International Journal of Network and Mobile Technologies
ISSN 1832-6758 Electronic Version
VOL 1 / ISSUE 2 / NOVEMBER 2010

This paper is available online at
http://ijnmt.intimal.edu.my/

Evaluation of the IEEE 802.11p-based TDMA MAC Method for Road Side-to-Vehicle Communications

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Abstract

Wireless vehicular communications (WVC) has been identified as a key technology for intelligent transportation systems (ITS) for a few years ago. IEEE 802.11p is the proposed standard for physical and MAC layer of WVC devices. The main objective of the standard is to change the frame format and increase delay spread tolerance introduced by vehicle mobility, in which the channel bandwidth is scaled from 20 MHz i.e.802.11a to 10 MHz i.e. 802.11p. This paper proposes TDMA technique with fixed time slots and guard band between slots to ensure interoperability between wireless devices communicate in rapidly changing environment where transactions must be completed in small timeframe. The new TDMA sub-layer is proposed to be on-top of the conventional 802.11p MAC. The simulation results present the performance analysis and validate the efficiency of the proposed scheme.

Key words: Wíreles Vehicular Communication (WVC), ITS, TDMA

1 Introduction

The wireless LAN technology 802.11 offers high data rate wireless access for local area environments. WLANs provide much higher data rates than the mobile WiMAX and 3G networks and are relatively cheap and easy to install and maintain, where the fast advancements and sophistication of chipset and semiconductor industry, IEEE 802.11 devices price curve continues to drop-down. All these introduce WLAN as a good networking choice to be adopted by vehicular communication standard. Many organizations and standard bodies agreed to that 802.11 WLAN standard will be adopted in dedicated short-range communications (DSRC) projects. This allows vehicles on the road to communicate with each other (also called Inter-vehicle communication (IVC) and to communicate with road side equipments for safety and ITS applications.

The Federal Communications Commission (FCC) has allocated 75 MHz of spectrum at 5.9 GHz that will used by IEEE 802.11p wireless access in vehicular environments (WAVE) and dedicated short-range communications (DSRC) chipsets.

The objective of using TDMA with contention-free topology rather than contention-based IEEE802.11 is to increase the coverage distance of the AP in the RSU. This due to sensitivity of the acknowledgement (ACK) messages to propagation delay in IEEE 802.11 CSMA/CA (Carrier Sense Multiple Access/ Collision Avoidance) protocol with binary exponential backoff where a positive acknowledgement is used to notify the sender that the transmitted frame has been successfully received.

Acknowledgement is send after the Short Inter Frame Space (SIFS) with the reception of frame. SIFS is smaller than the Distributed Inter-Frame Space (DIFS) and hence the receiving station does not need to sense and apply back-off procedure to transmit an acknowledgement. If the acknowledgement is not received due to some reason, the sender assumes the frame to be lost and enters the backoff process again to retransmit the previous frame. To reduce the probability of collisions, after each unsuccessful transmission attempt, the contention window is doubled until a predefined maximum value of contention window (CW) (i.e. CWmax) is reached. In addition, to improve the channel utilization, the contention window is reset to a fixed minimum value (CWmin) after each successful transmission.

Another reason that due to the short time of associate and disassociate in WVC, once a vehicle station reserves the access to the medium, it may occupy the medium for long time without any vehicle can interrupt its transmissions even in the high priority traffics case; i.e. if the onboard unit (OBU) has lower data rate due to the high-speed, then it may occupy channel for whole period since it associate until disassociate [13], [10].

In order to 802.11a WLAN standard to be suitable for vehicular environments some amendment is needed for physical layer and data link layer. The key amendment to the physical layer is to scale the channel bandwidth from 20 MHz in 802.11a to 10 MHz to mitigate the delay spread caused by rapidly changing communications environments due to high-speed vehicles. In addition to the medium access control (MAC) amendments, data frame format and using wildcard Basic Service Set Identifier (BSSID) to allow transmit and receive data frames without the need to belong to a BSS. Also, a new operation mode has been introduced, called WAVE mode, which is describing the communication between Vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V). By introducing new TDMA access, this paper has two main contributions (a) extend the WLAN distance by eliminating the propagation delay impact on the contention-based channel. (b) Also, provides fast dedicated connection to vehicles by assigning time slots to any new joining request to wave basic set services (WBSS), more discussions in Sections 2 and 3.

The reminder of the paper is organized as follow: Section 2 introduces the differences between IEEE802.11a and WAVE system and the challenges of the standard. Section 3, presented brief overview for WAVE standards set throughout TCP/IP protocol stack. Section 4 discussed the system design and proposed method. Section 5 presented simulation results. Finally, the paper is concluded in Section 6.

2 Vehicular Communication-Based IEEE 802.11 Challenges

Using IEEE802.11a WLAN with 5.9GHz frequency, vehicular communications introduces three main challenges and problems compare with 802.11a network:

(1) Vehicular speed i.e. 60km/hr, IEEE802.11 PHY and MAC is designed for fixed/nomadic stations; where a high velocity causes a large and fast variation of the channel conditions which may increase frame error rate (FER) dramatically due to the flat fading Rayleigh channel. FER can be calculated as [1]:

$$FER = 1 - \exp(-\rho - f_d\sqrt{2\pi\rho Tpi}) \quad (1)$$

where ρ is the channel fading margin which is defined as defined as ρ = Rreq/Rrms, Where Rreq is the required received power level and Rrms is the mean received power. f_d is the maximum Doppler frequency and Tpi be the frame duration which is calculated as [2]:

$$T_{pi} = T_H + T_{DATA} + T_{ACK} \quad (2)$$

where T_H is the overhead which is include preamble transmission time, PLCP header transmission time and MAC header transmission time. T_{DATA} is MSDU transmission time and T_{ACK} is ACK frame transmission time.
So some work is needed for both MAC and PHY to accommodate this problem. We introduce changes in frame duration Tpi by reducing the overhead time T_H and eliminate acknowledge time T_{ACK}.

(2) Distance, IEEE 802.11 is for short range communication with up to a few hundred meters. With this limitation, high number of APs/RSUs is needed to cover the road. For example, to update/upload location map using IEEE 802.11a data rate needs about 2 to 3 minutes, if the speed was 60km/hr then the vehicular will spend about 6 seconds within the 100 meters coverage, which is not sufficient to download the location map. Usually 802.11 have many management frames and messages for network association and authentication before start to exchange the actual data. So, we need to consider the associate and link establishment time which reduces the data transfer time.

(3) Handover and mobility management also is a challenge due to vehicular high-speed mobility where the handoff is frequently happen between access points (APs) along the road.

(4) Unique multihop inter-vehicular communication, IEEE 802.11a is designed for single hop. IEEE802.11s is capable for multihop communications but again it is for fixed access- points (APs)/routers and not applicable for moving APs/nodes. However, some features from 802.11s can be polled to the 802.11p protocol stack. In the road, vehicles take the matrix/chain shape with dimensions [NxM], where M is the number of vehicles per lanes typically 2 to 8 lanes per road and M is the the number of vehicles along the road which is infinity (∞). This network can be modeled as grid topology which is discussed extensively in the literature [3], [9].

Since, most of the vehicle to vehicle communication (V2V) is for accident avoidance which is can be done efficiently by sensors. The most heavy traffic/data is usually come from roadside units i.e. localization map, traffic efficiency information, and other value-added applications. So, in this paper we consider vehicle-to-infrastructure (V2I) scenario. A lightweight point-to-multipoint (PMP) protocol based on TDMA-WiFi technique is discussed between the road side units, RSUs and on-board units, OBU. The proposed protocol overhead massages are reduced to be appropriate and efficient for high-speed vehicles.

The upcoming IEEE 802.11p MAC method is based on 802.11e with QoS support, where four different access classes are provided. This will help to counteract many of above mentioned challenges. However, 802.11e is quite heavy and need many control messages and initiation to provide QoS function. In addition to that 802.11e is still using CSMA/CA protocol. To cope these problems, many enhancements and evaluation were proposed in the literature [8], [4]. In this paper we propose a new point-to-multipoint (PMP) - based TDD/TDMA technique on each downlink carrier for 802.11p wireless local area network rather than random access. Downlink is the transmission from the roadside unit (RSU) to onboard units (OBU) in infrastructure mode or from OBU to OBU is ad-hoc (multihop) mode. The protocol signaling and control messages are also discussed where a new cross layer approach is introduced to provide lightweight protocol suitable for vehicular environment.

3 Vehicular Communications Related Standards

The initial effort in vehicular communication was by DSRC (Dedicated short range communication) radio technology group in U.S., 2002 [5]. DSRC is a short to medium range communications service work at 5.9 GHz. DSRC is developed to provide very high data rate and to minimize link latency in vehicle speed environment. First DSRC was RFID technology and then migrated to IEEE 802.11 WLAN technology, due to maturity and global support for WiFi. IEEE 802.11p study group is initiated in 2004 to handle DSRC radio technology; the scope of the project is to amend and adjust IEEE 802.11a standard for low overhead operations to be suitable for vehicular communication. IEEE 802.11p is known as WAVE, which stands for Wireless Access in Vehicular Environments.

In addition to IEEE802.11p, there are another IEEE group (working group 1609) working in vehicular communications with scope of developing specifications to cover upper layers in the protocol suite. The IEEE 1609 standards set consisted of four sub-groups: IEEE 1609.1 works in Resource Manager (RM) which is describes procedures that allow the interaction among the OBUs with limited computing resources and that other complex processes running outside the OBUs. IEEE 1609.2 undertook the security service which is covers the format of secure messages and their processing. IEEE 1609.3 WAVE short-message protocol (WSMP) provides addressing and routing services within WAVE system. The objective of this group is to allow vehicular communication system to work with two protocol stacks, TCP/IPv6 and WSMP. WSMP is introduced to accommodate high-priority, time-sensitive communications between vehicles [6].

Finally, IEEE 1609.4 works in multichannel coordination (MCC) mechanism which is provides enhancements to the IEEE 802.11p MAC to support multichannel operation. Sometime both IEEE802.11p and IEEE 1609 are called as WAVE. Figure 1, illustrate vehicular communications standard family. The shaded areas (PHY and MAC) illustrate the scope of IEEE802.11 group and what this paper is pretend to modify. For more details in IEEE802.11p and IEEE1609 groups [13]. This paper is describes new protocol stacks deliver high availability, low-latency (HALL) services between vehicles and infrastructure for IEEE802.11p by eliminating frames collision in the medium and provide long distance transmission by allowing high propagation delay guard time.

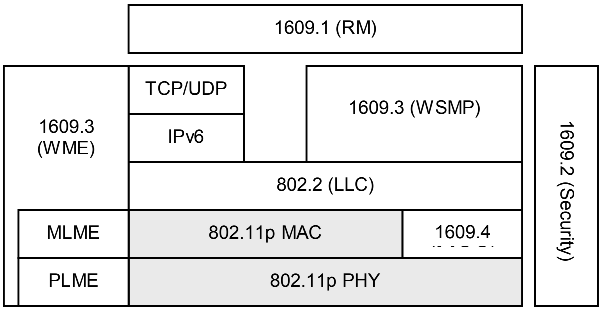

Figure 1: Wireless Vehicular Communication Standards Family

4 Methodology

RSU send Beacon frame periodically with the free slots available in the TDMA frame. OBU scan for RSU beacon. If more than one RSU respond, compare their (received signal strength indicator) RSSI's and select the best one. Put the other RSUs as first, second, etc candidates according to their RSSI. OBU uses the beacon for synchronize its frame with the RSU. OBU sends the data in the free slots (in the coming uplink frame). Check the RSSI < threshold then compares the RSSI's again and selects the best. These steps are illustrated in flow chart in Figure 2.

The TDMA frame structure is shown in Figure 3. TDMA frame encapsulates 802.11 frames in the payload subsection. The frame is repeated periodically every 20msec (which is the length of the frame). Each frame contains beacon filed i.e. broadcast control channel (BCCH) which is comprises of timestamp, SSID, BS-node capabilities. The frame is also contains frame control channel which is carries information about the structure and format of the ongoing frame i.e. slots scheduler which is containing the exact position of all slots and Tx/Rx times and guard times. GACH and RACH are used for random access channel when the OBU want to join the WBSS. RACH is the channel that OBUs use it for association request. GACH is the grant access channel contain all the OBUs accepted for transmit in the next frame.

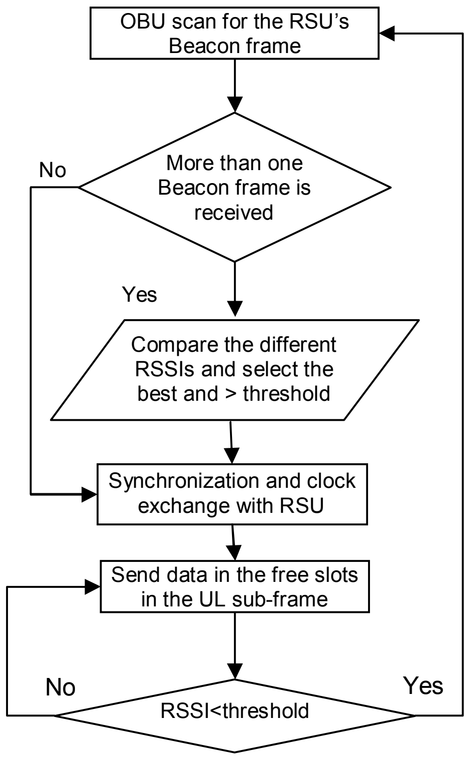

Figure 2: Flow Chart of TDMA Procedures

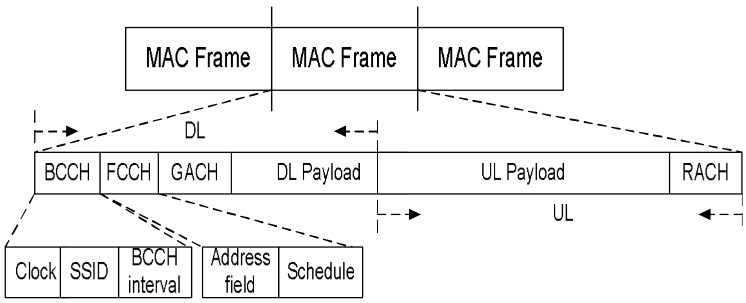

Figure 3: Frame Structure of the Proposed TDMA Protocol

TDMA is using transmission opportunities (TXOPs) mechanism originally provided by IEEE 802.11e to calculate the DL and UL time slots duration. TXOP is predefined start time and a maximum duration for station to access the medium. A RSU shall set its own NAV to prevent its transmitting during a TXOP that it has granted to OBU through. Rather than categorize the data traffic based on voice, data and video as in 802.11e, the data traffic priority categories is based on the OBU's channel quality. RSU gives high priority to vehicles with high speed to send more frames before it leaves the WBSS. Vehicle with high channel fading gets more number of slots. Of course this mechanism will introduce performance anomaly, however we can use any of the solutions available in the literature for performance anomaly [11], [12]. Figure 4 shows that a feedback of a channel condition parameters i.e. RSSI from physical layer to TDMA module to set the stations priority within the WBSS.

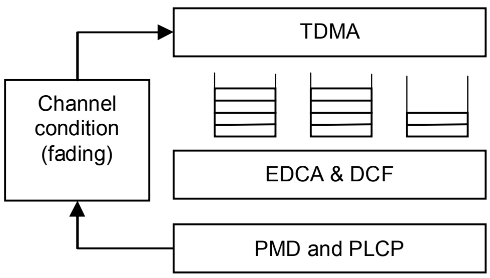

Figure 4: Channel Fading Parameters Feedback for Vehicles Transmission Priority and TXOP Setting.

5 Results

In the simulation, the PHY layer is modeled by using an Orthogonal Frequency-Division Multiplexing (OFDM) as in WAVE draft [7] with data payload capabilities of 3, 4.5, 6, 9, 12, 18, 24 and 27 Mbit/s in 10 MHz channels operating with 6 service channels, 2 safety channels and 1 control channel. NS-2.33 environment is used under Cygwin environment. The simulation is run to verify whether our TDMA model meets the WAVE PHY specification of having signals between OBUs and RSUs at speeds of up to 120 km/h. the simulation setup consists of one RSU and three OBUs in different locations from the RSU, as shown by Figure 5.

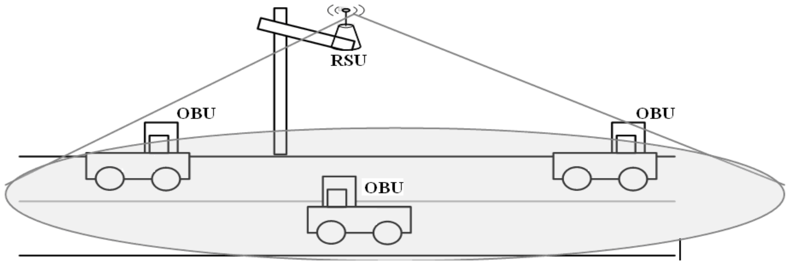

Figure 5: Point-to-multipoint downlink scenario from RSU to OBUs

The RSU access point is allocated at height point i.e. lamp pole and directional antenna is used for concentrate the radiation along the road. Of course; using beamforming antenna will increase the throughput of our system, however we only use simple directional antenna for design simplicity without loss the generality. The ns-2 simulation configuration parameters are shown in Table 1.

Table 1: Simulation Design and Performance Parameters

Parameter	Value
Directional antenna gain	15dB
Frequency Channel (178)	5890 MHz
Transmit power	20dB
Rx/Tx Switch Time	10 µs
CCA Time	27 µs
TXRX turnaround Time	10 µs
Frame length	20ms
NAV update	10ms
Time slot	500µs
Max data length allowed in one slot (byte)	1500
Max number of slots in one frame	32
The min size of the CW, in units of a Slot Time (CWmin)	15
The max size of the CW, in units of a Slot Time (CWmax)	1023

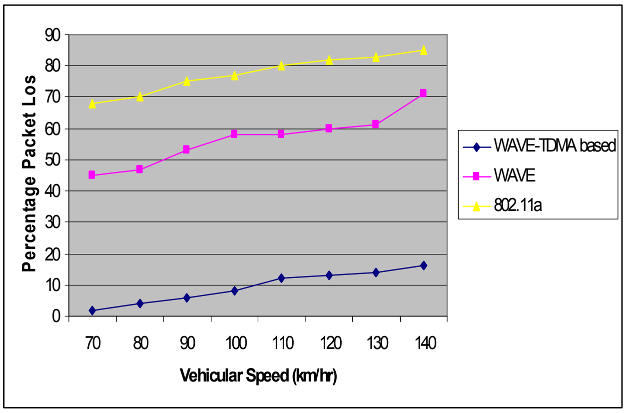

Figure 6: Packet Loss (%) Comparison of 802.11a, WAVE and WAVE-based TDMA for Varying Vehicle Speeds

Figure 6 shows the packet loss (in percentage) for pure 802.11a, WAVE and the proposed WAVE-based TDMA, which is outperform the first two protocols. The percentage of packet loss at a speed of 140 km/hr is slightly less than 10 % for packets length 1500 bytes long which shows that the TDMA is suitable with rapid change environments due to high speed mobility and shadowing.

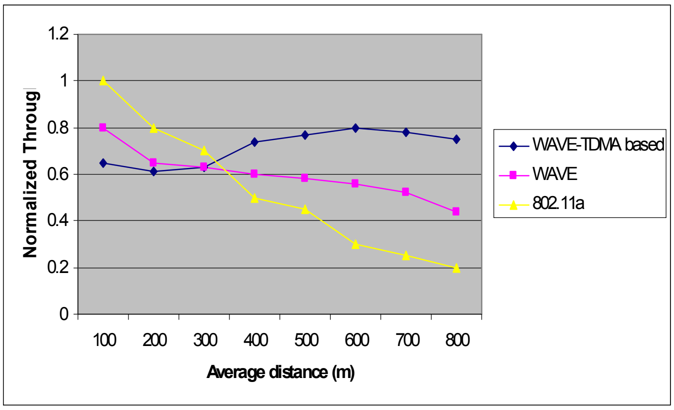

Figure 7: Average throughput for 802.11a, WAVE and WAVE-based TDMA

In Figure 7, we compare average throughput in the scenario in Fig. 1 for the three systems for model varying average OBU distance from RSU. The proposed TDMA and conventional WAVE are show lower performance than 802.11a, however they are gradually increase to outperform 802.11a. When the distance of the OBU become far from RSU, the WAVE-TDMA based dramatically outperform the conventional WAVE protocol.

6 Conclusion

The paper proposed new TDMA multiple access method based on 802.11p suitable with the unique characteristics of vehicular communications. The proposed scheme is extension for WAVE protocol for extending distance and enhancing throughput performance. The simulation results approved that the proposed algorithm is outperform IEEE802.11a and IEEE802.11p (WAVE) in high vehicle speed mobility and long distances.

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