Wireless Access for Vehicular Environments

Bo Li, Mahdieh Sadat Mirhashemi, Xavier Laurent, Jinzi Gao

Group 5

{blia,sadatm,xavier,jinzi}@student.chalmers.se

Abstract— **This report is to present the research of Wireless Access for Vehicular Environments (WAVE). It introduces the basic technologies used in this standard, also proposes some limitations and applications of this criteria. Based on this, this report focuses on two limitations: real-time communication constraints and unfairness dedication of channel with using distributed coordination function on Medium Access Control (MAC) layer. Some ideas for improving these limitations are raised with the results of simulations. For the real-time problem, a Time Division Multiple Access (TDMA) MAC layer is studied and evaluated. For the unfairness dedication of channel problem, a priority is given to each node of different speed to achieve a dynamic contention window size. The result of simulation shows this method efficiently improves this limitation.**

***Keywords*— IEEE 802.11p, IEEE P1609, WAVE, MAC, RSU, TDMA**

I. Introduction

Wireless Access for Vehicular Environments (WAVE) is an approved amendment to the IEEE 802.11 standard. WAVE is also known as IEEE 802.11p. WAVE is required to support the Intelligent Transportation Systems (ITS) applications in the short-range communications. The communication between vehicles (V2V) or between the vehicles and the roadside infrastructure (V2I) is relied on the band of 5.9 GHz (5.85-5.925 GHz) [1]. With the equipment installed in the car and on the road, WAVE supplies the real time traffic information, improves the safety of the transportation and reduces the traffic congestion. It also benefits for the transport sustainability.

In 1992, Unite States started to research the Dedicated Short Range Communication (DSRC). It is the wireless communication protocol for the vehicles. United States, Europe and Japan are the main countries of research and application for DSRC. From 2004, the concentration of DSRC has been migrating to the IEEE 802.11 standard group. At first DSRC is based on the IEEE 802.11a, which focus on the low overhead operations. DSRC standard is based on the Wireless Fidelity (Wi-Fi) architecture [2]. However, in order to support high-speed moving vehicle and simplify the mechanisms for communication group, IEEE working group dedicate more efforts on the WAVE, which is the core of the DSRC. WAVE ensures the traffic information collection and transmission immediate and stable, and keeps the information security.

Besides the IEEE 802.11p, WAVE also contains the standard of IEEE 1609, which is the upper layer standard. IEEE 1609 completes the WAVE by its sub-detail standards, for instance, IEEE 1609.2 standard is responsible for the communication security; IEEE 1609.3 standard covers the WAVE connection setup and management [3]. IEEE 1609.4 standard that is based on the IEEE 802.11p Physical (PHY) layer and Medium Access Control (MAC) layer supplies operation of high-level layers across multiple channels [4].

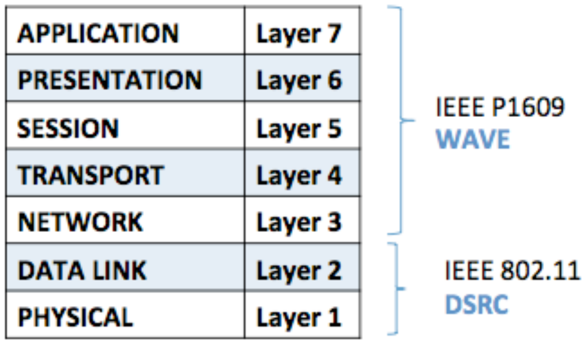

Figure. 1 IEEE P1609 and IEEE 802.11 in OSI model

As shown in Figure 1, within IEEE 802.11, DSRC is known as IEEE 802.11p, which amend the IEEE 802.11 on MAC and PHY.

The rest of the paper is structured as follows. In Section II, a comparison between WAVE and IEEE 802.11 is given. In Section III, some limitations of this standard are listed. Ideas and the results of simulations for improving some limitations are showed in Section IV. Also some applications and future usages of WAVE are discussed in Section V, before drawing the conclusions in Section VI. Section VII is about the review question.

II. Comparison to IEEE 802.11

In order to meet ITS applications. The architecture of WAVE is an expansion of IEEE 802.11. However, it is almost entirely a new architecture. WAVE fully draws on the IEEE 802.11a, IEEE 802.11e and IEEE 802.11q characteristics.

Compare to IEEE 802. 11, the amendment for IEEE 802.11p can be addressed in two levels: MAC and PHY.

A. MAC Amendment

MAC is a sub layer between Data Link Layer and PHY in Open Systems Interconnection (OSI) model. It provides an interface and control mechanism in order to make different nodes in network is able to communicate with each other. It aims at making communication between vehicles faster and more efficient. Therefore, the main updating of IEEE 802.11p is on MAC layer.

1) Basic Service Set: As shown in Figure 2, Basic Service Set (BSS) is a group of stations, which connected, by an Access Point (AP) over a wireless link. For instance, of a scenario that a family wants to establish a wireless network which can make more than one computer in this family connect to the Internet. A wireless router, which should be used at here to create a Wi-Fi hotspot, which performs as an AP, and all the computers are, stations that in a BSS.

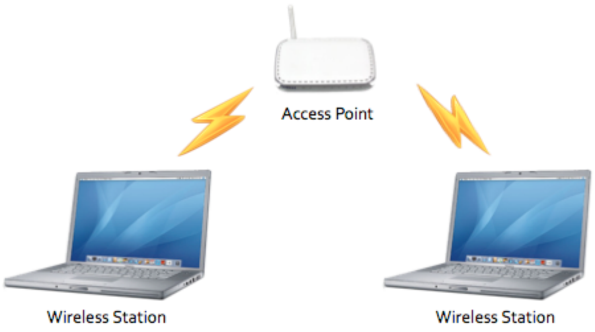

Figure. 2 Basic Service Set concept

When a station intends to access a BSS, it must acquire a Service Set Identification (SSID). In the situation described above, it corresponds to the name of Wi-Fi hotspot. SSID must not be confused with the Basic Service Set Identification (BSSID). BSSID is only the name of a BSS. It can be simply named by using the MAC address. Each BSS has a unique BSSID, which is shared, by all stations in the BSS [2].

2) WAVE BSS: Because of mechanism or frame in IEEE 802.11 MAC uses, much more time is consumed in such a process. The communication between vehicles or vehicles and infrastructures may be in a very high-speed environment. Therefore, the time for communication may be very short. It is essential for IEEE 802.11p to modify such mechanism to reduce time consuming. In this situation, a term "WAVE mode" is introduced by the IEEE 802.11p [2]. This mode introduces a new BSS type: WAVE BSS (WBSS). In short, this WBSS enables a station to join and complete a WBSS process and exchange data by only receiving a WAVE advertisement, using BSSID that is available all times. Because there is no further interactions (such as authentication and association) are required. This change improves the efficiency of transmitting and receiving data.

B. *PHY Amendment*

In order to acquire more fast and efficient communication, IEEE 802.11p make very few changes at PHY. IEEE 802.11p works in the range of 5GHz band like IEEE 802.11a with a 10MHz wide channel that is different with IEEE 802.11a whose bandwidth is 20MHz [5].

In addition, with the development of hardware manufactures, the performance of sending and receiving data with this standard will be better.

III. LIMITATIONS

A. *Multipath Environment*

Multipath environment is one in which radio signals will be reached to the receiver via one or more paths, so as a result there not exists any Line of Sight (LOS). Constructive and destructive interference as well as signal`s phase shifting (phase offset) are the effect of the propagation phenomenon. These effects will cause the resulting signals to be distorted. Most multi-carrier modulations such as Orthogonal Frequency-Division Multiplexing (OFDM) is a common way to avoid the inter symbol interference; hence designing an OFDM-based receiver seems to be a challenging task [7].

B. *Latency*

This limitation is what is of importance in safety applications. IEEE defined that the latency for safety applications in vehicular environment is to be set between 50 to100 milliseconds. However, for other applications, it is not required to be in that range and can be around 100 milliseconds. (Vehicular Safety Communications Consortium (VSCC) has decided latency limit of 100 ms) [8].

In practice V2V communication suffers delivery latency and packet loss [8]. Especially when node density is high, throughput will decrease while latency increases.

C. *Security*

In vehicular environment, 802.11p standard provides reliable wireless communication. But this wireless communication between roadside and vehicles will of course cause some implications in security while transferring information.

There are some common threats to security and possible kind of attacks against this environment. Intruders may track the vehicles with the intention of having control on the wireless communication. Intruders can sniff packets and change them to send false messages to the destination or even block or prevent a packet to be delivered. Techniques listed below are proposed to prevent attacks:

1) Anonymity: Using certificate and make the communication anonymous or even randomize the Internet Protocol (IP) and MAC address of On Board Unit (OBU) to avoid tracking the vehicles. For example, when broadcasting messages from a specified OBU, group signatures as well as providing large number of certificates can be used.

Each RSU has a fixed MAC address with 48 bits long, which is generated by OBU when device starts up. It can change the MAC address whenever collision of MAC addresses occurs or in order to provide privacy as discussed above, when the signing key change, it can be ordered every five to ten minutes.

2) Authentication: Public Key Infrastructure (PKI) and certificate authorities can be used in order to provide authentication for messages and based on the importance of message, different levels of encryption would be applied. The standard component P1609.2 defines security service such as secure message formats and secure message transfer for applications in WAVE. Authenticated RSU announcement prevents sending false messages to vehicles.

It is proposed that messages must be transitioned fast so they should be short. In order to broadcast messages with high priority, there defined a certificate and public key algorithm which uses short keys to provide security in transition.

3) Implementing Trust Model: In the safety applications, the application is isolated from the un-trusted operator, because in general the operator is believed to be un-trusted, while in e-trade applications, conventional trust model is being applied and in public ones, the operator is considered being trusted [14].

D. Support for Real-Time Applications

In the future, many applications based on the WAVE technology will be safety-oriented. Unfortunately the IEEE 802.11p amendment designed as it is now does not provide enough guaranties for the support of such applications. One reason of this issue is because the MAC layer of the 802.11p amendment cannot provide any time boundary when transmitting a message. So we will explain why the current MAC layer cannot supply real-time applications and we will introduce an idea for improvement.

The 802.11p MAC Layer is the 802.11e amendment, which is an improvement of the previous 802.11 MAC layer [15]. The MAC layer reposes on Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA), and the main idea of this method is that when a node wants to transmit, it must listen the medium first and only if this one is idle. It can start transmitting while listening at the same time in case of a collision occurs. Using such a method allows sharing the medium in a totally decentralized way, but cannot provide any transmission deadlines and cannot supply guaranties for safety applications, especially if the traffic is overloaded, it will be not rare that a node will not be able to transmit.

E. Unfairness Dedication of Channel

The only standard for the MAC in wireless access for vehicular environment is 802.11P and this standard employs basic mechanism of Distributed Coordination Function (DCF), which is not specifically designed, for high mobility network. In 802.11P the priority is assigned by the traffic type and some factors like Speed, resident time in the communication range and direction of movement is not considered. So if two mobile nodes are in a communication range with high and low speed, then they have different chance in accessing the channel, so fairness problem exists.

IV. IDEAS AND IMPROVEMENTS

A. Idea of a Time Division Multiple Access (TDMA) MAC Layer

An idea for sharing the medium will be introduced here, based on time division, which is used in most of current researches [16][17] on this subject. The idea is to provide a collision-free access to the medium by dividing the transmission time among vehicles. Then all vehicles will have its own time slot for transmitting and will be able to determine the deadline for the transmission of a message. We must now decide on which pattern dividing the time to match the requirement of the WAVE [15].

The 802.11p as been designed to work with vehicles at a speed up to 250km/h and a 1000 meters range. The minimal data rate is 3Mbps and if we assume a 500 bytes message, which is large enough to contain information such as speed and location, the time needed to transmit such a packet is 1,33ms. Lets assume that a car, which is going at a speed of 250km/h, needs to broadcast a message every 10 meters, then it needs to broadcast a message every 144ms. So we will need to divide a time of 144ms by 1.33ms, which is the time, needed to send a packet of 500 bytes at a throughput of 3Mbps. So we can divide our time by 108 slots. So up to 108 cars can send one message every 144ms in a range of 1000 meters. This value represents 1 car every 18.5 meters if we have 2 lanes. Which is reasonable value for a loaded traffic but not realistic in a traffic jam, or if we are on a highway with 8 lanes, that represents 1 car every 74 meters in a lane, which is unrealistic in a overloaded traffic.

There are other drawbacks in this idea. First we assumed a network of 1000 meters range. That means we need to divide the road in several networks, one every 1000 meters, so the vehicles need to be aware of this partitioning. This task seems to be a real challenge. We can override this problem by placing a Road Side Unit every 1000 meters who can broadcast a special message on its own network, with a signature, to mark the begin of a new time frame.

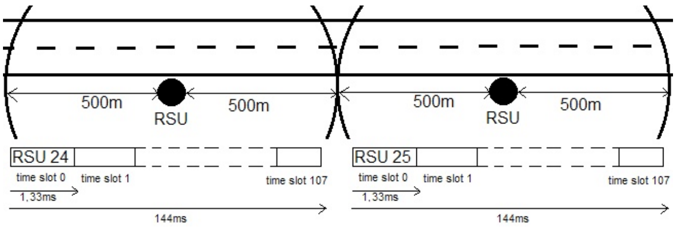

Figure. 3 Road and time division

One other problem is how a car will know which time slot to use. The simplest solution should be to let a car listening a complete time frame and choose randomly an empty time slot for the next round. This method is very simple but can result also in a collision if two or more cars choose the same time slot when arriving in a new network.

So a Time Division Multiple Access could improve the current 802.11p MAC layer for providing support of real-time constraints, but seems to be impossible to design in a decentralized way.

B. Idea of Fairness in Channel Access

1) Improvement: The problem described has been mentioned in [18] for vehicle to infrastructure network and some solution has been addressed which modifies DCF to provide fairness in such network. As it is illustrated in Figure 4 mobile nodes A and B have not the same residential time in communication range, so at the start Node A is communicating with the RSU, then node B enters and start communicating with RSU, but due to high speed node b will be out of range while A is still in and can continue talking with RSU.

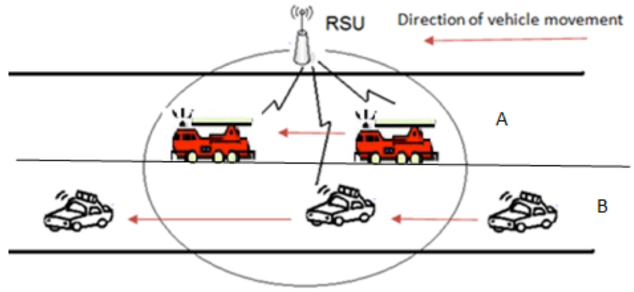

Figure. 4 Unfairness happens to B after leaving the communication range

The same scenario applies when there are three nodes communication with each other, as illustrated in Figure 5, node A (sender) and B (receiver) are with same speed and C (receiver) is in higher speed than others. Node A and B are communicating while after spending some time, node C is out of the transmission range. And the sender Node (A) cannot reach it.

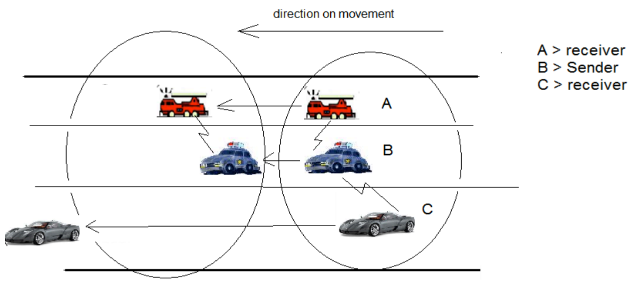

Figure. 5 Unfairness happens to C at a certain time

Hence the best MAC protocol should consider this problem and then provide priority to B in two examples to be able to transmit messages before leaving the range; hence fairness in channel access will be determined.

MAC protocol uses back off mechanism to reduce the collision, so each node is facilitated with a back off timer and will wait until it expired and then retransmits. As it determined, the back off window size is constant in the standard and it seems that this mechanism will not be effective when considering mobility and speed. So we tried to develop a new MAC algorithm considering such factors in it , so we thought of having dynamic contention window size instead of constant one. It means during a certain time interval, a node with average or low speed has reduced access to channel and node with relatively higher speed has increased priority. So by this method we will gain fairness in transmission time and the sharing of medium among diverse speed nodes.

By the above theory we can change the back off contention window size to give priority to moving node.

According to the Figure 6, we have T nodes which are neighbours, Let S' be the average speed of those communicating nodes and S_{T_k} is the speed of node n. So according to statistical equation the deviation from the S' can be as follow:

$$D = |S_{T_k} - S'|$$

So according to the gained results we can group nodes into high and low speed and give priority respectively if the amount of D is high or low, so one node can have a maximum and a minimum back off contention window size (CWmin and CWmax). As an example vehicle between the deviation speeds of 1 to 10(m/s) has Low priority and can have CWmin of for example 7 and maximum of 255 while ones between 8 to 20(m/s) can have high priority with CWmin 3 and maximum of 7. These will be also considered as requirements for simulations provided in follow.

2) Simulation: To provide a simulated result of what we have discussed and for vehicle-to-vehicle applications, we will use network simulator and for writing the script, we have considered the following requirements:

- Speed varies from 50 to 100 Km/h.
- Communication range: 200 m.
- Time slot is 13microseconds / system time is 100 seconds.
- Rate of packet transmission is 1.2 Mbps / each packet 1024 bytes.
- Minimum CW is {3, 7} and maximum CW is {7, 255}.
- We have number of nodes contending for accessing the channel up to 250.

In order to evaluate the performance of the system, we need to graph throughput, Packet Delivery Ratio (PDR) and delay. As illustrated in Figure 6 and 7, contention reduced by assigning priority dynamically and hence collision reduced, so packet lost decreased and throughput increases. And so as a result we notice that ration of packet delivering and fairness has been efficiently gained. But it should be mentioned that altering the suggested feature in MAC protocol is not enough for gaining complete performance, so other factors should be considered to make the protocol completely efficient.

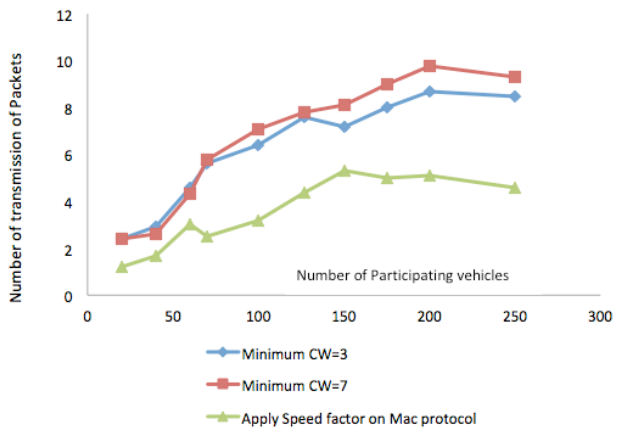

Figure. 6 Average number of retransmissions for contention window size of 3, 7 and dynamic

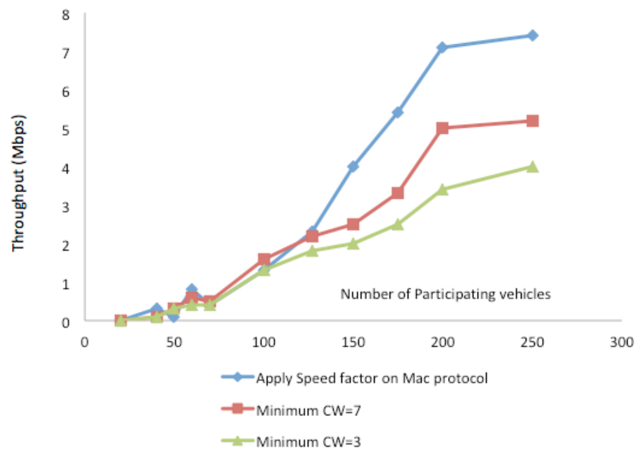

Figure. 7 Throughput of contention window size of 3, 7 and dynamic

V. APPLICATIONS

For now, some applications based on the IEEE 802.11p standard are on the market, but some projects are testing yet with few vehicles. A large number of companies, car-constructors and universities are involved in those projects, and we may see appearance in our cars the first applications in the next few years. The application can be separated into three aspects.

A. Safety-oriented

Most of applications are safety related, but these applications need real time constraints that the IEEE 802.11p is not able to provide itself. So some extensions of the amendment are needed to allow the use of safety applications. So safety-oriented applications are based on the IEEE 802.11p, but also rely on some extensions of this amendment [9].

The communication could be based on the point to point or multipoint. It also demands the low latency, which requested by the real time communication.

Car-to-car communication (C2C) can be used to provide a global view of the traffic that the driver could not be able to have by himself. For example, by exchanging of information such as position and speed, a driver can see on a screen in his car, all vehicles around. This is very useful if the weather prevents a good visibility, like fog or rain, and in a turn or at an intersection. A driver can also be advertised of a traffic jam or a traffic collision. This is also very useful especially if the driver have a bad visibility [10]. For an emergency vehicle, because it has to arrive the destination without delay, it can broadcast a message to the cars around it and make a place for itself.

Car-to-infrastructure communication (C2I) can be used, for example, to allow an emergency vehicle to pre-empt a red light on its way, and then have green light all along its path [11], or at the intersection, the traffic light sends the light information to the cars that are in its communication scope. It assists drivers better know about the conditions of the intersection to avoid traffic collision.

B. Traffic Control-oriented

Some other applications are not related to the safety, but by exchanging information about position we can have a global view about the density of the traffic and used it to regulate the traffic. For example the traffic jam advertiser, enumerated for safety purpose, is also a traffic control oriented application in a way that the user knows about a traffic jam further and then can choose a other way.

We can also imagine a “smart red light” that could collect information about number of cars waiting and how long time they have been wait, and then change its status based on that [12].

The infrastructure can also supply the localization map for the drivers and make a suggestion of appropriate path to the destination and avoid traffic jam.

The Electronic Toll Collection (ETC) has been applied in some Europe countries. ETC charges the road price for reducing the congestion. The system can recognize the car by car’s identification by the equipment based on the WAVE technology without stopping the cars. The antenna is installed on the gantry can communication with the on-board equipment, which is on the car.

C. User Comfort-oriented

Some previous applications could be also in this section, such as the traffic jam advertiser or the smart red light, because they can avoid the driver to wait too long time in a traffic jam or at a red light. But the comfort-oriented applications are more service that the users could enjoy themselves in their cars like download movies or music or upload some documents to their friends. Actually having access to the Internet can summarize comfort applications.

Some researches are in-going for that, but for some obvious reasons the IEEE 802.11p is not design for that. First of all having always a path to an access point for the Internet is almost impossible, because of the high mobility of vehicles, which should be routers [13]. There is also a big problem of security in a way that it is not possible to trust any routers on the path [14]. So having the Internet now in our vehicles by using the IEEE 802.11p amendment is not a really good solution and using other technology like the 3G is still better. But we may imagine some applications using IEEE 802.11p, for example talking with friends in a car close to our cars.

VI. Conclusions

WAVE is a short-range communication technology that is based on IEEE 802.11p and IEEE 1069. This paper is mainly based on the study of the basic technologies of the WAVE and because it is a quite new standard issued by the IEEE group, it still exists some limitations. We do our researches on the limitations' part and also give some ideas and improvements. Finally we mention about the applications of the WAVE and its applying environments and requirements.

The first idea is using the TDMA MAC to achieve real-time constraints. But it shows some drawbacks on using it with centralized way and on perfectly avoiding the collision. As a solution of the fairness in channel access problem, we give each node in the network a priority. According to the result of simulation, the ration of packet delivering and fairness has been efficiently gained.

VII. Review Question

What is WAVE and what are the main differences between WAVE and IEEE 802.11a?

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