A Hybrid MAC Mechanism for Multiple Load Intelligent Vehicle Transportation Network

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Abstract- The Media Access Control (MAC) mechanism of intelligent vehicle communication network meets a new challenge due to the multiple load data traffic and high speed mobility. This paper proposes a hybrid MAC mechanism which takes the advantages of both TDMA and CSMA mechanism. This hybrid mechanism is based on TDMA, while CSMA mechanism is added in time slots to improve the slot utilization in both high and low load networks. Through the simulation in NS2 we compare the results of the hybrid MAC protocol with those of using CSMA and TDMA individually. It is verified that in terms of flexibility and reliability in channel utilization, packet loss ratio and fairness index, the hybrid MAC protocol is superior. The hybrid mechanism makes the MAC layer self-adaptively switch between TDMA and CSMA according to the data traffic load.

Index terms*:* hybrid, MAC mechanism, multiple load, intelligent vehicle transportation, CSMA, TDMA.

I. INTRODUCTION

Intelligent Transport System (ITS) has been a hot research topic as a key solution for the problem of traffic safety, efficiency and comfort. Japanese Ministry of Transport defines the new generation traffic system comprising of advanced information and telecommunications network for users, roads, and vehicles. US Department of Transportation sets up two major projects, one is the Vehicle Safety Communication (VSC) project and the other is the Vehicle Infrastructure Integration (VII) project. In Europe, There are a lot of projects funded by the European Commission focus on ITS, and the research plan has been set up till the year of 2013 [1]. Intelligent Vehicle Traffic System consists of intelligent road traffic control system and intelligent vehicle system. The intelligent vehicle system is a network that the vehicles can transmit and exchange traffic information acquired from various on-board sensors (e.g. GPS, video and audio). All these must be based on traffic information acquisition and high quality wireless communication. With the development of vehicle sensors, the traffic data transmitted on the communication network is very diversified. When coming to the design of MAC protocols, both high mobility and multiple data load should be considered. At present, the MAC protocol used in ITS can be divided into competition MAC protocol based on CSMA and reserve MAC protocol based on TDMA mechanism [12].

CSMA assigns channels to nodes by competition among the nodes that keep listening to the channel. The node which authenticates the channel free and has a shorter backoff time can access the channel. CSMA is a flexible and convenient mechanism which is suitable in high mobility communication network. The Dedicated Short Range Communications (DSRC) project which is led by the US Department of Transportation and some European ITS projects use IEEE 802.11p , which is based on CSMA mechanism, as MAC protocol. Reference [2] did simulation and analyzed the performance of 802.11p for vehicle communication in NS2. The paper analyzed throughput, packet loss ratio and delay in same speed but different node number simulation, and made the conclusion that the performance in terms of packet loss ratio and longer access delay gets worse, as the node number increases. Reference [3] did research on the V2V communication with different radio coverage on highway and compared the result of 802.11 with that of STDMA. It verified that the packet loss ratio and delay increases when the collision got serious. Through the comparison between the performances of CSMA and TDMA used in VANET,

reference [4] drew a conclusion that CSMA is suitable in the network that the topology changes frequently. However, CSMA cannot deal with the raised delay caused by collision.

TDMA is a MAC mechanism which is widely used in cellular network. The typical practice that TDMA used in traffic system is Automatic identification System (AIS) in the shipping industry. Ships can exchange information, such as position, course and shipping. This system requires complete topology information from GPS or Galileo system to assign slot and synchronize time. TDMA have a good performance in stability and reliability, especially in the high load network. Both [5] and [6] proposed a distributed TDMA MAC protocol is based on the two-hop distance topology information. However, when it comes to a low load network, the management cost is higher than that of CSMA because of the control and management messages. Due to the inflexibility of the assignment, TDMA mechanism has a low flexibility. Reference [8] drew a conclusion that the throughput of TDMA was obviously lower than that of CSMA when the speed of mobile nodes rose up in the NS2 simulation.

According to the above research, the strong and weak points of CSMA and TDMA mechanism are obvious, so is the complementary between CSMA and TDMA. TDMA is suitable in high load but low mobility network, and the performance of CSMA in low load but high mobility network is better. Based this observation, we proposes a hybrid MAC protocol which combines the advantages of TDMA and CSMA mechanism. This hybrid mechanism is based on TDMA and mixed CSMA mechanism in time slot. The hybrid MAC mechanism can switch between TDMA and CSMA according to data traffic by access control rules. It improves the utilization of slot in both high and low load networks, and satisfies the multiple load request of intelligent vehicle transportation system.

II. HYBRID MAC PROTOCOL

Based on these technologies, the mechanism is designed as followed: firstly, it is important to plan the length and structure of slot, which provide a basic to carry out the design of the theory of hybrid MAC protocol. Then assign the initial slots to the nodes in related area through a certain distribute TDMA algorithm. At last, design a reasonable access control rule that the nodes must follow.

a. Slot Planning

Two hop neighbors form a local area. The node which is out of the local area does not interfere with the central node. The topology of intelligent vehicle network is generally multi-hop. The distributed slot assignment algorithm DRAND will be used in this paper, which makes the nodes that get away from each other more than two hops can use the same slot [10]. That can improve the utilization of slot and divide a complex network into simple and small local areas. Different algorithm can be chosen in different communication situation.

Such communication processes must be finished in one slot:

1) The different priorities distinction between slot owner and neighbors,
2) Competition among neighbors,
3) Transmission of data traffic.

Setting time thresholds Ta and Tb (Ta<Tb) in a slot as Figure 1, the slot owner have the highest priority to access channel in [0 Ta], when the data load is high, every node has its own data to exchange on the network, that means slot owner have data load in its own slot, it will access the channel preferentially in [0 Ta], its neighbors will keep listening to the carrier but not take part in competition. This process is essentially a TDMA mechanism. When the data load is low, slot owner have no data to transmit, the channel will keep free in [0 Ta], and the neighbors in one hop distance area will start the CSMA competition in [Ta Tb], so the neighbors that have data load can utilize the channel in the slot that does not belong to them. Through the planning of slot, the channel utilization is improved and the unbalance problem of data traffic load is solved by the hybrid MAC protocol. The setting of Ta and Tb is to divide the slot owner and its neighbors into different priorities. The process of preparation work of and transmission of data must be completed in a slot.

Such factors must be considered in the planning of packet transmission time: firstly, the initialization [0 Tb] of a slot is very important to transmission control, so packet size should not be too big, so that the next slot owner's data transmission will not be interfered. But if the packet size is too small, the transmission may be completed before Tb, and the neighbors may misjudge that the channel is free and start competition thus interfere the slot owner. The design of Ta and Tb is the threshold of switching between TDMA and CSMA. The time of Tb is a fixed value. If Ta increases, the protocol tends to be a TDMA protocol. On the contrary, if the value of Ta

decreases, the protocol tends to be a CSMA protocol. Different Ta can be used in different communication situation to satisfy different requirements. The planning of slots is shown in Figure 1.

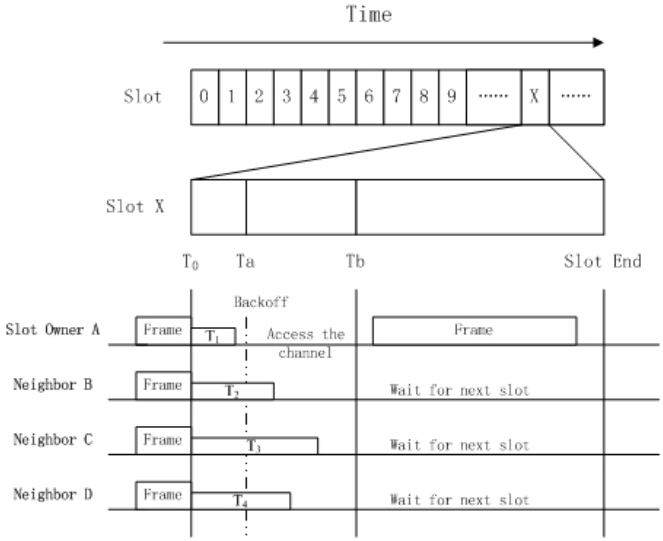


Figure 1. Slot Planning

b. Proposed Access Control Rule

First of all, nodes access a channel according to the slots assigned to them. When the slot owner has no data to transmit, its one hop neighbors would take the free status of the channel by carrier sensing. The neighbors that have data to transmit can access the channel by competition through CSMA mechanism. Furthermore, these nodes have higher priority in their own slot. The neighbors start competition only when the slot owner has no data to transmit. The priority is determined by the length of backoff time, the MAC mechanism can adaptively switch between TDMA and CSMA based on the different priorities of the slot owner and neighbors. According to this design of access control rule, when the network traffic is heavy, the nods have data to transmit in their own slot, the CSMA competition mechanism shall not be started, so it is TDMA essentially. In contrast, when the network load is low, some nodes may have no data to transmit, its one hop neighbors can access the channel through CSMA competition.

Suppose node A have data traffic, it firstly checks the time and determines whether the slot belongs to it. If yes, the node choses a random backoff time T_1 in [0 Ta], and transmits data immediately after the backoff time. Otherwise, it keeps listening to the channel for Ta. If the

channel is free after Ta, that indicate the slot owner have no data traffic. Node A starts a CSMA mechanism. Node A choses a backoff T_2 in [Ta Tb], if the channel is free for T_2, that indicate node A win the competition. If node A find the channel busy in T_2, which indicates other neighbor node won the competition by using a shorter backoff time then node A waits for the its slot or the next slot that can be competed. The rule is as shown in Figure 2.

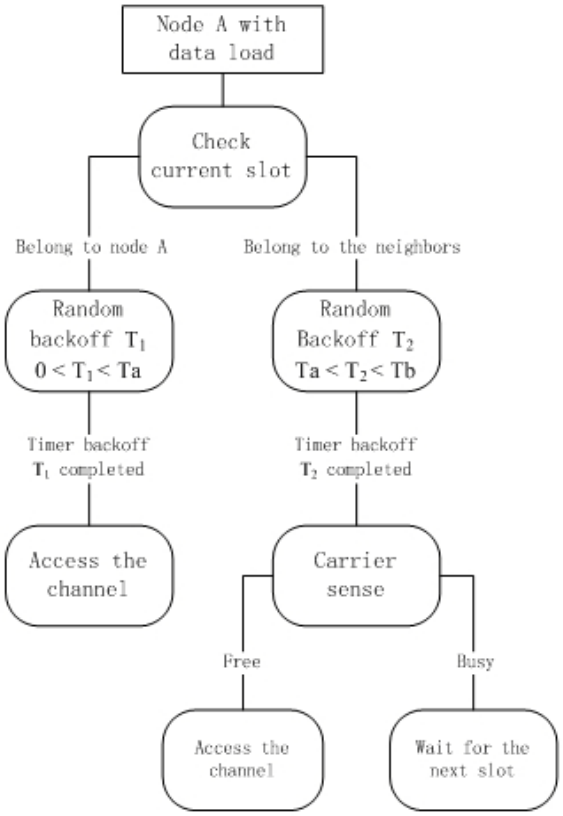


Figure 2. Proposed Access Control Rule

III. SIMULATION AND ANALYSIS

a. Simulation Setup

In this section, length and width of the scene are 600 meters and 20 meters respectively as shown in Figure 3. The moving nodes do back and forth motion in the simulating scene. Therefore these nodes can be under a moving state during the simulation. 19 nodes which consist of 18 moving ones and a static one are set up. The static node locating in the center is taken as the sink node. It

is used to simulate road-side beside the road. While the rest 18 moving nodes divided into two groups equally are used to simulate the process of the motion of vehicles by letting the two groups move to each other face to face. During the motion, the distance between two nodes is 50 meters while the velocity of the motion is a custom value. In this paper, we will contrast two typical speeds: a speed of 45km/h of normal driving 90km/h of high-speed driving.

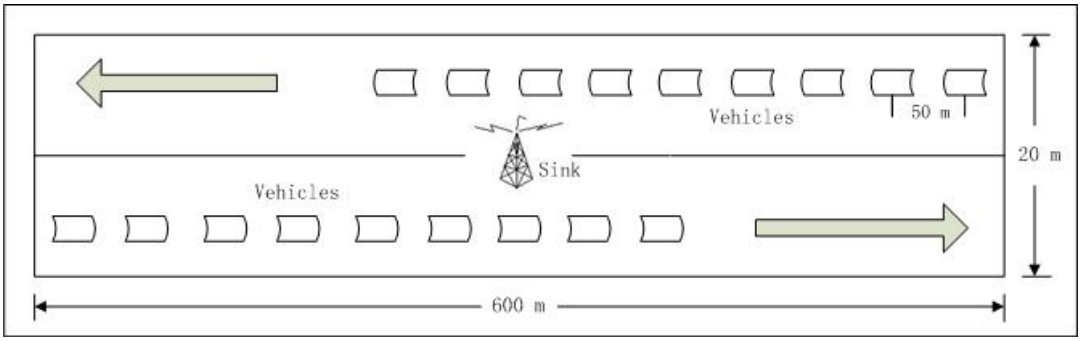


Figure 3: A graphical guide of the simulating scene

Different parameters must be set in the simulating program first of all, especially the parameters of physical layer and the generator of Constants Bit Rate (CBR) data stream. Since the result of proposed hybrid MAC mechanism is required to compare with that of 802.11 protocols, parameters of the physical layer are almost taken from those of 802.11 protocols. The generator of CBR data stream used in this paper is setup independently. The routing protocol adopted here is Destination-Sequenced Distance-Vector Routing (DSDV) which can not only establish routines and send data for nodes rapidly but also avoid generating routing loop. Parameters of the simulation are listed in the following Table 1.

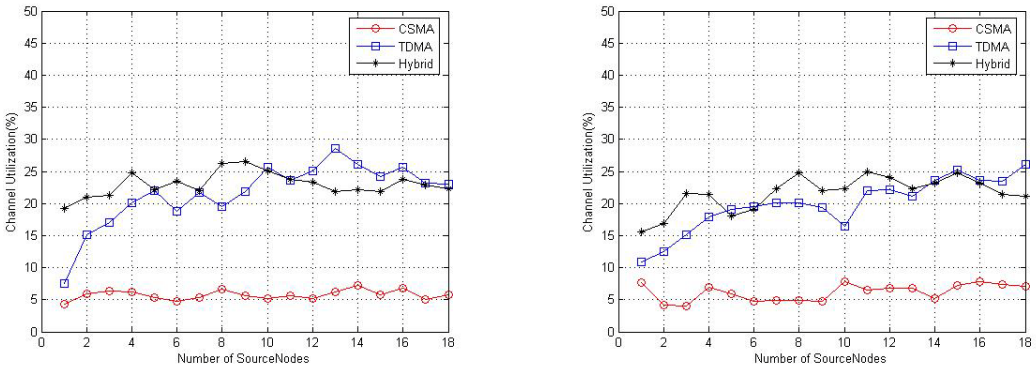
Simulation Time	200 s
Carrier Sense Distance	90 m
Transmission Distance	60 m
CBR Packet Size	200 byte
Slot Size	50 ms
Communication Bandwidth	2 M

Table 1. Simulation Parameters

In this paper, the study focuses on the performance of MAC protocol under the circumstance of many loads in a network of transportation. Therefore, load and velocity are regarded as two variables. The change of load is mainly reflected by the number of information sources. As for the aspect of the velocity of the node, we obtain the adaptability of the access protocol to transportation network which has a rapid topology change by comparing the two typical velocities of vehicles (45km/h for normal driving and 90 km/h for high-speed driving). Three parameters which are channel utilization, packet loss ratio and fairness are considered to evaluate the performance of the protocol. The method of simulation is calculating the results of three different protocols when applied to different situations: the velocity of vehicles is either 45km/h or 90km/h while the information sources of nodes in the network are various (increasing from one to eighteen). Conclusion is drawn through comparing the results of simulation.

b. Analysis of Channel Utilization

Under the shared channel communicating condition, the source of channel is limited. So channel utilization is a very important indicator when evaluating the performance of a protocol. We compare the utilization of different situations: the velocity of vehicles is either 45km/h or 90km/h while the information source of nodes in the network is various (increasing from one to eighteen). And the results are shown in the Figure 4 as below:



a: Utilization when speed is 12.5m/s b: Utilization when speed is 25m/s

Figure 4. The Utilization with Different Speed

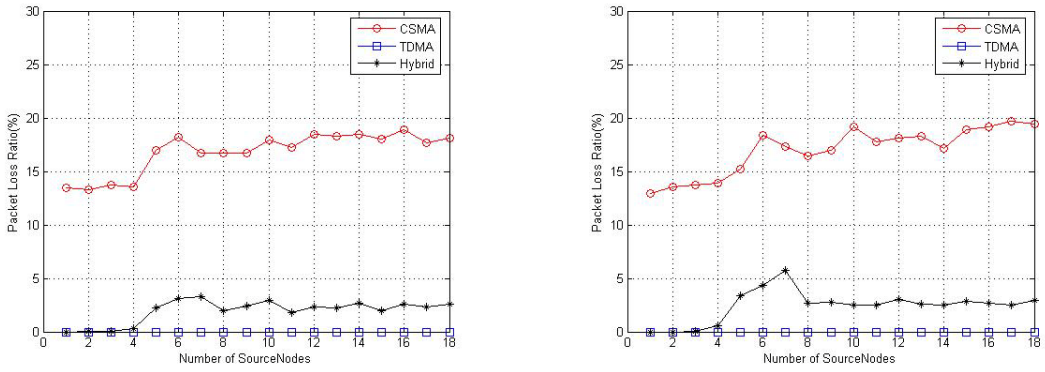
From the above figures, we can see that when CSMA is employed, because of the existence of some inherent drawbacks like out-of order contention and hidden terminal, the rate of channel utilization is low.

As for TDMA, when the network is under low load the rate of channel utilization is also low, which is due to the fixed allocation of channel that causes a waste of resources when the network has a low load. As the number of nodes increases and consequently the load of network increases, TDMA will have a distinct advantage compared to the other two protocols.

The hybrid protocol proposed by this paper maintain a high rate of channel utilization whether it is under high or low load thus showing flexible adaptability to various load conditions. When the velocities of nodes increase, utilization of three protocols all share some declines, but those of TDMA and the hybrid protocol are more distinct while CSMA only has a minor change. This is because when the topology structure of a network changes frequently, reserved protocols have to spend more resources in management. However, protocols based on competition do not need to update information of the typology structure, thus showing a higher flexibility under high speed moving conditions.

c. Analysis of Packet Loss Ratio

The packet loss ratio can fully reflect the quality of communication. Results of packet loss ratio are shown as Figure 5.



a: Packet loss ratio when speed is 12.5m/s b: Packet loss ratio when speed is 25m/s

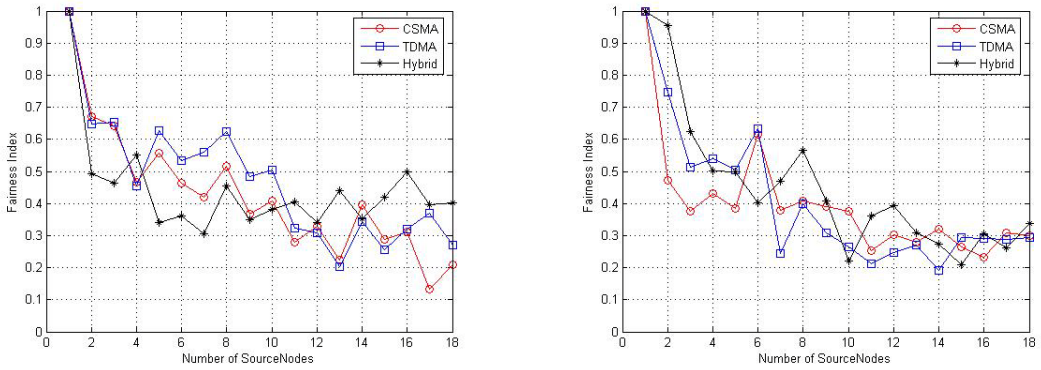
Figure 5. The Packet Loss Ratio with Different Speed

The loss of packages under CSMA is caused by collision, which is an inherent drawback of contention protocols and can be ameliorated by some aiding mechanism. When we enable the RTS/CTS mechanism during the simulation, the quality of communication is dramatically improved.

As shown in Figure 5, under TDMA, the rate package loss in the MAC layer is always zero because fixed channel allocation will not cause collisions. It should be noted that zero loss of packages is concluded only when we trace the process of communications in the MAC layer. When we trace the process of communications in the network including the routing layer, we find that packages loss occurs due to the routing protocol and the situation that queue cache is full. Considering that hybrid protocol employs a scheme that contains both fixed allocation and competition mechanism, the loss of packages is unavoidable in the hybrid protocol. However, the rate of package loss is far lower than that of single CSMA. The value is acceptable under carious load situations. As velocity increases, the uncertainty of the network increases and the quality of the network decreases. Consequently, the rate of packages loss increases.

d. Analysis of Fairness Index

Fairness is important when evaluating the performance of a network. Performance of different protocols on fairness index is as shown in Figure 6.



a: Fairness Index when speed is 12.5m/s b: Fairness Index when speed is 25m/s

Figure 6. The Fairness Index with Different Speed

The fairness of TDMA which is fixed allocation of channel stays in a high level while CSMA reveals a low performance. During the contention, due to the change of relative locations of

nodes and load of the network , the accessing probability varies, especially when velocities of nodes increase. Contention among nodes becomes more complicated and the fairness will correspondingly become more difficult to be guaranteed. However, the hybrid protocol greatly increases the fairness of the network by planning the contention of nodes orderly and achieves a highly stable performance even under the circumstance that network has many information sources and loads. When the velocities of nodes increase, FI of the hybrid protocol decreases to some extent yet it is acceptable.

IV. CONCLUSION

In ITS network, according to the simulation results, single MAC mechanism is hard to meet the challenge of multiple load data traffic caused by more and more vehicle sensors. With the change of source node number, TDMA have a good performance in high load network and show its excellent stability in packet loss ratio and fairness. However, due to the management cost, its utilization is lower than that of CSMA and hybrid MAC mechanism when it comes to a low load network. On the other hand, CSMA is good at flexibility. But the stability of CSMA is unacceptable when the network load changes. In particularly the fairness index reduces significantly when the load becomes higher. Through the scientific and suitable mechanism design, slot planning and access control rule, the hybrid mechanism can meet the requests of both mobile Ad hoc network and wireless sensor network. The hybrid MAC mechanism has a good and stable performance in the channel utilization, packet loss ratio and fairness index according to the result of simulation. Hybrid MAC protocol performs better at different speeds through the comparison with single MAC mechanisms. According to the research in this paper, the improvement only in MAC layer cannot meet the request of wireless communication in the future, so the cross layer research will become an important trend. And the RTS/CTS mechanism can greatly improve the performance of the competition based MAC protocol, so RTS/CTS mechanism will be considered to develop in the CSMA part of the hybrid MAC protocol so as to improve the performance of the hybrid MAC mechanism in the future work.

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