Smart Computing Review

Survey of MAC Protocols for Vehicular Ad Hoc Networks

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Abstract: A vehicular ad hoc network is a special kind of mobile ad hoc network, and can be divided into two further types of networks, a vehicle-to-vehicle network or a vehicle-to-infrastructure network. However, unlike existing mobile ad hoc networks, vehicular ad hoc networks have unique characteristics, including high node mobility and a rapidly-changing topology. Vehicular ad hoc networks should be designed to accommodate these characteristics when we design them. To do this, many researchers have proposed Media Access Control protocols to improve the performance. Most of these studies deal with quick message transmission to support the high mobility of nodes, multiple channels for multiple connections in high-density urban node areas, and channel coordination.

In this paper, we provide a survey of Media Access Control protocols for vehicular ad hoc networks and classify the existing Media Access Control protocols into the three major categories of time-based, dedicated short-range communication-based, and directional antenna-based. Moreover, we discuss the characteristics of these Media Access Control protocols and show their advantages and disadvantages. In addition we define some open issues and future work related to Media Access Control protocols for vehicular ad hoc networks.

Keywords: V2V, VANET, MAC Protocols, Multi-Channel, Channel Coordination

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Introduction

Vehicular Ad hoc Networks (VANETs) are a special kind of Mobile Ad hoc Network (MANET), and can be further divided into vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) networks [1]. However, unlike existing MANETs, VANETs have unique characteristics including high node mobility and a rapidly changing topology [2]. VANETs should be designed to accommodate these characteristics [3]. To do this, many researchers have proposed Media Access Control (MAC) protocols to improve the performance of VANETs. Most of these studies are quick message transmission to support the high mobility of nodes, multiple channels for multiple connections in urban areas, and channel coordination for these multiple channels and multiple connections.

In order to improve VANET MAC protocols, the IEEE 1609 Working Group (WG) made up a standard VANET to support the data link layer of OSI layer 7 for Multi-channel Operations. To do this the IEEE 1609 WG adopted IEEE 802.11p [4] as a subsystem. The IEEE 802.11p is designed to support multiple connections using Orthogonal Frequency Division Multiplexing (OFDM) in VANETs. Thus, it will support orthogonal channels between vehicles.

However, even with these improvements, VANETs still have problems with traffic contention, hidden terminals, data transmission delays, decreasing throughput, and dynamic assigned channels for MAC protocols [5][6].

Many researchers have proposed MAC protocols to improve the performance of VANETs. Therefore, in this paper, we provide a survey of MAC protocol for VANETs, and classify existing of MAC protocols into the three major categories of time-based, dedicated short-range communication-based, and directional antenna-based. Moreover, we discuss the characteristics of these MAC protocols, and show their advantages and disadvantages. In addition, we define open issues and future work related to MAC protocols for VANETs.

Background: Standard Technology for VANETs

■ Wireless Access Vehicular Environment

The Wireless Access Vehicular Environment (WAVE) was made up to the standard of VANETs by the IEEE 1609 WG. As shown in Figure 1, the WAVE is divided into four categories of IEEE 1609.1 [7], IEEE 1609.2 [8], IEEE 1609. 3 [9], and IEEE 1609.4 [10]. First of all, the IEEE 1609.1 shows a Resource Manager. It is guide to deal with resources in VANETs such as On Board Units (OBUs), Road Side Units (RSUs) and Access Points (APs).

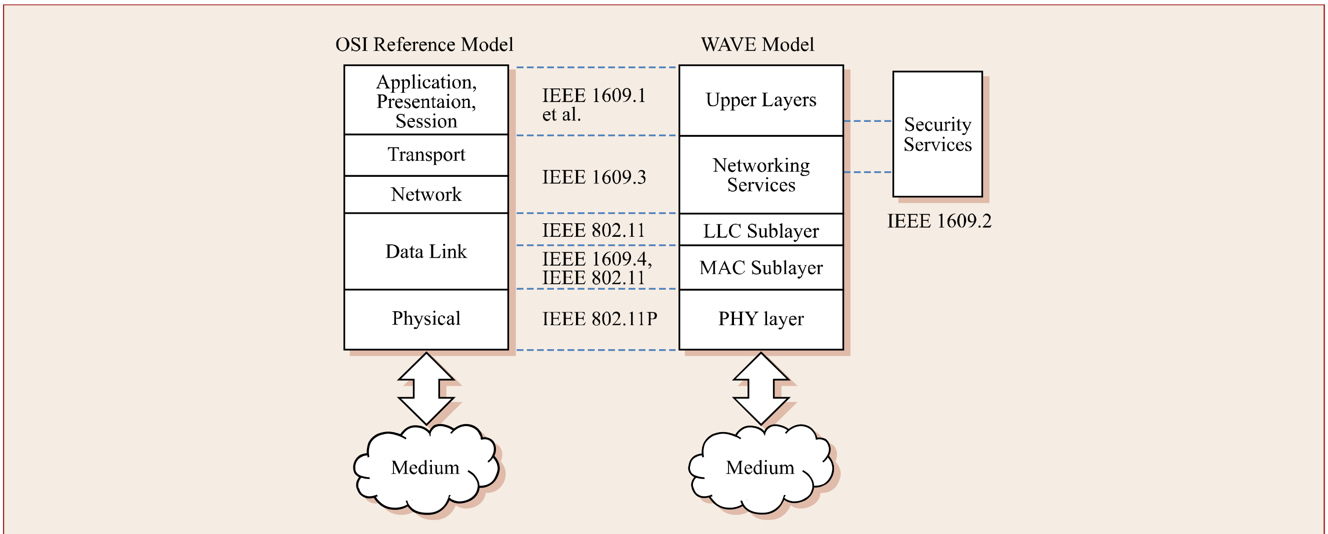

Figure 1. Related of WAVE Reference Model and OSI Reference Model

The IEEE 1609.2 is defined as a Security Service and IEEE 1609.3 is defined as a Networking Service, which is guide to deal with V2V and V2I communication. Finally, IEEE 1609.4 is defined as a Multi-channel Operation, which is a guide to deal with multiple connection access. In order to access multiple connections, it adopted IEEE 802.11p as a subsystem. IEEE 802.11p use OFDM for VANETs and has developed a new PHY/MAC protocol according to the IEEE 802.11 standard [11]. In the new PHY/MAC protocol technology, Distributed Coordination Function (DCF) is a generic technology. However, the technology requires a channel coordination method to use multiple channels in parallel due to having only one transceiver.

The channel coordination has two operation modes: Control Channel (CCH) and Service Channel (SCH). It uses synchronization to monitor and it guards intervals between CCH and SCH to protect the exchange of information when changing channels. In addition, channel coordination omits the authentication and association procedure of IEEE 802.11 to protect network link breakage by high node mobility. Therefore, it can reduce transmission delay via directing communication between vehicle devices.

The Figure 2 shows the MAC Architecture function of channel routing, prioritization, and channel coordination, which are all used to control the channel. This reference model construct of CCH and SCH and data is decided priority by the Access Category (AC). Each priority is provided by difference contention and transmission parameters. WAVE has management and data frames to exchange information. The management frame is defined by IEEE 802.11 and uses a WAVE Announcement in CCH. The data frame includes WAVE Short Message (WSM), it is transmitted in CCH and SCH. But the IP data frame is transmitted only by SCH.

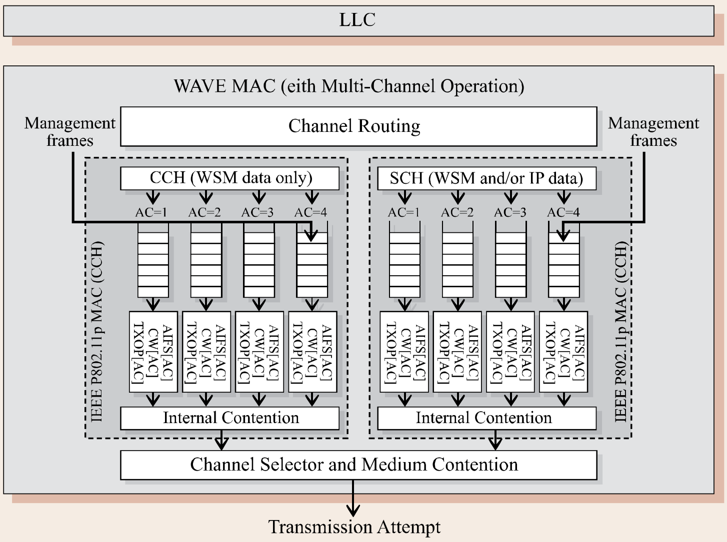

Figure 2. Reference Model of defined MAC in IEEE 1069.4

■ Dedicated Short-Range Communication

Initially, Dedicated Short-Range Communication (DSRC) [12] was used in Europe to explain the protocols used in Electronic Toll Collection (ETC), but nowadays it is used around the world. DSRC introduced wireless local area networks for Intelligent Transport System (ITS) service. The DSRC construct of RSU and OBU is placed on the side of the road and in vehicles. DSRC is divided into passive DSRS and active DSRC. When wireless data communication between OBU and RSU uses passive DSRC, it has specifications as follows:

- Communication cell size: within 10m
- Frequency range: 5.8GHz
- Data rate: 250Kbps (uplink), 500Kbps (Downlink)

This communication method is able to manage multiple connections between RSUs and OBUs, but during an uplink, it should provide Contention Windows (CW) by RSU. Thus, the passive DSRC has half-duplex communication, and requires a distance of up to 260m between roadside stations due to the power of CW. Therefore, passive DSRC has some problems such as reducing frequency due to interference cells and reducing reuse of the frequency. On the other hand, the active DSRC has specifications as follows:

- Communication cell size: within 100m
- Frequency range: 5.8GHz
- Data rate: 1Mbps (both)

Therefore, active DSRC has a lot of advantages over passive DSRC. First of all, active DSRC is able to create multiple connections between RSUs and OBUs. And roadside stations have to be up to 60m apart to reuse frequencies. Table 1 shows specification of passive DSRC and active DSRC.

Table 1. Specification of passive DSRC and active DSRC

	Passive DSRC	Active DSRC
Frequency Range	5.8 GHz	5.8 GHz
Cell Range	10m	100m
Bandwidth	5 MHz	10 MHz
Modulation	Lower : ASK, Upward : DPSK	ASK
Data Rate	Uplink : 250 Kbps, Downlink : 500 Kbps	1 Mbps (both)
Multi Access	Point-to-Multi Point	Point-to-Multi Point
Protocol	HDLC	Slotted ALOHA

The DSRC was assigned a frequency range of 75 MHz (5.850 - 5.925 GHz) for VANETs from the Federal Telecommunications Standards Committee (FTSC). As shown in Figure 3, channels of DSRC are divided into one CCH and six SCH, which have 10MHz bandwidth each. The channel number of 178 (ch. 178) is used as a safety message and alarm service, and other SCH are used as non-safety service channels. When using bandwidth of 10 MHz, the DSRC supports a data rate of 3Mbps to 27 Mbps, and when using the maximum bandwidth (20 MHz), the DSRC supports a data rate of up to 54 Mbps. In addition, DSRC supports OFDM technology.

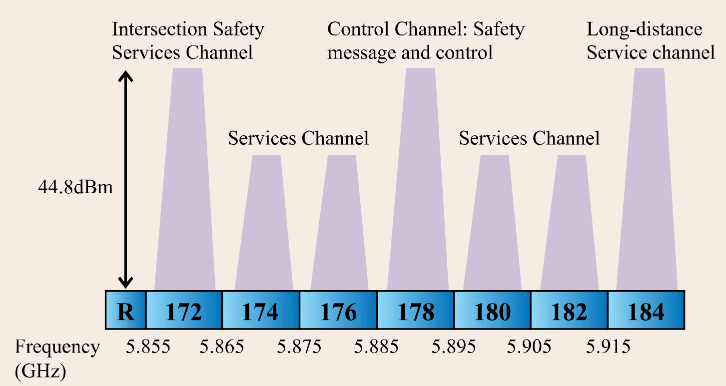

Figure 3. Assign Channel of DSRC

■ IEEE 802.11e Enhanced Distributed Channel Access

The IEEE 802.11e Enhanced Distributed Channel Access (EDCA) a kind of WAVE sub technology that is used for other channel accesses to support Quality of Service (QoS). The EDCA shows operational modes based on the competition of Hybrid Coordination Function (HCF), which is based on DCF and Point Coordination Function (PCF) protocols [13]. However, DCF transfer frames only via one AC, and EDCA transfer frames via AC using different parameters. Each AC has different priority and it makes up for the fact that DCF is not guarantees to QoS.

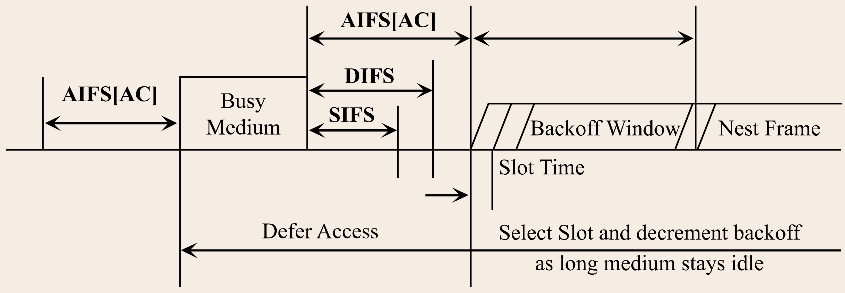

Figure 4. Channel access mechanism of EDCA

$$AIFSD[AC] = SIFS + AIFS[AC] * SlotTime$$
$$Backoff\ Window = 2 * (CW+1)-1$$

As shown in Figure 4, EDCA is CW and Arbitration IFS (AIFS), which shows the time interval to wait before transmission. In addition, EDCA uses AIFSD (AC), CWmin, and CWmax to decide the Backoff Window (BW). Table 2 shows the AC perimeter

Table 2. Access category parameter of EDCA

AC	CW min	CW max	AIFS
0	aCWmin	aCWmax	9
1	(aCWmin + 1) / 2 -1	aCWmin	6
2	(aCWmin + 1) / 4 -1	(aCWmin + 1) / 2 -1	3
3	(aCWmin + 1) / 4 -1	(aCWmin + 1) / 2 -1	2

VANET MAC Protocols

In this section, we classify the existing VANET MAC protocols into the three major categories of time-based, DSRC-based, and directional antenna-based. In addition, we analyze their characteristics. Finally, we describe their advantages and disadvantages.

■ Time Division Multiple Access-based MAC Protocols

Time Division Multiple Access (TDMA) is a multiple communication protocol that is divided into two or more carrier waves using time. In addition, TDMA could support orthogonal channels using only its own channel. TDMA is more powerful than Frequency Division Multiple Access (FDMA). However, if the data rate increases, interference of symbols increase as well. Thus, it requires synchronization. In this chapter, we introduce existing VANET MAC protocols using TDMA, and we analyze the advantages and disadvantages of these MAC protocols.

Reliable Reservation ALOHA (RR-ALOHA) is a medium access algorithm in ad hoc MACs, and is an extended version of R-ALOHA. The goals of RR-ALOHA achieve the TDMA mechanism [14].

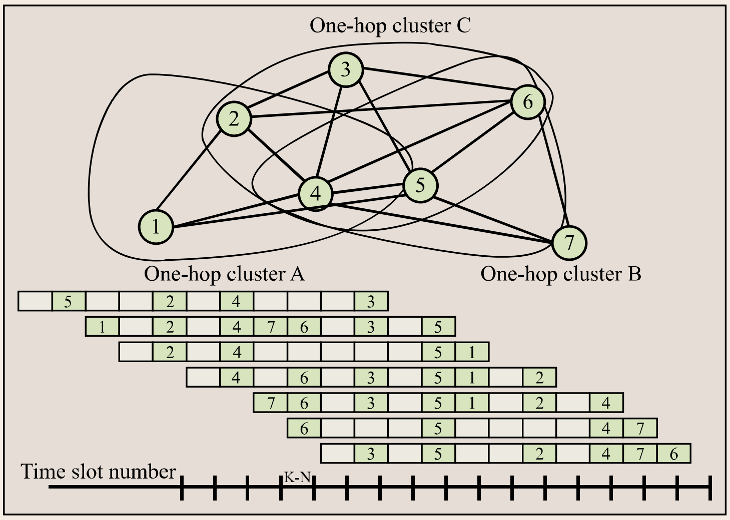

Figure 5. Transmission of FIs in RR-ALOHA

RR-ALOHA uses frames, which are comprised of slots. When we construct a network, all of the nodes should be synchronized due to the starting transmission in the boundary of a slot. At this time the synchronization uses information from a GPS receiver. RR-ALOHA supports QoS for 1-hop broadcasts, Point-to-Point communications, multi-hop broadcasting, and application. In addition, RR-ALOHA distributes assigned slots and the management of each node. For example, in Figure 5, Node 1 decides a time slot and duration for a neighbor using received Frame Information (FI) from Nodes 2, 4 and 5. And then, Node 1 decides a time slot and duration for Nodes 3, 6, and 7 via reading FIs from Nodes 2, 4 and 5. Through these methods, the RR-ALOHA resolves the hidden terminal and transmission collision problems.

C. Xianbo [15] proposed simulation results about RR-ALOHA and CSMA, and Y. Fan [16] proposed the Vehicular Self-Organizing MAC Protocol (VeSOMAC). VeSOMAC is a non-competitive MAC protocol based on TDMA in that it uses a time slot. Therefore, VeSOMAC supports periodic condition messaging and event-based messaging. The advantage of this algorithm is that it can transfer messages within a predefined delay range. Thus, it is suitable for a real-time application as a VANET. When changing topology from a distributed TDMA access method, the VeSOMAC restructure schedules more quickly than TDMA. In addition, VeSOMAC is supported to be both synchronous and asynchronous. And also, VeSOMAC sends at least one packet per frame because it exchanges network topology information in-band. Therefore, VeSOMAC assigns slots faster via this information and it knows 2-hop neighbor information.

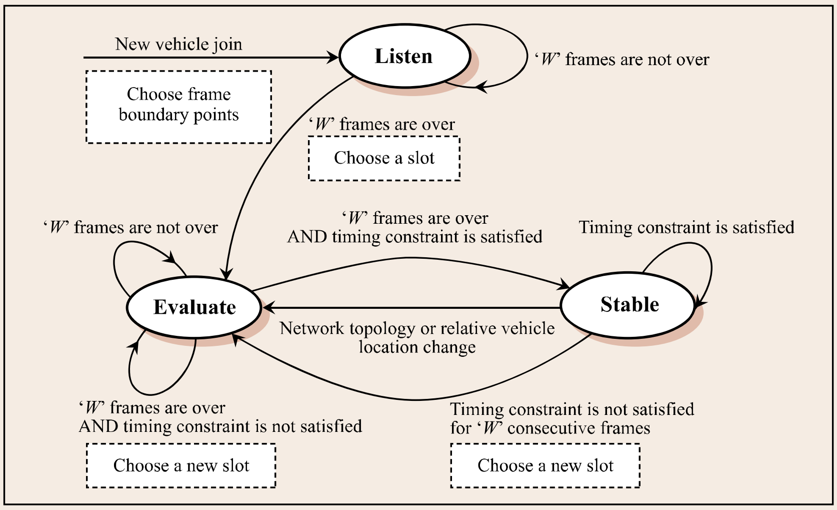

Figure 6. State machine for the VeSOMAC protocol logic

However, VeSOMAC has constraints in that it cannot be used to communicate with the same slot to 1-hop or 2-hop neighbors at the same time. If it is not satisfied, it generates data collisions. The author compares the performance with IEEE 802.11 in a highway and urban environment. As a result, when in a rapidly changing topology, VeSOMAC provides more reliability than IEEE 802.11 via low pack delays. However, VeSOMAC also causes excessive packets due to finding empty slots via broadcasting. In addition, VeSOMAC does not assign slots within real-time in a heavily-changing topology environment. Figure 6 shows a state machine for the VeSOMAC protocol logic.

■ DSRC-Based MAC Protocols

To resolve the disadvantage of TDMA-based MAC protocols, researchers have proposed DSRC-based MAC protocols for VANETs. This is an attempt to reduce the transmission delay and increase throughput to improve efficiency and driver comport using CCH and SCH in monopolistic access or reservation-based technology of 5.95 GHz DSRC.

J. So [17] proposed a DSRC MAC protocol for VANETs using dynamic assignment channels to resolve the hidden terminal problem in a single MAC protocol and to improve network throughput in a complex vehicular environment using multiple channels. Figure 7 shows the operation of DCF, which provides a higher bandwidth for non-safety applications in OBU and infrastructure. In addition, the DCF operation does not impair other safety communications.

In order to resolve the adjustment channel problem, it uses an ad hoc method when we could not use RSU. However, the DSRC MAC protocol should have different protocols to utilize ad hoc and infrastructure modes in the MAC and network layers due to the need for a transceiver on each host. Therefore, J. So's MAC protocol is too complex to implement.

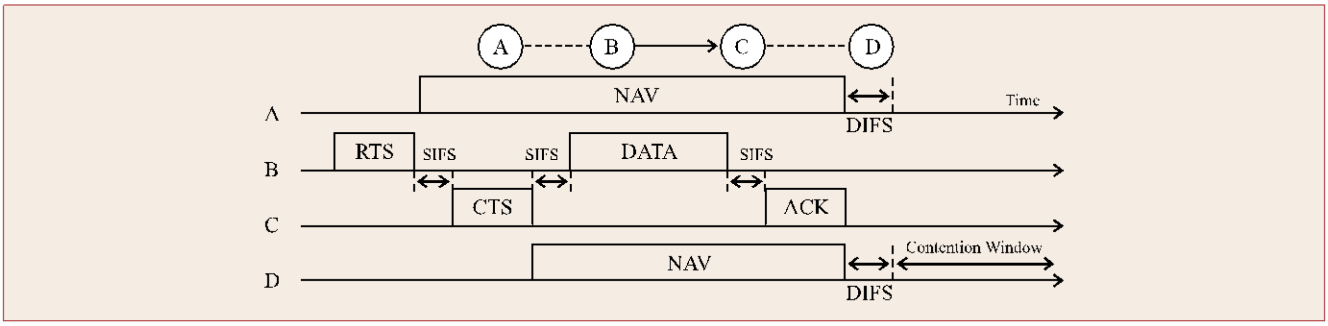

Figure 7. Operation IEEE 802.11 DCF

To do this, Y. Zang [18] proposed Vehicular MESH (VMESH) protocol to support non-safety applications without contention in SCH and to design the multiple architecture of a WAVE system.

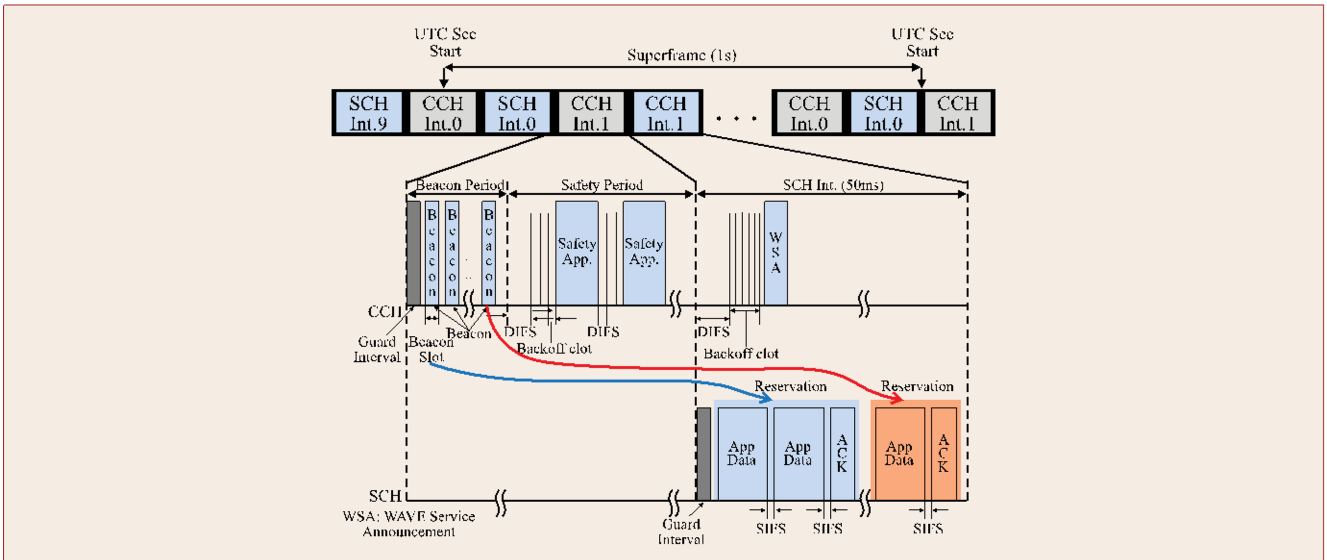

Figure 8. Channel access procedure of VMESH MAC

As shown in Figure 8, the VMESH applied a reservation channel access scheme. It is divided into a Beacon Period (BP) and Safety Period (SP) to improve the performance of VANET applications. The BP does signal transmission for dynamic resource reservations in SCH and SP reserves a safety application using EDCA for monopolistic channel access. However, the throughput of VMESH is similar to a typical WAVE MAC.

Q. Wang [19] proposed a Variable CCH Interval (VCI) and multi-channel adjustment mechanism. The VCI can be the adjusted rate of dynamic length between CCH and SCH as shown in Figure 9. The multi-channel adjustment mechanism provides non-contention access for SCH. Therefore, Q. Wang provides public road safety services and driver comport.

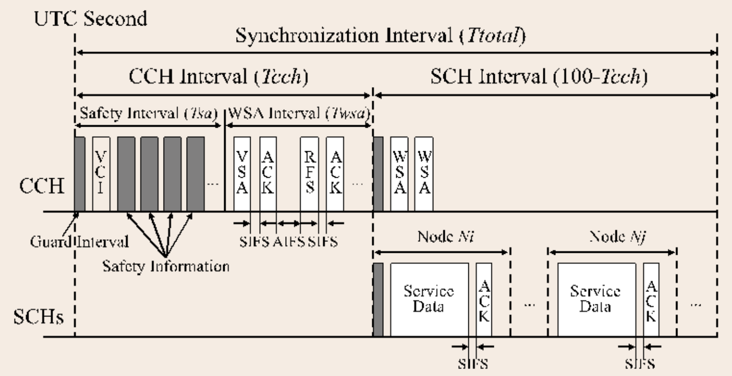

Figure 9. Channel access produce of VCI multi MAC

However, vehicles in the entire communication range could not provide service due to the number of limited RSUs. In addition, RSU reservation increases in a high-density vehicular environment. At this time, SCH interval is reduced due to increasing CCH interval. Therefore VCI and multi-channel adjustment mechanism have packet loss problem in reducing SCH interval

■ Directional Antenna-Based MAC Protocols

Y.B. Ko [20] has proposed a Directional MAC (D-MAC) protocol. As shown in Figure 10, Nodes A and B are located in the communication range of Node C, and Nodes B and C are located out of the communication range of Node C. If Node A sends an RTS frame to Node B, Node C makes up a block to protect transmission in the Node A direction during communication between Nodes A and B. On the other hand, if Node B receives RTS from A, and Node B does no communication with other neighbors, Node B sends a response, which is the CTS frame and message. This mechanism can improve performance of the MAC protocol in a vehicular environment. However, directional antennas are hard to manage in the implementation level and to be made more compliable. In addition, Node D tries communication with Node B, but Node B could not receive a CTS message due to communication between Nodes A and B.

Recently, many researchers have proposed to resolve these problems. However, the deafness problem is generated in a vehicular environment due to a rapidly-changing topology. Figure 10 shows the procedure operation of D-MAC

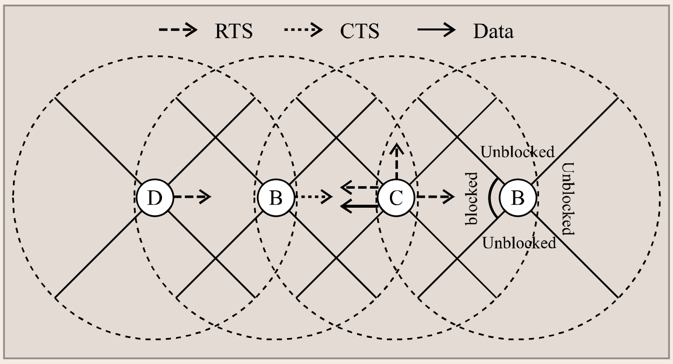

Figure 10. Procedure operation of D-MAC

P. Li [21] proposed broadcasting-based communication. In the algorithm, if any node broadcasts to a neighbor, other neighbors do not communicate to that node. In other words, when nodes communicate with each other, the P. Li algorithm sends RTS to all nodes and destinations. Thus, the algorithm protects the network collision problem. However, the algorithm has a lot of packets in communication range. This problem makes up for the delay, low throughput, and broadcasting storm problems.

Conclusion

In this paper, we introduced the existing VANET MAC protocols, and analyzed the advantages and disadvantages of each. We provided qualitative comparisons of their objectives, design approaches, and requirements. All these approaches tend to focus on V2V communication, and they also utilize CCH and SCH to guarantee packets. However, many studies still do not resolve the problems of short messages, collision, and contention of nodes. Therefore, future work must resolve these problems.

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