CSMA/CA	No	No	Distributed	No	V2V, V2I
CBRC-MAC [25]	FDMA, TDMA	Yes	No	Centralized	No	V2I
CBT [7]	TDMA	Yes	Yes	Centralized	No	V2V
CESFRA [8]	TDMA	No	Yes	Distributed	No	V2V
CFR-MAC [9]	TDMA	No	Yes	Distributed	No	V2V
CS-TDMA [29]	CSMA/CA, SDMA, TDMA	No	Yes	Distributed	No	V2V
ETCM [12]	TDMA	Yes	Yes	Centralized	No	V2V
HER-MAC [26]	CSMA/CA, TDMA	No	Yes	Distributed	No	V2V
IGPS-MAC [16]	TDMA	Yes	Yes	Centralized	No	V2V
MMAC-CL [21]	CSMA/CA	No	Optional	Distributed	No	V2V, V2I
MQOG [22]	CSMA/CA	No	No	Distributed	Yes	V2V, V2I
OBV [30]	CSMA/CA, OFDMA	No	Yes	Distributed	No	V2V, V2I
PTMAC [13]	TDMA	No	Yes	Distributed	No	V2V
QL-MAC [23]	CSMA/CA	No	Yes	Distributed	No	V2V
R-MAC [28]	CSMA/CA, TDMA	Yes	Yes	Centralized	No	V2V, V2I
STDMA [17]	TDMA	No	Yes	Distributed	No	V2V
TC-MAC [18]	TDMA	Yes	Yes	Centralized	No	V2V
UTSP [14]	TDMA	No	Yes	Centralized	No	V2I
VeMAC [10]	TDMA	No	Yes	Distributed	No	V2V
e-VeMAC [11]	TDMA	No	Yes	Distributed	No	V2V

IV. Conclusion

In this paper, an overview of available MAC schemes for vehicular networks has been made. These schemes can be applied in 5G-VCC systems in order optimal manipulation of communication resources to be performed. As presented, the main multiple access protocols used include the TDMA and the CSMA/CA, while hybrid solutions combine FDMA SDMA or OFDMA with the aforementioned protocols. Also, some schemes organize the vehicles into clusters, while GPS receivers are used in some cases in order the vehicles to be timely synchronized with each other. The discussed schemes apply either distributed or centralized control. In a 5G-VCC system the centralized control could be enhanced using an SDN controller, while the distributed control could be easily configured using a Fog computing infrastructure. Furthermore, V2V communication is supported from the most schemes, while some schemes support V2I communication. Finally, during the medium access, CRN could be applied to take advantage of free white spaces into the available spectrum.

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