MAC-aware Routing Protocols for Vehicular Ad Hoc Networks: A Survey

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***Abstract*—The constantly growing number of vehicles on our roads has become an increasing major cause of serious injury and death. Efficient data dissemination in Vehicular Ad hoc Networks (VANETs) inevitably requires an efficient and robust routing protocol. In this context, several categories of routing protocols have been proposed in the literature to meet VANETs application requirements in terms of delay, packet loss and throughput. In this paper, we focus on cross layer routing protocols. We present a survey of state-of-the-art MAC aware routing protocols designed for VANETs. These solutions can broadly be divided into two categories: contention-free and contention-based MAC-aware routing. In this paper we carryout a comprehensive comparison of these approaches. Finally, we identify open research issues that should be addressed in order to improve MAC aware routing techniques in VANETs.**

***Index Terms*—Vehicular Ad hoc Networks, Routing, Medium Access Control, Contention-free, Contention-based**

I. Introduction

A Vehicular Ad-hoc NETwork (VANET) is a technology based on a mobile network, where each node represents a moving vehicle. This technology has similar characteristics to Mobile Ad-hoc Network (MANETs), often in the form of multi-hop networks. However, VANETs have their own specificities such as high mobility of nodes, unlimited lifetime, different QoS requirements, etc. VANETs are currently receiving increased attention from manufacturers and researchers to improve road traffic safety or assist drivers. They may, for examples, warn other motorists that roads are slippery or that an accident has just occurred. Vehicular networks are an integral element of Intelligent Transportation Systems (ITS). The vehicles communicate with each other via Vehicle-to-Vehicle communications (V2V) as well as with the road facilities via Vehicle-to-Infrastructure communications (V2I). The aim is that VANETs will contribute to safer and more efficient roads in the future by providing timely information to drivers and the appropriate authorities [12].

VANET applications include traffic management, accident or traffic congestion signaling and obtaining information via the Internet while the vehicles are in motion. But before successfully deploying these applications, many issues need be addressed. The proposed access control and routing protocols for VANETs are designed to improve specific metrics, such as packet loss, end-to-end delay, and throughput. However, inconsistent decisions from these two layers may not lead to optimal performance. Therefore, MAC protocol and routing decisions should be correlated to optimize the transmission time.

"Cross-layer" approaches solve this problem either by combining the two layers into a new layer or by providing internal communications between two-layer protocols. Accordingly, several MAC-based routing protocols have been designed for VANETs in order to improve system performances and provide efficient routing/dissemination decisions. Contention-based protocols use the CSMA/CA technique which allows random access to the channel when nodes have data to transmit. Contention-free protocols are based on the Time Division Multiple Access (TDMA) technique, which offers a kind of fairness by enabling different nodes sharing the medium where each vehicle has a defined time slot reservation [1], [6].

The goal of this paper is to conduct a comprehensive survey and comparison of state-of-the-art cross layer MAC Routing protocols for vehicular networks. To the best of our knowledge, this is the first attempt that gives an overview on MAC aware routing protocols for VANETs.

The rest of the paper is organized as follows: Section II provides an overview of the cross layer concept in VANET. Section III presents a detailed survey of existing MAC aware routing protocols that have been proposed for VANETs. In Section IV, we discuss the proposed discussion and provide qualitative comparison of these approaches. Section V sets out certain research issues that remain to be addressed and gives future directions for cross layer routing in VANETs. Finally, the conclusion and future work are presented in Section VI.

II. Cross Layer Concept

Traditional network architecture is based on the layering model where the role of each layer is to achieve a subset of required communication functions and challenges such as high throughput, low latency, etc. Also, each layer offers its services to the next higher layer in such a way that parameters and details of one layer are masked to the rest of layers. As a result of the non-inter layer cooperation, changes occurring in one layer do not affect the other layers. Such non-cooperation and lack of coordination between network layers is considered to be a relevant issue for VANETs as they can cause several limitations in network performances in terms of QoS requirements, mobility management, Security, etc.Hence, working layers individually should not be applied in VANETs: it is necessary to combine various parameters from different layers to make efficient and accurate decisions in VANETs. The cross layer concept was to create cooperation and interaction between all layers in order to improve network performances. The idea is to allow information sharing between different layers. Hence, layers will update their rules and status based on the parameters they receive [13]. In VANETs, cross-layer design could be useful to achieve 3 main goals: Quality-of-service (QoS), Road Safety and Mobility Management.

A. Quality-of-Service (QoS):

Guaranteeing high quality-of-service (QoS) is a very important requirement for vehicular networks given the need to achieve high-speed and high-quality communications. Cross layer design aims at providing networks the ability to handle their traffic in such a way as that they meet the needs of different applications. The nature of VANETs introduces new problems due to network mobility, lack of central control, route maintenance, etc. Thus, all these issues must be dealt with in order to satisfy QoS requirements. We need to have QoS model provisioning, cooperation among routing and traffic engineering. To ensure QoS needs in cross-layer approach, different information from different layers such as the delay, channel rate, queue status, etc., should be incorporated in the process of taking routing decisions [14].

B. Road Safety

The basic idea of vehicular networks is the ability to alert and warn road users about problems or event. However, routing protocols based on the ordinary strict architecture cannot always guarantee the efficiency of dissemination of alerts which are very sensitive to delay constraints. Thus, solutions based on cross layer approaches can very effectively improve the dissemination of information (signaling accidents or traffic congestion, etc.). In fact, by allowing communication between the different layers, the transfer decisions will consequently be improved, which makes the information exchanged in the network both useful and timely. Moreover, passenger safety is very much linked to time, since a simple delay of a few seconds can lead to serious consequences and the more warnings that are received have arrived within the right delays the greater the chance of avoiding road problems. This means that using a routing solution based on cooperative approaches is essential [13].

C. Mobility Management

One of the most important features of VANETs is mobility management. Mobility management depends on the mobility model, which is characterized by a set of features like the number of vehicles, the speed of the vehicles, the type of road: highway/freeway, one way/two way, etc. Due to the high mobility of the nodes and frequent changes in network topology, mobility management is required to supply seamless VANET services. VANET requirements cannot be provided by traditional mobility management schemes because they use unique characteristics in their design. Therefore, an exchange between multiple layers will effectively resolve the problem and enhance efficiency via a cross-layer scheme that allows interaction between layers [14].

III. MAC-aware Routing Protocols

Medium Access Control (MAC) and routing protocols are fundamental for building VANET architectures, and designing a MAC-aware routing protocol seems to be essential. Different parameters from the MAC layer, like transmission time slot allocation, channel state, and collision probability, should all be taken into consideration when building VANET Routing Protocols. In this section, we detail MAC-aware routing protocols recently proposed in the literature to efficiently support multi-hop communication and disseminate safety messages in vehicular networks in a timely manner.

In [1], the authors propose a TDMA-aware Routing Protocol for Multi-hop communications (TRPM) in Vehicular Ad Hoc Networks in order to provide the ability to send/receive packets over long distances. In TRPM, accessing the channel by vehicles is ensured by the DTMAC protocol [2], which is based on the TDMA technique. Delivering a message from source to destination via multiple relay nodes needs an efficient decision to the next best relay based on the TDMA scheduling information and packet destination position. The main idea of TRPM is that the sender constructs two sets of candidate forwarders. The first set contains vehicles that are moving in the adjacent right-hand area and the second set contains vehicles that are moving in the adjacent left-hand area. Then, it selects the best next relay from one of these sets depending on the geographic position of the packet's destination. More precisely, TRPM uses a weighted next-hop selection function that uses the access delay and the distance between the sender and its neighboring vehicles to choose next relay node. This process is repeated until the packet reaches its destination.

Another TDMA based routing protocol is proposed in [3]. This approach, called Priority-Based Direction-Aware Media Access Control (PDMAC), has been designed for warning message dissemination on bi-directional highways. To do so, PDMAC uses clustering and classifies nodes as cluster heads (CHs) and ordinary vehicles (OVs). After assigning nodes to different clusters, clock synchronization of the nodes is a critical issue to reserve time slots. In fact, since PDMAC is based on TDMA, its main issue is clock synchronization because only intra-cluster clock synchronization is considered. Hence, nodes will experience difficulty in the slot reservation process. To resolve this problem, PDMAC introduces inter-cluster clock synchronization in addition to intra-cluster clock synchronization and a three-tier priority assignment technique. Inter-cluster clock synchronization is achieved by using a timer validation bit in the message header that takes the value 1 to mean that the clock is synchronized and 0 if it is not.

The synchronization algorithm chooses an arbitrary cluster head CH from the set of CHs and broadcasts a clock synchronization message to the CHs. Then, CHs clocks will be synchronized with the commonly shared clock of the CH chosen. In this way, all CHs will be synchronized to a common local clock. In Intra-cluster clocks, member nodes of a cluster are synchronized by the reception of a message from their CH. To disseminate warning messages, PDMAC develops a three-tier priority assignment process. The first tier is Direction-Based Relay Selection. A source disseminates to its neighbors a request message (REQ) that indicates its direction, destination, etc. and reserves all available time slots in this frame for itself. Neighbors respond with an acknowledgment message (ACK) which contains all free time slots and the slot to be assigned for the transmission of the message according to the severity level of the message. The node selected as the best relay is the one that is closest in distance to the destination and is in the direction towards it. The second tier is the Priority on the Basis of Message Type. PDMAC prioritizes warning messages over non warning messages by adding a bit in the message header to indicate the type of the message. Finally, the third tier is Priority on the Basis of Severity Levels to differentiate between different warning messages depending on their severity levels by computing the collision probability. In this case, warning messages are classified into 3 levels. In the case of a lowest priority message, the sender should wait for a free time slot to send. If it is a second level priority, it requests the release of a slot of another non-warning or warning message with lower priority. Otherwise, in the case of a highest priority level message, it is mandatory to release on the time slot of a non-warning or a lower-priority message.

An opportunistic routing protocol called OB-VAN that uses a modified 802.11 MAC layer, is presented in [4]. The goal of this protocol is to disseminate a broadcast packet quickly and efficiently. OB-VAN uses an acknowledgement scheme to perform the choice of relays. Choosing the best relay here is performed by using an active signaling technique. Nodes that have captured the packet, transmit a short acknowledgement made up of signaling bursts that is calculated based on the distance criterion just after receiving the packet. This scheme is a generalized CSMA/CA where the backoff technique is replaced by the Active signaling technique. To prohibit interference on signaling bursts, OB-VAN uses the CDMA spreading code. First, this process can ensure that senders know that packets have been received by potential relays. Second, it allows the selection of the furthest relay and thus reduces hop count, collision and message delivery time. Signaling bursts can be presented by 0 or 1. 0 denotes a listening interval and 1 denotes a transmission interval. This binary sequence is composed of two parts. The first part, is dedicated to optimizing the criterion for the best relay selection while the second is used to discriminate between nodes and permit the winner to relay the data packet.

In [5], H.A.Omar et al developed a novel packet routing scheme (MH-VeMAC) based on a multichannel medium access control protocol, known as VeMAC: an approach to mitigate transmission collision [7]. MH-VeMAC aims, first, at discovering the existence of a gateway to the Internet by vehicles. Then, defining the way how a packet can be delivered via multihop communications from a vehicle to a gateway and vice versa. For Gateway discovery, each gateway should periodically broadcast a Gateway Discovery Packet (GDP) containing the necessary information that a vehicle needs to access. At each hop, the subset of vehicles that can relay the GDP should be determined. The GDP relaying process in MH-VeMAC is based on time slot scheduling information on the Control Channel (CCH). In packet forwarding, each vehicle stores a routing table which has an entry corresponding to each gateway that should be updated based on the current network topology. Delivering a packet from a vehicle to a gateway and vice versa are different. In fact, in the first case, the vehicle chooses a relay randomly from the routing table entry to forward the packet until the packet is delivered to the destination gateway. However, routing a packet from a gateway to a vehicle is ensured by a source gateway that includes the MAC address of each vehicle that should relay the packet in the header of each transmitted packet until it reaches the destination vehicle.

A new routing protocol, named ECLCR, has been proposed in [8] to improve message dissemination in VANETs with IEEE 802.11p. ECLCR presents two main aspects: route discovery and the addition of a new mobility parameter in the RREP packet header which contains the entire network's fewest neighbors for each Route Request (RREQ). Route discovery aims to reduce the forwarding delay and the number of control packets through the selection of the next relay that has the lowest number of common neighbors. Hence, every node that receives a RREQ, decides either to accept the packet and forward it or to drop it by checking the ratio of neighboring vehicles.

A recent protocol called Multi-Channel Token Ring Protocol (MCTRP) is presented in [9]. MCTRP employs the multi-channel structure defined in IEEE 802.11p. The network is composed of multiple virtual rings. Nodes are classified into 5 types: Ring Founder Node (RFN), Token Holder Node (THN), Ring Member Node (RMN), Dissociative Node (DN), and Semi-Dissociative Node (SDN). There are 2 types of radio: Radio-I and Radio-II. A DN uses only Radio-I since it does not belong to any ring but other nodes use both of them. Also, the time system is partitioned into a control period and a data period. The MCTRP protocol follows 3 sub-protocols. The first sub-protocol is the Ring coordination protocol. Its functionalities consist of managing rings and nodes and scheduling Service CHannels (SCH) for each ring. First, the Ring Initialization Process consists of sending a Ring Founding Message (RFM) that includes a selected SCH number for the intra-ring data communications and wait for an invitation. In the absence of a response and the expiration of its time, the DN constructs a new ring and becomes a RFN. After establishing a ring, a Joining Invitation Message (JIM) which includes some information such as the SCH number, the speed, etc. will be broadcasted by the RFN to DNs. The DN will reply to the RFN with a Joining Acknowledgement Message (JAM) if the difference between its moving speed and that of the RFN is smaller than a predefined speed threshold. Other messages will be exchanged between RFN, DN and RMN such as Connection Notification Messages (CNMs), Connecting Successor Messages (CSMs), etc. using the contention based CSMA/CA scheme.

The second sub-protocol is the Emergency message exchange protocol. To efficiently deliver emergency messages, MCTRP uses radio-I or radio-II depending on the case. This can be done through 4 steps. Firstly, when an RMN detects an accident, it sends an emergency message to its RFN by adopting CSMA/CA and using radio-II. Secondly, the RFN node replies with an acknowledgement to the RMN, and then broadcasts the emergency message to all its RMNs using radio-II. Thirdly, it also broadcasts the message to its neighboring DNs, SDNs, RFNs using radio-I. Finally, neighboring RFNs rebroadcast the emergency message again to their RMNs using radio-II.

The third sub-protocol is Data Exchange Protocol. Two types of data communications exist: inter-ring data communications where packets are transmitted with the CSMA/CA mechanism and intra-ring data communications where data packets are transmitted using a token based mechanism. After receiving a token, nodes can transmit data during a token holding time and then pass the token to its successor.

Khalid A. Darabkh et al. have proposed a cross-layer algorithm for improving the AODV protocol over Vehicular Ad-hoc Networks named Multi Rate Mobility Aware Routing (MRMAR) [10]. The goal of MRMAR is to decrease the large number of RREQ control packets and to ensure fast data forwarding. MRMAR starts with a route discovery phase. The first step is rate selection from the underlying MAC layer, that aims at choosing the transmission rate with the highest value, which will be included in the RREQ. Then, the source broadcasts an RREQ with the chosen transmission rate. In the second step, before the recipient sends the RREQ, some tests have to be done. The recipient checks that it is not the intended destination, the RREQ is not duplicated and that the destination does not exist in its routing table. Then, the transmission rate of nodes situated between the source and the recipient is verified to prove their compatibility with the RREQ's optimal rate. The third step is to test mobility, the recipient node checks if its speed is less than a predefined threshold. Therefore, a RREQ will be broadcasted. The data rate admission, speed and direction, will be tested over intermediate nodes until reaching the destination. If these checks are verified, the recipient will participate in the route discovery phase, if not it will discard the RREQ.

IV. Classification and Qualitative Comparison

Table I analyzes the cross-layer protocols that we have presented according to certain criteria and distinguishes between solutions based on the access method used at the MAC layer: contention-free, contention-based or hybrid. In this section, we discuss some of the features presented in Table I. This table helps us to draw several conclusions and an important number of research issues and open questions related to MAC-aware routing aspects that need to be addressed in the future.

To summarize, TRPM, PDMAC and MH-veMAC are based on a contention-free access scheme namely, TDMA, where time slot scheduling is used to make routing decisions. In contrast, OB-VAN, ECLCR and MRMAR use the standard 802.11p contention-based access scheme where different parameters, such as position, mobility and neighborhood information are passed to the routing layer to enhance the forwarding process. ECLCR and MRMAR both use an AODV-like route discovery process and incorporate MAC parameters in the RREQ/RREP messages to assess path selection. Finally, the MCTRP routing protocol can be classified as a hybrid approach that combines contention-free (Token ring) and contention-based (CSMA-CA) access approaches.

Another important point that we can note from Table I is that the majority of the protocols have been proposed only for specific scenario, namely the Highway and do not address the issues presented by critical areas in urban road networks like intersections, traffic light, etc. Unlike TRPM, PDMAC, and MCTRP that simulate in dense networks, the other protocols work under either low or low/medium density. When node density is low, protocols perform well. However, when vehicle density increases, the collision rate also increases and thus their performance degrades. Moreover, only three routing protocols presented in this paper can support route maintenance to handle link failures due to the high mobility constraint in VANET, however none of them support security mechanisms which make them vulnerable to cyber-security attacks. Hence, we emphasize the need to use new security mechanisms in future routing protocols for efficient and reliable communications. We notice that some of these protocols have a significant overhead due to the route discovery process which periodically sends RREQs and RREPs like MRMAR, ECLCR, PDMAC, MCTRP and MH-VeMAC. This is in contrast to the rest of protocols TRPM and OB-VAN which have a low overhead. VANET routing protocols are required to provide

TABLE I
QUALITATIVE COMPARISON OF CROSS LAYER ROUTING PROTOCOLS

	TRPM [1]	PDMAC [3]	MH-VeMAC [?]	OB-VAN [4]	MRMAR [10]	ECLCR [8]	MCTRP [9]
Published	2017	2019	2014	2008	2019	2018	2009
MAC	TDMA	TDMA	TDMA	CSMA Active signaling	CSMA	CSMA	Token Ring CSMA
QoS parameters	Delay Bandwidth Packet loss	Delay Throughput Packet loss PDR	Delay	Delay Bandwidth PDR	PDR Route Losses	Delay Bandwidth PDR	Delay Throughput
Multiple route	No	No	Yes	No	Yes	Yes	No
Routing metric	Hop count Shortest delay	Distance Direction	Hop count Distance	Distance	Transmission Rate Distance Speed Direction	NSR Mobility	Token holding time
Link Repair	No	No	Yes	No	Yes	Yes	No
Overhead	Low	High	High	Low	High	High	High
Security	No	No	No	No	No	No	No
Mobility scenario	Highway	Highway	Highway	Straight road	Urban	Urban	Highway
Density	High	High	Low Medium	Low Medium	Low	Low	High
Simulator	NS2	Toolbox [11]	MATLAB	NS2	NS3	NS2	NS2

different QoS needs like the delay, bandwidth, PDR, etc. Due to dynamics topology changing and the mobility of the nodes, we need a routing protocol that ensures multi-path routing between nodes. Only three protocols encompass the multiple route feature like the MRMAR and ECLCR protocols since they are based on the AODV protocol and the MH-VeMAC protocol. In each route discovery they can build multiple routes between the source and the destination.

V. Open Research Issues

In our survey, we have touched on some of the routing protocols based on the MAC layer designed for VANETs. These protocols have algorithms that aim at building an efficient routing or disseminating data. There are, however, a number of issues that need to be addressed in the future, and we take a closer look at some of these issues in this section.

A. High Mobility of Nodes

Routing protocols should take into consideration the constraint of node mobility, which is one of the main characteristic of VANETs, as it is a major challenge for routing protocols, and one that can have a major impact on their performance. Due to mobility and high speed, the network topology changes rapidly. This makes it difficult to get information about next hop neighbors as they may change suddenly their position and become out of transmission range which consequently penalizes the process of route construction. Cross layer routing should manage the mobility by adopting a mobility model based on exchanging information coming from different layers that allows them to cooperate and try to choose the suitable features from the suitable layers in order to have better knowledge about network topology and consequently handle the high mobility.

B. Security

Notifying vehicles about dangerous situations like road accidents, collision avoidance, etc. over disseminating warning messages is a fundamental necessity in VANETs. Security, in VANETs, represents an incisive and critical issue especially for safety applications that should be protected from attacks for a reliable and secure communication with the intention of protecting human life and vehicle privacy. Malicious nodes can alter the content of these messages, for example, through announcing false position, etc or even send false warning messages between vehicles. These changes will have a negative effect on drivers' behaviors and road safety and may also provoke collisions. Since routing protocol performance is sensitive to such attacks, routing decisions are affected when attackers modify the destination of a message, vehicle positions or by announcing false locations. The absence of an effective security mechanism is especially remarkable in decentralized topology because there is no global vision of the overall system but only local information in each node. Up to now, cross layer routing protocols have not been able to ensure message dissemination security due to the absence of a security mechanism that verifies the authenticity of nodes and distinguishes between malicious and safe nodes. Furthermore, even known cryptography means, cannot detect attacks and there is no guarantees that enable data to be altered. Therefore, cross layer should define adequate means that ensure security.

C. Support of Different Routing Metrics

Another challenging task in VANET is supporting different routing metrics. Routing decisions are based on the choice of specific metrics and their efficiency depends on which metrics should be selected. Unlike normal routing protocols, the cross-layer protocols require the use of several metrics from different layers correlated with each other to make their routing decisions. Ongoing research should concentrate on how to provide an efficient selection of routing parameters to ensure applications requirements by receiving feed-backs from different layers .

D. Route Maintenance

Due to successive changes in network topology, routes established between nodes can not always remain fixed. Therefore, link failure due to node movements must be announced in order for the routes to be maintained. The protocol should take into account the mobility of vehicles and the network load for the maintenance of routes.

E. Routing Overhead

Routing overhead very much depends certainly on the nature of the routing protocol. Routing overhead should be reduced to avoid bandwidth wastage. A high overhead can be due to heavy control overhead, for example, through sending many route reply packets for the same route request or due to network enlargement.

F. Broadcasting/Disseminating Protocols

As VANETs must disseminate emergency messages for road safety and traffic congestion avoidance, multi-hop broadcasting is essential in order to distribute information to all the neighbors situated within transmission range of a vehicle. One node among all the nodes that have received a message will be chosen under specific conditions to relay a multi-hop message and the same process will be repeated. Thus, the message will be disseminated as widely as possible.

VI. Conclusion

Given emphasis on road safety in VANETs, designing a reliable and robust MAC routing protocol seems essential for ensuring efficient communications and reliable message dissemination. A major challenge lies in combining functionalities of different layers in order to enhance network performances. This paper, which presents an overview of MAC aware routing protocols based on contention-free, contention-based or hybrid scheme, also shows the performance of these protocols in meeting VANET requirements. In this paper, we have discussed the cross-layer concept and its role in designing routing protocols and investigating goals in terms of QoS, road safety and mobility management by considering the benefits of mixing different functionalities of different layers. Then, we have focused on some proposed MAC routing protocols based on the TDMA and CSMA/CA technique. Furthermore, we have examined these protocols through a classification and comparison conducted according to certain features and metrics performances. This comparison is intended to provide a better understanding of these protocols. Finally, we have presented some challenges for VANETs that should be addressed in design of new Mac routing protocols. To the best of our knowledge, the paper represents the first attempt that gives an overview on the MAC aware routing protocols proposed for VANET.

As a future work, we plan to design a new MAC-aware routing protocol based on the TDMA protocol and the active signaling technique. We try to take into consideration previous problems to provide an efficient dissemination of messages.

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