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Experimental Study on Channel Congestion using IEEE 802.11p Communication System

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Abstract—**Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications are expected to play an important role to improve road safety, road efficiency, and the comfort of road users. In order to support such ITS communications, IEEE standardized 802.11p amendment, which is adopted by ETSI as ITS-G5 for European usages. While much expectation has been put in using the system for V2V road safety and efficiency applications, very limited knowledge is achieved regarding its characteristics especially scalability. Motivated by this, we conduct experimental study using IEEE 802.11p communication devices with GeoNetworking (Geographic addressing and routing) and investigate its channel performances affected by number of devices, packet size and traffic rate.**

I. Introduction

Over recent years, the emphasis in intelligent vehicle research has turned to Cooperative ITS in which vehicles communicate with each other and/or with the infrastructure for enhanced safe, efficient, and comfort driving support utilizing diverse communications technologies including IEEE 802.11p [1] (which has been specified as ITS-G5 for the European usage), WiFi, 3G/4G, WiMAX. Nevertheless, because most of the road safety and efficiency applications require direct V2V communications, the IEEE 802.11p is expected to play the key role for such applications. The medium access control (MAC) of IEEE 802.11p adopts the Enhanced Distributed Channel Access (EDCA) defined in IEEE 802.11e [2], and the physical layer (PHY) adopts the Orthogonal Frequency Division Modulation (OFDM) used in IEEE 802.11a [3].

Since communications performance is largely affected by radio propagation characteristics and the channel condition, for a launch of ITS, it is necessary to have a detailed understanding of the performance of IEEE 802.11p. Indeed much work has been carried out to study the performances of PHY and MAC characteristics by theoretical analysis, simulation and testbed performances. The recent studies on outdoor signal propagation characteristics of the IEEE 802.11p show that the IEEE 802.11p can provide up to 1 kilometers of transmission coverage in V2I scenarios and stable communication can be achieved at low transmission rates: 6 to 9 Mbps [4]. Larger transmission coverage and lower data rate are desirable, especially for road safety applications, which require periodical message broadcasting that is not subject to frame loss detection and retransmission mechanisms at the MAC layer. A use of high transmission power (i.e., large transmission coverage) and low transmission rate can suffer from channel congestion problem more seriously compared to the case of low transmission power and high data rate. While channel congestion issues have been addressed in the literature mostly by theoretically and by simulation studies, we still miss experimental studies showing the seriousness of the issue. To this end, in this paper, we report our experimental study on the channel congestion issue and its dependency on the communication parameters, such as data size and data rate, using real multi-modal IEEE 802.11p testbed system.

This paper is organized as follows. Section II highlights the existing ETSI standards and related works. In Section III, we report our experimental study on channel congestion and discuss about the achieved insights and future works Section IV. Finally we conclude the paper in Section V.

II. Background

This section introduces research and standardization activities related with IEEE 802.11p communications. Then, we point out several issues on this communications.

A. Research and standardization activities

Cooperative ITS Applications: On a general assumption of ITS architecture, vehicles are equipped with the IEEE 802.11p in order to communicate between vehicles, and also between vehicles and the roadside (See Fig. 1). Vehicles can connect to the Internet via the roadside ITS Station. On the other hand, the ITS Station may be equipped with communication interfaces (e.g. 2G, 3G, Wi-Fi) that can connect to the general Internet infrastructure. A Vehicle ITS Station consists of a router (Mobile Router, MR) which is in charge of the communication of the entire ITS Station and hosts that are running applications. With this concept, the ITS Station hosts are free from managing the communication beyond the link where the hosts connect to, since the router is responsible for managing the communication of the entire ITS Station.

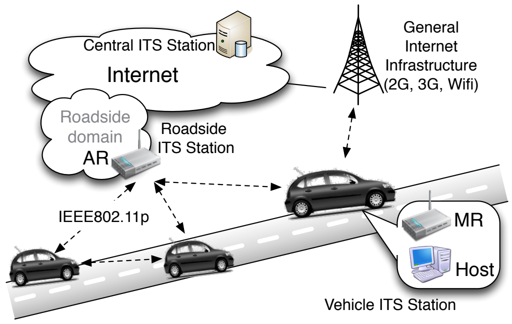

Fig. 1. ITS station reference architecture

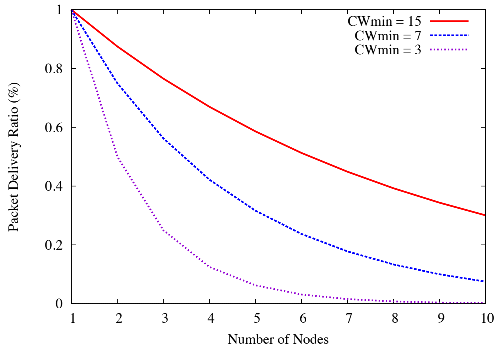

Fig. 2. Success probability in IEEE 802.11p

TABLE I
MODULATION AND DATA RATE FOR A 10 MHz CHANNEL

Modulation	Coding rate	Data rate [Mbps]
BPSK	1/2	3
BPSK	3/4	4.5
QPSK	1/2	6
QPSK	3/4	9
16-QAM	1/2	12
16-QAM	3/4	18
64-QAM	1/2	24
64-QAM	3/4	27

TABLE II
ITS-G5 CHANNEL ALLOCATION

Sub-bands	Channel type	Centre frequency	Channel number
ITS-G5A	G5CC	5900 MHz	180
ITS-G5A	G5SC2	5890 MHz	178
ITS-G5A	G5SC1	5880 MHz	176
ITS-G5B	G5SC3	5870 MHz	174
ITS-G5B	G5SC4	5860 MHz	172
ITS-G5C	G5SC5	5470 to 5425 MHz	

The ITS applications running on the hosts are classified into three categories: traffic safety, traffic efficiency and infotainment. The definition of a Basic Set of Applications were defined in ETSI (European Telecommunications Standards Institute) [5]. Especially on the safety applications, low latency (e.g., less than 100 msec) communications or communication guarantee are needed.

IEEE 802.11p: The IEEE 802.11p [1] is a wireless medium access technology for V2V and V2R communications over the 5.9 GHz band. The IEEE 802.11p basically uses the same PHY as defined in IEEE 802.11a [3] but by default, it operates utilizing 10 MHz bands. The detailed specs of this band are shown on Table I.

The IEEE 802.11p is adapted by ETSI to European context through ITS-G5 standard [6]. According to the usages, ITS-G5 divides the band into three sub-bands ITS-G5A, ITS-G5B, and ITS-G5C, where 1 control channel (CC) and 5 service channels (SCs) are defined (See Table II). The control channel, G5CC, is dedicated to road safety and traffic efficiency applications. It can also be used for ITS service announcements. The service channels G5SC1 and G5SC2 are for road safety and traffic efficiency applications. Finally, the service channels G5SC3, G5SC4, and G5SC5 are dedicated to other ITS user applications. All ITS-G5 stations (STAs) operating on ITS-G5A and ITS-G5B are treated equally disregard whether they are mobile or fixed. For operations in ITS-G5C, a distinction between mobile and fixed STAs is made for spectrum management based on distributed frequency selection (DFS).

B. Channel congestion issues in IEEE 802.11p

The IEEE 802.11p employs the contention-based channel access EDCA (Enhanced Distribution Channel Access) which uses CSMA/CA (Carrier Sense Multiple Access with Congestion Avoidance). In EDCA, a node with a pending frame first senses to the channel for a fixed period of time, EIFS (Extended Inter-Frame Space), then transmits the frame if the channel was idle or defers the transmission for a random backoff time, which is set from the range $\sigma \times [0, \mathrm{CW}]$. Here, σ is the slot time and CW is the contention window size. For the saturated scenario, i.e., nodes always have pending frames, the channel access probability, let us denote τ, is expressed simply as $1/(\mathrm{CW}+1)$ and the probability of successful transmission at a node is $\tau(1-\tau)^{n-1}$. Obviously, in order to avoid frame collisions consequently, channel congestion, CW should take on a large value when the number of contending nodes is large. Indeed, EDCA has a mechanism (so-called exponential backoff mechanism), which exponentially increases the CW in a given range of [CWmin, CWmax] after each consecutive transmission failure and resets the value to CWmin after a successful transmission. Unfortunately, for broadcast frame transmissions, which are the case for safety applications, the exponential backoff mechanism is not adopted and hence, CW takes always on CWmin). Adding to this, considering the strict delay requirement of safety applications, the IEEE 802.11p has set the default value of CWmin to relatively small values for the control channel: 15, 7, 3, and 3 for AC0, AC1, AC2, and

TABLE III
SYSTEM CONFIGURATION

CPU	Dual Core ARM11 600MHz SoC
Memory	128 MB RAM
Storage	16 MB Flash
Network	IEEE 802.11p (ETSI G5)
Kernel	Linux kernel 2.6.35.13
OS	Ubuntu 10.04 LTS

TABLE IV
KEY PARAMETERS

Parameter	Value(s)
Frequency	5900 MHz (ETSI G5CC)
Channel Spacing	10 MHz
Bitrate	6, 12, 24 Mbps
Packet Interval	100, 80, 60, 40, 20 ms
Packet Size	200, 500, 800, 1100 byte
Number of Transmitting Nodes	1, 2, 3, 4, 5, 6, 7, 8, 9, 10

AC3 access categories, respectively, for the control channel (CCH). Figure 2 shows the packet delivery ratio calculated following (1), which takes account of the transmission failures caused by collisions for the saturated scenario. The figure clearly shows the seriousness of the channel congestion issue.

$$\mathrm{PDR} = \frac{\mathrm{n}\tau(1-\tau)^{\mathrm{n}-1}}{\mathrm{n}\tau} \quad . \tag{1}$$

Much attention has been put the channel congestion issue in IEEE 802.11p. The authors of [7] disclosed the relationship between the transmit power and channel load in VANET through an analytical model and further proposed a power control approach to achieve the fairness and avoid the channel congestion. However, the proposed approach requires tight synchronization among the nodes and a global knowledge on the channel load, which are difficult to achieve in the real-world systems. The authors of [8] proposed an approach that controls both the transmission rate and power based on the prediction of the number of the neighbors. While power control and rate control can be an efficient to avoid collision, it is often not desirable for safety applications, unless the system can efficiently react to the network and channel dynamics that can be extremely challenging task. A utility-based congestion control approach is proposed in [9] for non-safety applications. The main idea is to dynamically assign the bandwidth according to the utility value of the message to be transmitted at each device. Since this approach needs the road to be segmented into sections for calculating the message utility metric, it can not be directly used in context of safety applications.

As can be seen, while channel congestion is well considered and studied analytically and by simulations, we lack experimental studies that show the seriousness of the channel congestion in real IEEE 802.11p systems. To this end, the following sections introduce our experimental study and achieved insights regarding channel congestion and its dependency on the packet size and transmission rate.

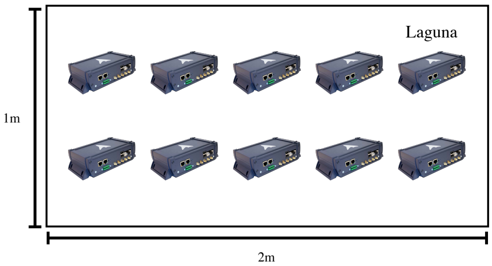

Fig. 3. Arrengement of nods

III. EVALUATION

In this section, we describe how serious the packet collision issues is in VANET by examining how packet delivery ratio changes with the increase number of transmitting nodes using the indoor testbed. In VANET, broadcast is used as either discover neighbors or propagate useful traffic information to other vehicles located within a certain geographical area. The broadcast mechanism may cause the broadcast storm problem in a scenario in which there is a high level of contention and collisions because of an excessive number of transmission packets. On safety applications, the drop of packet delivery ratio indicates a increase in probability of traffic accidents. Therefore, we investigate the channel performances affected by number of transmitting nodes, bitrate, and packet size with broadcasting for safety applications.

In Europe, the message formats are standardized by ETSI for safety application using broadcast. Two representative message formats are shown below.

1) The Cooperative Awareness Message (CAM) is transmitted at all times to enable the ITS station to aware of other stations in its neighborhood area as well as their positions, movement, basic attributes and basic sensor information [10].
2) The Decentralized Environmental Notification Message (DENM) is transmitted to provide information of specific driving environment event or traffic event to other ITS stations with occurrence of their event [11].

We conducted evaluation with parameters which were determined on the assumption of using these message formats in this paper.

A. Experimental Settings

The equipment used in this experimental study is Commsignia LGN-00-11 (Laguna). The Laguna consists of an IEEE 802.11p compliant wireless interface card, embedded ARM11 platform and 128 MB RAM (See Table III). We implemented a network protocol stack combining IPv6 and GeoNetworking by using CarGeo6 0.8.9 on Ubuntu 10.04 LTS with Linux 2.6.35.13. CarGeo6 is an open source implementation of the standardized ITS station architecture for Cooperative ITS. We put all Laguna on the table (See Fig. 3). All nodes were included in communication range with each other.

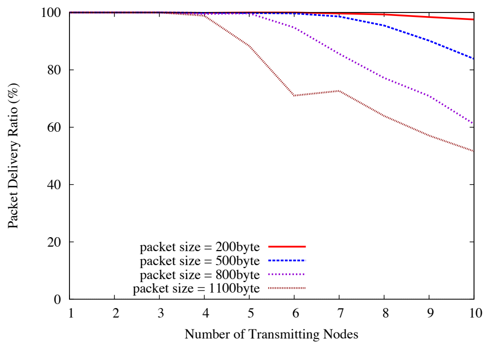

Fig. 4. Comparison between various packet sizes (bitrate = 6 Mbps, packet interval = 100 ms)

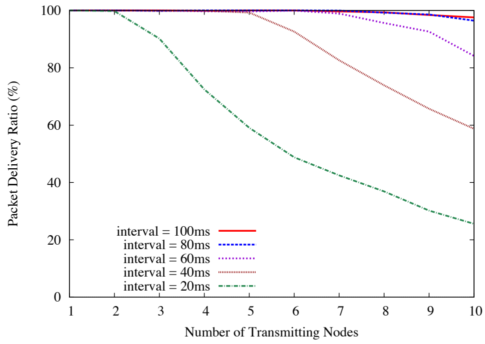

Fig. 5. Comparison between various packet intervals (bitrate = 6 Mbps, packet size = 200 byte)

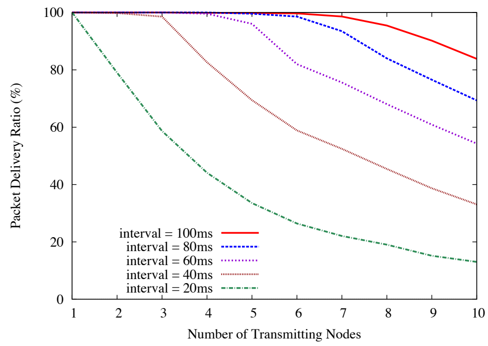

Fig. 6. Comparison between various packet intervals (bitrate = 6 Mbps, packet size = 500 byte)

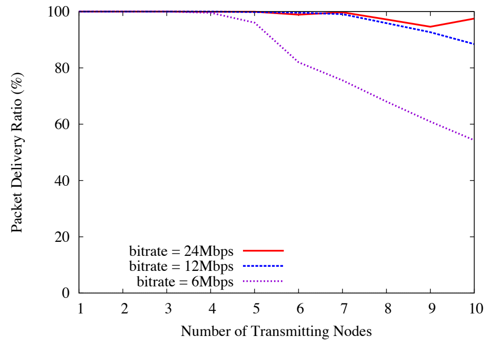

Fig. 7. Comparison between various bitrates (packet interval = 60 ms, packet size = 500 byte)

The prime objective of this paper is to investigate the influence of increase in number of transmitting nodes on the broadcast using IEEE 802.11p. We measured packet delivery ratio as metric in this evaluation. To perform these measurements, we used the *iperf* and *tcpdump* on each node. *iperf* generated traffic for 20 seconds according to the parameters of each scenario. Divided number of transmission packets by average of received packet which was captured by *tcpdump* on each node and we got packet delivery ratio. We increased number of transmitting nodes from 1 to 10 and measured the packet delivery ratio. Furthermore, we performed same experiments repetitively, setting the different combination of bitrate, packet interval and packet size (See Table IV). Besides, we used ETSI G5CCH for focusing on safety application [12].

B. Results

Minimum time interval between CAM generations is 100 ms [10] and the default bitrate of ETSI G5CCH is 6 Mbps [12]; therefore, we conducted the evaluation, setting packet interval to 100 ms and bitrate to 6 Mbps firstly (i.e., general traffic situation without specific driving environment event and traffic event). Figure 4 shows the packet delivery ratio of various packet sizes with 6 Mbps of bitrate and 100 ms of packet interval. The packet delivery ratio is high while number of transmitting nodes is small. Especially, there is almost no packet loss throughout the figure with 200 byte of packet size. However, the packet delivery ratio decreases in inverse proportion to the number of transmitting nodes. The longer the packet size gets, the more the packet delivery ratio decreases. Because the packet collision probability increase in proportion to the packet transmission time.

As is mentioned above, minimum time interval between CAM generations is 100 ms. However, the packet interval decrease more by DENM generation with occurrence of specific driving environment event or traffic event. Figure 5 shows the packet delivery ratio of various packet interval with 6 Mbps of bitrate and 200 byte of packet size. The packet delivery ratio decreases in proportion to the packet interval. It is caused by the increase in number of transmission packets with the packet interval decreases. However, the result with 100 ms of interval and the result with 80 ms of interval are almost the same.

Figure 6 shows the packet delivery ratio of various packet interval with 6 Mbps of bitrate and 500 byte of packet size. There is almost no packet loss with a number of transmitting between 1 and 7 with 100 ms of interval, between 1 and 6 with 80 ms of interval, between 1 and 4 with 60 ms of interval, between 1 and 3 with 40 ms of interval. With 20 ms of interval, packet delivery ratio is low in spite of number of transmitting nodes. It is caused by the increase in number of transmission packets with the packet interval decreases.

Figure 7 shows the packet delivery ratio of various bitrate with 60 ms of packet interval and 500 of packet size. The packet delivery ratio decreases in inverse proportion to the number of transmitting nodes. However, the higher bitrate gets, the smaller such effect becomes. Because a packet transmission time decreases by using high bitrate.

IV. Discussion

Our data show the channel congestion issue on IEEE 802.11p. Packet delivery ratio is affected by increase in number of transmitting nodes. This is attributed to the increase of packet collision probability which is caused by the increase in number of transmission packets. Furthermore, various transmitting parameters also effect the packet delivery ratio. In Fig.4, the packet delivery ratio decreases in inverse proportion to the packet size. This is also due to increase of the packet collision probability. Because the packet collision probability increase in proportion to the packet transmission time. Of course, the packet transmission time increase by the increase of packet size. This result suggests that the packet collision occur probably if CAM packet size is 200 byte and there are over 7 nodes within communication range in general traffic situation without specific driving environment event and traffic event. In Fig.5 and 6, the packet delivery ratio decreases in proportion to the packet interval. The smaller packet interval gets, the greater number of transmission packets gets. This result suggests that the packet collision occur probably if CAM packet size is 200 byte, packet interval is over 80 ms and there are over 7 nodes within communication range. We assume that the packet collision increase by generation of DENM in a case with specific driving environment event and traffic event as compared with a case without such event because the number of transmission packets increases. In Fig.7, the packet delivery ratio increases in proportion to the bitrate. Because the packet transmission time decrease with the bitrate increasing. This result suggests that the packet collision occur probably with CAM packet size is 500 byte and there are over 4 nodes within communication range, but there is almost no packet loss no more than 7 nodes if the bitrate is increased to 12 Mbps.

From the above, the packet delivery ratio was found to depend on number of transmission packets and packet transmission time. It is assumed that the packet delivery ratio is more lower in real environment because this results are gotten by indoor evaluation using nodes which don't move. On safety applications, the drop of packet delivery ratio indicates a increase in probability of traffic accidents. Therefore, we need to decrease the packet size, increase the packet interval, and increase the bitrate for road safety. However, decreasing the packet size and increasing the packet interval have limitations because the safety applications should send the necessary and sufficient informations on apposite timing to work effectively. In addition, high bitrate has not only advantage points, but also disadvantage points as compared with low bitrate. The higher bitrate is set, the more modulation technique complicates (See Table I). Complicated modulation techniques tend to have smaller communication range than simple modulation techniques because they are susceptible to noise [4]. Therefore, another drastic way is required for keeping the high packet delivery ratio on condition there is a lot of transmitting nodes.

V. Conclusion

In this paper, we investigated the packet delivery ratio as channel performance affected by number of devices, packet size and bitrate for Cooperative ITS applications. Our data show the channel congestion issue on IEEE 802.11p. On safety applications, the drop of packet delivery ratio indicates a increase in probability of traffic accidents. We need to decrease the packet size, increase the packet interval, and increase the bitrate for road safety. However, decreasing the packet size and increasing the packet interval have limits. High bitrate has small communication range as compared with low bitrate. Therefore, another drastic way is required for keeping the high packet delivery ratio. In our future work, we will consider how to keep high packet delivery ratio.

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