Performance Evaluation of IEEE 802.15.4 MAC Layer

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***Abstract*—ZigBee is arguably the most prominent alliance dedicated to low-power embedded system. Its PHY and MAC layer protocols rely on the specification of IEEE 802.15.4. In this paper, we briefly detail the IEEE 802.15.4 MAC layer protocol, especially the slotted CSMA/CA algorithm. Then we calculated the average transmission delay. At last, we proposed an improved algorithm of the average transmission delay time, compared the result with the original algorithm and illustrated the simulation's application scenarios**

Keywords—IEEE 802.15.4; CSMA/CA; PER; simulation. Introduction (**HEADING 1*****)***

I. INTRODUCTION

Recent years, Intelligent Transport System (ITS) has been gaining popularity. In ITS, communication is different from traditional. The network is dynamic and the time is short. To satisfy these scenarios, various technologies have been proposed. Most of us familiars are Dedicated Short-Range Communication (DSRC), Wi-Fi and ZigBee.

Generally speaking, DSRC[1] should be more suitable for the transport applications. It is a highly efficient wireless communication technology which could identify the moving target and communication with each other in the specific area. At the PHY and MAC layers, DSRC utilizes IEEE 802.11p Wireless Access for Vehicular Environment (WAVE), a modified version of the familiar IEEE 802.11 (Wi-Fi) standard. In the middle of the stack DSRC employs a suite standards defined by the IEEE 1609 Working Group: 1609.4 for Channel Switching, 1609.3 for Networking Services (including the WAVE Short Message Protocol-WSMP), and 1609.2 for Security Services. As these standards are either recently published or expected to be completed in the coming year, the real applications are limited.

Compared with DSRC, ZigBee[2] have proposed for a long time and we have plenty of mature products. Its link and access protocols rely on the specification of IEEE 802.15.4,whersas higher layers are subject to the profile definition of the ZigBee special interest group. ZigBee operates in two frequencies, that is 2.4GHz and 900MHz. But we just consider 2.4GHz.

In the paper, we concentrate on the performance evaluation of protocols. Before real usage, we always want to know the theoretical performance indicators. Then we need test or simulate related arguments such as throughput, packet discard probability, average power and so on.

We have three kinds of protocol evaluation methods: analysis-based evaluation, simulation-based evaluation and test-based evaluation[3].

In analysis-based evaluation, only the analytical models can be used to analysis the performance of the protocol for different network environment are presented.[4–6]proposed different models for various application scenarios. For simulated-based evaluation and test-based evaluation the difference is the arguments acquired one is simulated and the other is tested. In[7], the IEEE 1609 WAVE and IEEE 802.11p trail standards are evaluated under three distinct simulation scenarios. In[8], the authors evaluate IEEE802.11p by considering collision probability, throughput and delay, by means of simulation and analysis. In[9] the authors present an IEEE 802.11p full-stack prototype implementation of data exchange among and between vehicles and the roadway infrastructures.

In vehicle to vehicle or vehicle to roadside communication, the transmission delay requires as short as possible. For example in the highway, the total communication time maybe four seconds (consider the longest communication distances is 200m, the vehicle's speed is 90km/h and the two vehicles move in the opposite direction).Then if the access time cost much, we may not have enough time to exchange data. For the specific application, we always want to know whether the access time or access delay satisfied the scenario. As illustrated before, we can evaluate the performance with three kinds of methods.

In this paper, we use the simulation-based evaluation method acquired the result of transmission delay time of different size of network. As the different of vehicle speed result in the different packet error rate (PER), we proposed an improved average transmission delay time algorithm. At last, we compared these result and made some conclusions.

The rest part of this paper is organized as follows. In Section II, we briefly detail the IEEE 802.15.4 MAC protocol to aid in the understanding of subsequent sections. In Section III, we proposed our improved algorithm and compared the average transmission delay time in different vehicle speed. Finally, Section IV concludes this paper.

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II. IEEE 802.15.4 MEDIA ACCESS CONTROL PROTOCOL DESCRIPTION

In a low-rate wireless personal area network (LR-WPAN), the personal area network (PAN) coordinator (the central controller) builds the network in its personal operating space. Communications from nodes to coordinator (uplink), from coordinator to nodes (downlink), or from node to node (ad hoc) are possible.

The CSMA/CA algorithm shall be used before the transmission of data or MAC command frames transmitted with the contention access period (CAP), unless the frame can be quickly transmitted following the acknowledgement of a data request command. The CSMA/CA algorithm shall not be used for the transmission of beacon frames, acknowledgement frames, or data frames transmitted in the contention-free period (CFP).

If beacons are being used in the PAN, the MAC sublayer shall employ the slotted version of the CSMA/CA algorithm for transmission in the CAP of the superframe. Conversely, if the beacons not being used in the PAN or if a beacon could not be located in a beacon-enabled PAN, the MAC sublayer shall transmit using the unslotted version of the CSMA/CA algorithm. Here we just consider the slotted CSMA/CA algorithm.

In the CSMA/CA algorithm, the basic time unit is the backoff period, that is, a time slot of length a UnitBackoffPeriod.

As showed in Fig.1, every data transmission shall maintain three variables: NB, CW and BE. NB is the number of times the CSMA/CA algorithm was required to backoffwhile attempting the current transmission; this value shall be initialized to 0 before each transmission attempt. CW is the contention window length, defining the number of backoff periods that need to be clear of channel activity before the transmission can commence; this value shall be initialized to 2 before each transmission attempt and reset to 2 each time the channel is assessed to be busy. BE is the backoffexponent, which is related to how many backoff periods a device shall wait before attempting to assess a channel.

Before every new transmission, NB, CW and BE are initialized to 0, 2 and macMinBE. The node waits for a random number of backoff periods specified by the backoff value, which is uniformly drawn in the range of [0, 2^{BE}-1]. Then, it performs the second CCA, and if that is also successful, then it transmits the packet. Then an ACK is fed back to the sender node after a minimum time, which allows for the transceiver of the node to switch from transmission mode (TX) to reception mode (RX). The ACK is expected by the sender node to be received before a fixed maximum time of macAckWaitDuration. If the ACK is not correctly received after this time, then a collision is declared. A collided packet can be retransmitted at most R = aMaxFrameRetries times if required before being discarded. Therefore, every time a transmitted packet collides, r is incremented by 1, and if r ≤ R, then the packet is retransmitted using a new transmission procedure with NB, CW, and BE reset to their initial values.

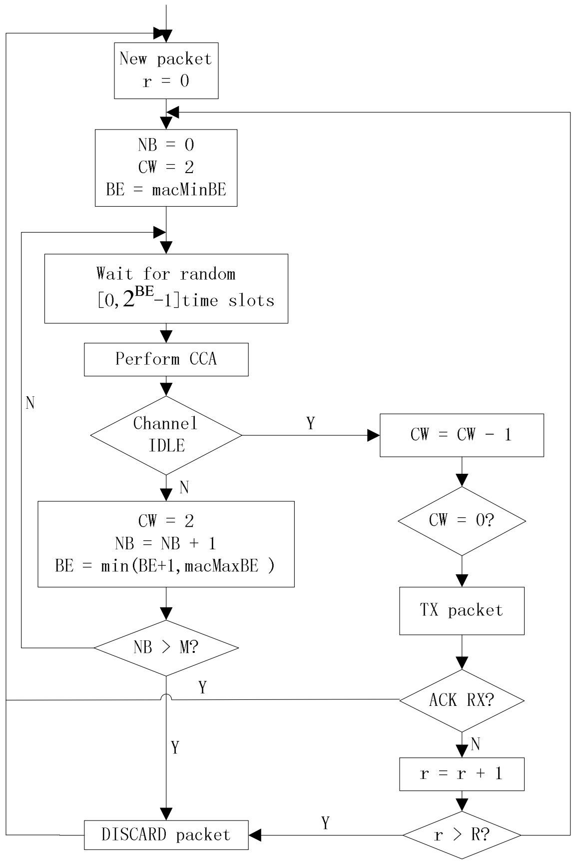


Fig. 1. Flowchart of the channel access procedure

If either of the CCAs fails, both NB and BE are incremented by 1, ensuring that BE levels at macMaxBE, and CW reset to 2. The node repeats the procedure for the new backoff stage by drawing a new backoff value unless the value of NB has become greater than a constant M = macMaxCSMABackoffs. In that case, the CSMA/CA algorithm terminates with a channel access failure status, and the concerned packet is discarded.

III. AN IMPROVED CSMA/CA ALGORITHM

We define the the packet transmission delay time is the time a packet transmits from the source node until the destination node returned an Ack. Then we will have:

$$Delay = T/num*0.32 \qquad (1)$$

Where T is the total transmission time, num is the destination node succeeded received packet number.

With the equation and the algorithm mentioned before, we can get the original result of the transmission delay time showed in Fig. 2

TABLE I. SIMULATION PARAMETERS

Number of node	1 5 10 20 40

Packet length	3 slots(25Bytes)
Ack length	2 slots
Maximum frame retransmission times R	3
Maximumbackoff times M	4
MinimumbackoffexponentaMinBE	3
Maximumbackoffexponent aMaxBE	5
Symbol rate (ksymbol/s)	62.5(2.4GHz)
Simulation time(/slots)	10^8

From Fig.2, we know that the transmission time will increase with the node number increased, but the transmission distance won't affect it. But the fact is that the transmission time should be increased when the distance is longer. Then we proposed an improved algorithm.

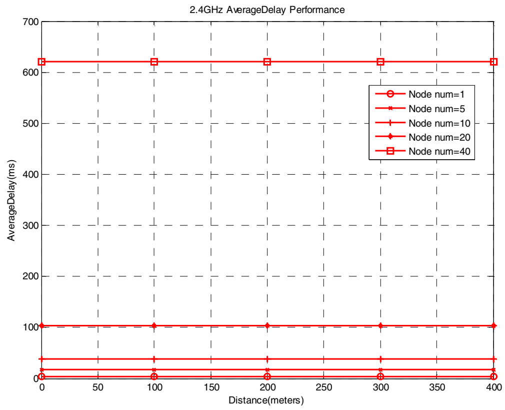


Fig. 2. The original transmission delay

In fact, when the communication distance increased or the vehicle is moving, we can't make sure the packet will be success received by the other vehicle. The packet has a failing transmission probability, which is the packet error rate (PER).

As illustrated in Fig.3, this is our revised channel access procedure. In the flowchart, we added a new part. After the packet transmitted, we didn't directly send an ACK from the destination node. We should judge whether the packet is right consider the packet error rate.

TABLE II. PER DATA IN DIFFERENT DISTANCE AND VEHICLE SPEED ON THE CONDITION OF LOS

Km/h	50m	100m	200m	300m	400m
0	0	0.0001	0.0005	0.0029	0.0129
40	0	0.0001	0.0007	0.0032	0.0136
60	0.0001	0.0001	0.0007	0.0035	0.0111
120	0.0001	0.0001	0.001	0.0032	0.0134

TABLE III. PER DATA IN DIFFERENT DISTANCE AND VEHICLE SPEED ON THE CONDITION OF NLOS

Km/h	10m	50m	100m	150m	200m	300m
0	0	0.0207	0.202	0.6435	0.947	1
40	0.0009	0.0227	0.213	0.6595	0.942	1
60	0.0006	0.0225	0.2375	0.6645	0.936	1
120	0.0052	0.0317	0.25	0.664	0.9425	1

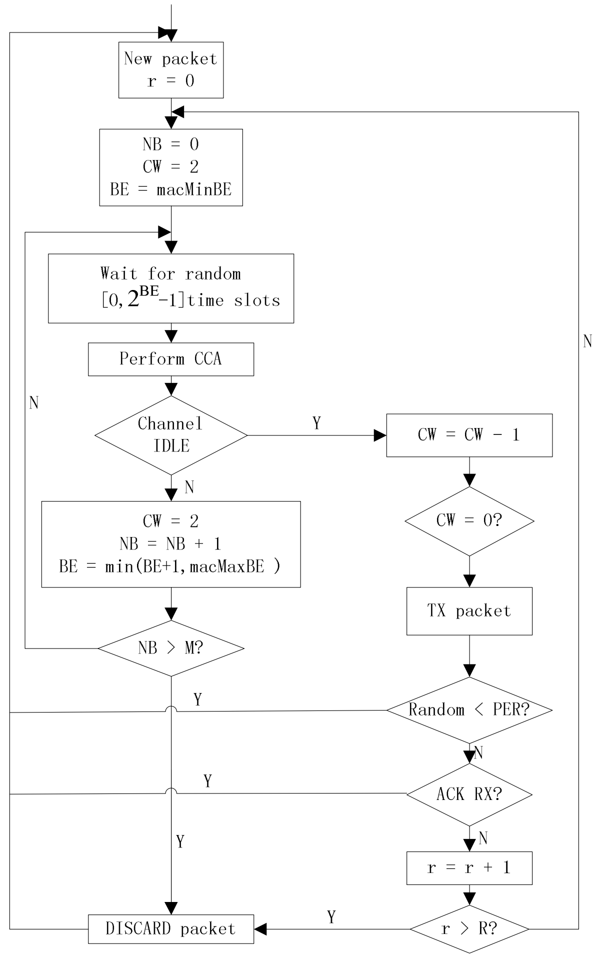
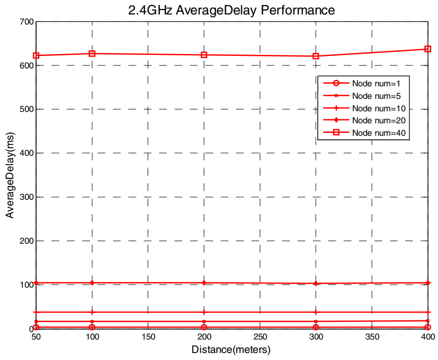


Fig. 3. Flowchart of the revised channel access procedure

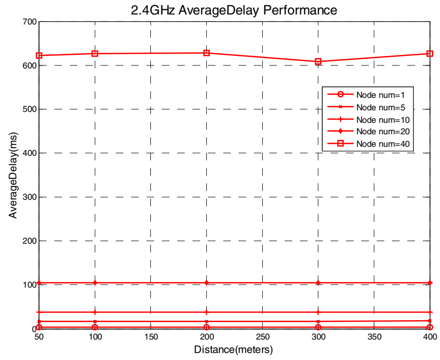
The detail procedure is as follows:

1. Generate a random number Err range from 0 to1, the number represents the probability
2. Compare Err with PER, if the number less than PER, then the transmission failed and the packet should retransmit. Otherwise the program will continue the Ack transmission.

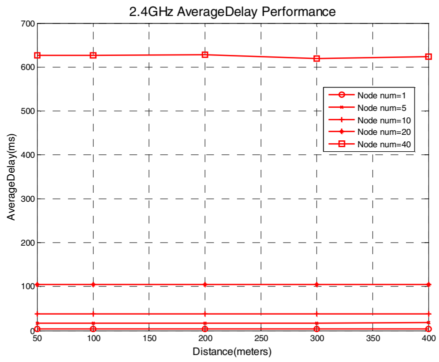
In addition, we didn't consider the Ack's PER as the length is very short and the tested PER data us approximately zero.



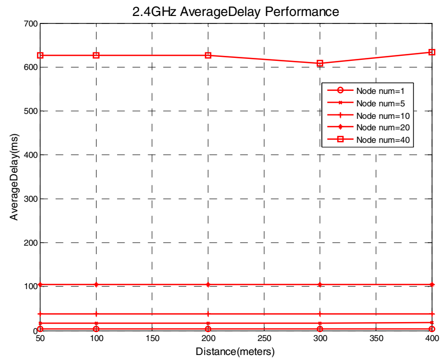
a) V = 0km/h



b) V = 40km/h

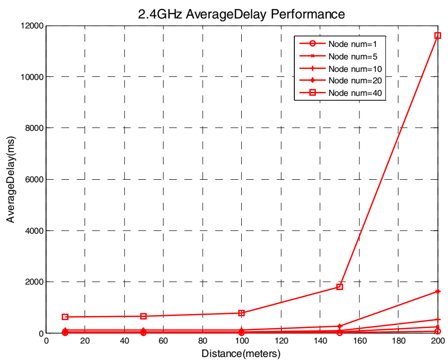


c) V = 60km/h

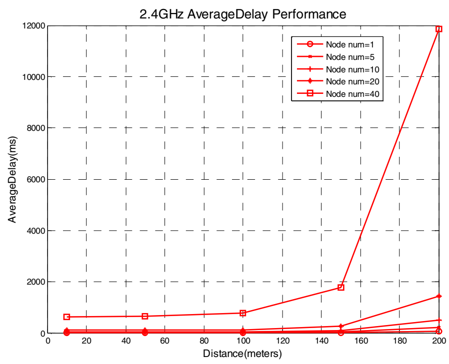


d) V = 120km/h

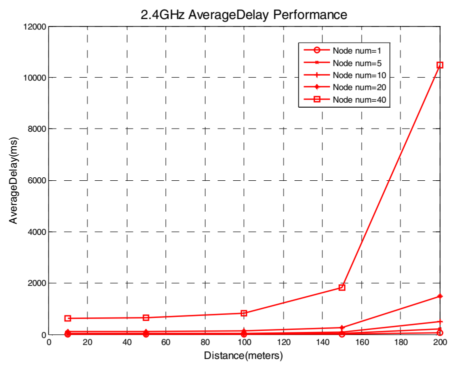
Fig. 4. The average transmission delay time with PER considered (The PER data is calculated on the condition of LOS)



a) V = 0km/h



b) V = 40km/h



c) V = 60km/h

d) V = 120km/h

Fig. 5. The average transmission delay time with PER considered (The PER data is calculated on the condition of NLOS)

The PER data is showed in TABLEII. The data is provided by the former researchers. The first one is the PER with the condition of Line Of Sight (LOS), the other is with the Non Line Of Sight (NLOS)

Then we can get these results as showed in Fig.3 and Fig.4. In Fig.3, the PER data is calculated on the condition of LOS. In Fig.4, the PER data is calculated on the condition of NLOS. Here we just show the 2.4GHz's result, and the 900MHz's result is similar.

Basically, from Fig.2 we know that the transmission delay time is increase with the increase of node numbers. Fig.3 shows us that the vehicle's speed almost has no effect on the transmission delay time on the condition of Line Of Sight. While in Non Line Of Sight, the result changed much. When the distance is less than 100 meters, the time is changed little, but it increased much when the distance is more than 140 meters. When the distance is equal to 200 meters, the time is more than 10 second. That means the vehicle's distance has a big effect on the vehicle to vehicle communication. In addition, compared with PER data and the delay time, we deduce that if the PER less than a threshold, the time won't change much.

We think we can compare these data with the actual test. In urban areas, the V2V communication is always sheltered or interfaced, and the Fig.4's result is more reliable. While in rural areas or the highway, the two communicate vehicles could "see" each other, the Fig.3's result is more acceptable.

IV. CONCLUSIONS

In the paper, we firstly introduced the methods of evaluation of the protocols' performance. Then we detailed the IEEE 802.15.4 MAC layer, especially the CSMA/CA algorithm, and proposed our improved algorithm considered the PER. Compared these simulation result, we deduce that when PER less than a threshold, it won't affect the transmission delay time much. At last, we illustrate the simulation's application scenarios.

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