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V2V 통신을 위한 경량 데이터 전송 프로토콜 설계 및 구현

Design and Implementation of

a Lightweight Data Dissemination Protocol

for V2V Communications

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컴퓨터공학부

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지도 교수 전 화 숙

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위 원 ________________________ (인)

Abstract

Design and Implementation of a Lightweight Data Dissemination Protocol for V2V Communications

Hwang, MinSik
Department of Computer Science and Engineering
The Graduate School
Seoul National University

IEEE 802.11 b/g/n enabled devices are popular and widely used to provide wireless network access. Therefore, it is often considered for configuring networks for vehicles. However, because of its short signal coverage and long link setup latency, this standard cannot be used directly to support vehicle-to-vehicle (V2V) communications. In this paper, a lightweight data dissemination protocol is proposed to tackle the aforementioned issues. By utilizing a management frame format of IEEE 802.11 for data transmission, the devices can directly communicate with each other without a prior link setup process. Moreover, it supports multi-hop transmission to deliver data to out of its transmission range through relay nodes. The proposed protocol has been implemented in commercial devices and evaluated in a real vehicular network environment. The experimental results show that it is able to support seamless data dissemination through multi-hop communications in vehicular environments.

Keywords : IEEE 802.11, V2V communications,

Lightweight data dissemination protocol, Multi-hop

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Chapter 1

Introduction

The rapid growth in the number of vehicles has increased the safety problem and traffic congestion on the road. To cope with these issues, sharing traffic information between vehicles is considered as one of the solutions. By utilizing this traffic information, drivers can take appropriate actions to improve road safety and avoid traffic congestion. This can be realized through vehicle-to-vehicle (V2V) communication, which is one of vehicular ad hoc networks (VANET).

One of the well-known standards to support VANET is IEEE 802.11p [1]. IEEE 802.11p was standardized by adding IEEE 1609 WAVE (Wireless Access in Vehicular Environments) protocol stack to the existing IEEE 802.11 WLAN standard. It operates in a 5.85 ~ 5.925 GHz band in the US and a 5.855 ~ 5.925 GHz band in Europe. The signal can reach up to 1 km and 3 ~ 27 Mbps of bit rates are supported. Unlike the conventional WLAN devices, IEEE 802.11p enabled devices are allowed to exchange information without prior link setup process using the concept of wildcard BSSID [2]. It lets the IEEE 802.11p enabled devices instantly exchange message once they encounter each other. Because of these promising characteristics, many researches on VANET have been done under IEEE 802.11p, [3]–[6].

However, IEEE 802.11p has experienced slow market penetration, despite the fact that it was particularly designed for VANET and was released in 2010 [7]. Therefore, a realization of V2V communications over IEEE 802.11p standard may not be expected in the near future. In addition, even though IEEE 802.11p is adopted, it has to be integrated into the On-Board Unit (OBU) of the vehicle. This means that the users should install the new OBU in their cars or change their cars in order to utilize the service.

The practical solution for the aforementioned problem is to use the widely available IEEE 802.11 b/g/n enabled devices to support V2V communications. However, for this purpose, IEEE 802.11 b/g/n faces the issues such as short signal coverage and long link setup latency. The former one prohibits the device to communicate with other devices which are located out of its transmission range. The later one disallows instant data exchange between devices when they encounter each other due to time-consuming link setup process.

Despite the limitations, there were several efforts to utilize IEEE 802.11 b/g/n to support V2V communications. In [8], the authors proposed a method for constructing a WLAN ad hoc network for vehicles using the rooted android devices. However, even though it configures UDP/IP-based ad hoc network, IP management in driving condition was not considered. Because vehicles that make up the topology are frequently changed, IP management becomes a major issue. Next, in [9], Wi-Fi Direct was proposed for V2V communications as an alternative method for exchanging safety messages. This mechanism organizes P2P groups and makes each group leaders exchange safety messages for sharing with group members. Even though it results in reasonable transmission delays on well-organized topology, it has a problem that initial link setup takes a long time. On the road environment where a location of vehicles is frequently changed, this mechanism is not suitable.

In this paper, we propose a lightweight data dissemination protocol (so-called LDDP) to overcome the existing limitations of IEEE 802.11 b/g/n when it is used to support V2V communications. For this purpose, we utilize the management frame of IEEE 802.11 to transmit data in a broadcast manner. Through this mechanism, all the neighboring nodes may receive the data without a prior link setup process. In addition, multi-hop transmission is considered to support communication between the devices which are located out of transmission range. For multi-hop, the relay nodes are appropriately selected to avoid a broadcast storm problem. Finally, the working channel is fixed into a predefined channel to eliminate a time for a channel scanning process.

Our contributions in this paper are as follows:

1) Proposing a lightweight data dissemination protocol for V2V communications using widely available IEEE 802.11 b/g/n enabled devices.
2) Implementing the proposed protocol in the real commercial devices by software modifications.
3) Evaluating its performance using the experimental results in the real V2V network environment.

The rest of this paper is organized as follows. Chapter 2 describes a system model, and detail descriptions of the LDDP are given in chapter 3. Chapter 4 describes implementation details of the proposed protocol, and chapter 5 discusses performance evaluations. Finally, we conclude the paper in chapter 6.

Chapter 2

System model

We consider IEEE 802.11 b/g/n based vehicle-to-vehicle networks where multiple vehicles move along the road as shown in Figure 1. A user device equipped with IEEE 802.11 b/g/n is placed inside each vehicle, so the vehicles will communicate through the devices. For the sake of simplicity, we refer to the vehicle with the associated user device as a vehicle or a node. The vehicle is equipped with a GPS system to track its location, direction, and speed. The network topology dynamically changes over time due to the random mobility of vehicles. The vehicles in the system may intend to send information/contents to other vehicles. All information is for the public such as safety messages, warning alarms, videos for see-through vision, etc.

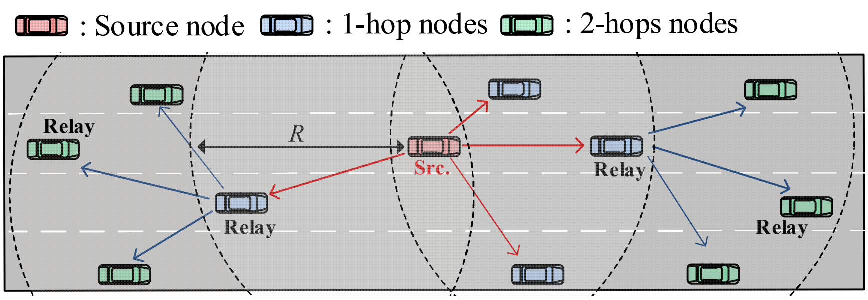

Figure 1. An example of LDDP operation

The transmission range of each vehicle is denoted by R. A vehicle can directly communicate with other vehicles located within its transmission range. Furthermore, the vehicle may transmit data to vehicles outside its transmission range in a multi-hop manner. Considering the aforementioned condition, there are three possible roles of a vehicle while communicating with other vehicles. The source node is an original node which is a creator of the information/content. The relay node is a node that relays the data received from the source or another relay node. Both of the source and the relay node are also referred to as a sender node. The receiver node is a node that only receives the data without relaying it any further.

Chapter 3

Lightweight data dissemination protocol

The goal of the LDDP is to realize the data transmission to a large number of vehicles moving along the road using widely available IEEE 802.11 b/g/n enabled devices. To achieve this goal, the operation of the LDDP consists of two main parts i.e., data transmission/reception and a relay node selection. In this section, we describe the frame formats for the LDDP and introduce data transmission/reception processes and a relay node selection process.

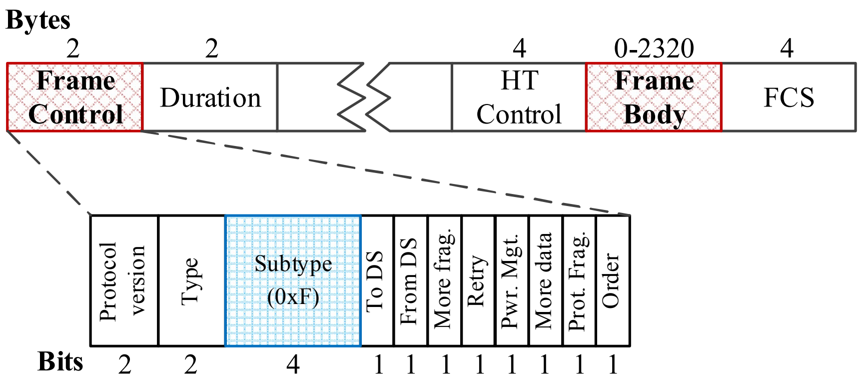

Figure 2. Management frame format of IEEE 802.11

A. Frame Format

To eliminate a time required for a link setup as in the conventional IEEE 802.11 WLAN, all frames in the LDDP utilize the management frame format of IEEE 802.11. This is because the IEEE 802.11 enabled devices can recognize any management frame regardless of its sender without a prior link setup process. The format of this management frame is depicted in Figure 2. The reserved value, namely 0xF (1111), in the subtype of the frame control is used to identify a frame of the LDDP. In addition, the specific information required by the LDDP are defined in the frame body field of the management frame.

Bytes

1	7	6	6	1	3	1	2	0-2293
Vtype (0x10)	Session ID	Relay (front)	Relay (back)	Cat.	Sequence Number	TTL	Length	Payload

Figure 3. Frame body format of the management frame
for data transmission in the LDDP

Figure 3 depicts the frame body format for data transmission. The VType field is set to 0x10 which tells that the current frame contains data. Note that there can be concurrent ongoing transmissions from several information sources. The Session ID is used to uniquely identify an information source of ongoing transmission. Thus, the receiver node can track and classify the sequence of frames received from a particular application of a source node. The Session ID is generated using six bytes MAC address of the content creator and one byte random number by concatenating them. Two Relay fields of six bytes contain MAC addresses of relay nodes in the front and the back of the sender node, respectively. A node whose MAC address is listed in one of these fields should relay the frame after receiving it. The Cat field contains information regarding a category of the corresponding content which can be a safety message (0x01), a warning alarm (0x02), a video for see-through vision (0x03), etc. The Sequence Number is used to identify the frame order, and the TTL (time-to-live) is used to check whether the frame should be relayed or not. The source node should set initial TTL value to a desired maximum number of hops that the frame should be relayed. This value is decreased by one each time the frame is relayed. The Length identifies a size of a payload in the current frame body. Finally, a data block of the content from the upper layer is placed in the Payload field. We will refer to the frame constructed above as a data frame.

On the other hand, we define three frames for relay node selection process: survey request frame, survey response frame, and survey ACK frame. Figure 4 shows the frame body formats of these frames. The VType fields in the survey request frame, survey response frame, survey ACK frame are set to 0x01, 0x02, 0x03, respectively. The Session ID is used to identify relay node survey frames for ongoing transmission. The GPS info field contains a GPS coordinate which includes a longitude value (4 bytes) and a latitude value (5 bytes) of the sender node. The Direction Azimuth and the Speed give information regarding moving direction and velocity of the sender node. The Cat field contains the same information as in a data frame. The Period field contains a period of the relay node selection process, denoted by T_{RS}.

[Survey Request]

	Vtype (0x01)	Session ID	GPS Info.	Direction Azimuth	Speed	Cat.	Period
Bytes	1	7	9	2	1	1	1

[Survey Response]

	Vtype (0x02)	Session ID	Distance	Pos.
Bytes	1	7	1	1

[Survey ACK]

	Vtype (0x03)	Session ID
Bytes	1	7

Figure 4. Frame body formats of the management frame

for survey request, response, and ACK frames

Next, in the survey response frame, the Distance field tells the Euclidean distance between the GPS coordinates of the sender node and the receiver node, where the sender node is the node that sends the survey request frame and the receiver node is the node that receives the survey request frame and responds with the survey response frame. The Position field represents whether the receiver node is located in the front (0x00) or in the back (0x01) of the sender node. To calculate its position, the receiver node creates a Cartesian plane and uses the GPS coordinate of the sender node in the survey request frame as an origin point. The positive *x*-axis of the Cartesian plane is a line formed by the moving direction vector of the sender node starting from the origin point. If the mapped GPS coordinate of the receiver node to the Cartesian plane is in quadrant I or IV, the receiver node is located in the front of the sender node. Otherwise, it is located in the back of the sender node. This information is used by the sender node for the relay node selection process.

B. Data Transmission and Reception

Once the V2V mode is activated, the node fixes the working channel into a predefined one. For a specific Session ID, the node determines its role and transmits/receives frames according to the role. If the node is a sender (i.e., a source or a relay node), for data frame transmission purpose, it maintains a list of relay nodes for each Session ID which contains {*Session ID*, *Front Relay*, *Back Relay*}. Whenever the sender node wants to transmit a data frame for a particular

Session ID, it first checks the list of relay nodes. If there is no entry for the corresponding Session ID in the list, the sender node should initiate the relay node selection process as described in the Subchapter 3-C. The sender node being not the source (i.e., the relay node) conducts the relay node selection process only if the TTL of the received data frame is greater than one. It is because the data frame will not be forwarded any further by any node in the next hop. In addition, the sender node should also perform the relay node selection process with a period of T_{RS} and update the corresponding entry in the list. This is important in order to adapt to the dynamic changes of the network topology in vehicular environments. Note that the sender node may find either its front or back relay node being unavailable, as the result of the relay node selection process. In such case, the sender node updates the list entry for the corresponding Session ID by setting the value of the relay node field to 00:00:00:00:00:00. After the aforementioned process, the sender node constructs the data frame as described in Subchapter 3-A and transmits it.

On the other hand, if the node is the relay or the receiver, for data frame reception purpose, it manages a list of data reception flows for each Session ID. The list contains {*Session ID*, *Sequence no.*, *Timestamp*}. The sequence number tracks the reception order of the data frames for the corresponding Session ID, and the timestamp records the latest reception time of a data frame for the corresponding Session ID. Upon receiving a new data frame, the node checks the Session ID of the frame and adds a new entry in the list if the corresponding Session ID does not exist. If the Session ID exists, it checks the sequence number of the frame. The node discards the frame if the sequence number is equal or less than the currently recorded sequence number for the corresponding Session ID. The node also discards the frame if it is originated from itself or the category of the frame is forbidden by the receiver. In addition, upon receiving the data frame, the node also checks the Relay and the TTL fields. If its MAC address is listed in one of the fields and the TTL of the data frame is greater than zero, the node acts as a relay node and should relay the data frame using decode-and-forward mechanism. Lastly, each entry of the relay node list or the data flow list will be removed if it is not updated during T_{CI} ($\gg T_{\mathrm{RS}}$) or if the sender node intentionally closes the corresponding communication by setting the more data field in the MAC frame header to zero. These imply that the on-going communication which corresponds to the Session ID is terminated.

C. Relay Node Selection

To enable multi-hop transmission, each sender node should select relay nodes from one-hop neighboring nodes. Considering the dynamic network topology, the relay node selection process is conducted with a period of T_{RS} based on a local clock of the sender node. And node transmits frames for the process N_r times to improve the reliability. The relay node selection procedures are as follows:

1) The sender node broadcasts a survey request frame and waits for a survey response frame during T_{RF}.
2) The neighbor node-i which receives the survey request frame checks the information inside the frame and replies with the survey response frame in a unicast manner if the following conditions are satisfied:

    a) RSSI from the sender node should be stronger than a predefined RSSI threshold ($RSSI_{\mathrm{TH}}$). It means that the node-i has a high probability to successfully decode the data frame.

b) $|\delta_{\mathrm{sdr}} - \delta_i| < A_{\mathrm{TH}}$, where A_{TH} is angle threshold, δ_{sdr} and δ_i are azimuth values of moving direction for the sender node and the node-i, respectively. This states that the node-i should move in a relatively similar direction with the sender node.

c) $d_i + |T_{\mathrm{RS}} \times (v_{\mathrm{sdr}} - v_i)| < R$, where v_{sdr} and v_i are moving speeds of the sender node and the node-i, respectively, and d_i is the distance between the node-i and the sender node. It estimates that the node-i will not move out of the transmission range of the sender node within a time interval of T_{RS}. Together with the condition in b), it will allow continuous multi-hop transmission.

d) $T_{\mathrm{cur}} - T_{\mathrm{rsf}} > T_{\mathrm{RS}}$, where T_{cur} is a current local time of the node-i, and T_{rsf} is a time that the node-i sends the last survey response frame of the same session ID. It prohibits the node-i from replying to the survey request frame with the same session ID multiple times within a period of T_{RS}. With this condition, the source node can select the relay nodes both in the back and the front, while the relay nodes select a next relay node only according to relay direction.

e) The category of the survey request frame should not be forbidden by the receiver node.

If the node-i satisfies the conditions, the node calculates its relative distance and position (front or back) from the sender node to construct the survey response frame.

3) When receiving the survey response frame from the node-i, the sender node sends a survey ACK frame. In the case of no acknowledgment from the sender node within T_{ACK}, the node-i should retransmit the survey response frame with maximum re-transmission attempt M_{rtr}.
4) After T_{RF}, the sender node gathers all information from the received response frames and compares the relative distances of nodes. Then, it selects the furthest nodes located in the front and in the back as the relay nodes if they are available. For reaching other nodes which are out of transmission range of the sender node, the selection of the relay nodes in the front and the back is enough because the other nodes will likely be located either in the front or in the back of the sender node as considering the characteristic of the vehicle moving along the road.

Chapter 4

Implementation

The proposed LDDP has been implemented using four notebooks, i.e., HP ProBook 4310 (Intel PRO/Wireless 5100 AGN), LG XNOTE P310 (Intel WiFi Link 5100), Lenovo ThinkPad X200 (Intel PRO/Wireless 5100), and Sony VAIO PCG-4NAP (Intel PRO/Wireless 4965 AGN). The Operating System is Ubuntu 14.04 (Linux kernel 4.2.8).

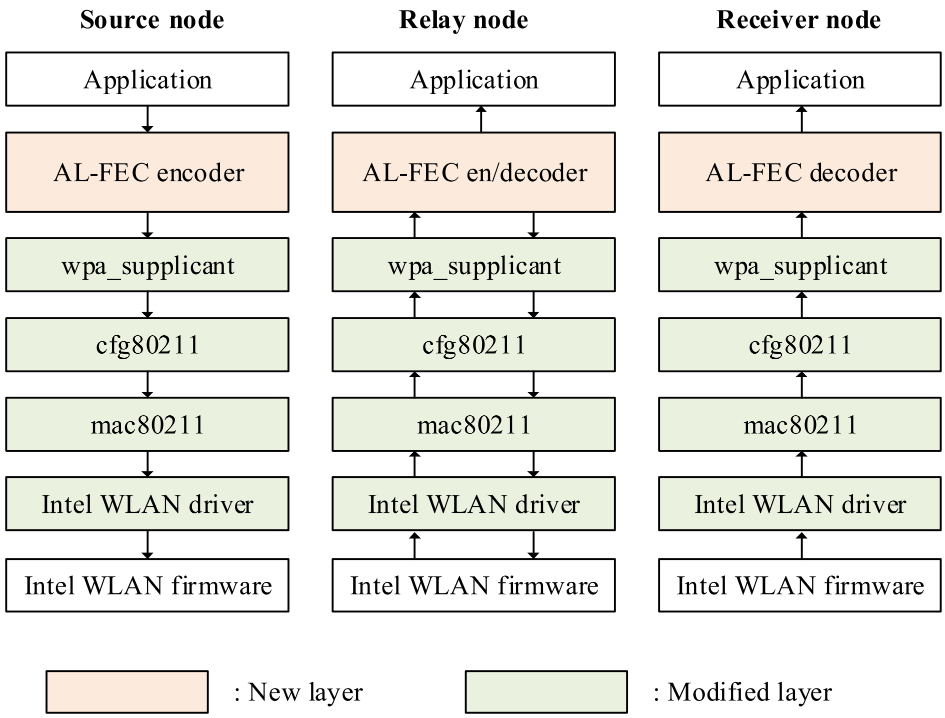

Figure 5. Data dissemination flows by the LDDP

For implementation, we modified wpa_supplicant, cfg80211, mac80211, and Intel WLAN driver. Then, to improve the reliability of broadcast transmission, we utilize the application layer forward error correction (AL-FEC) mechanism as applying for the payload of a data frame using OpenRQ library [10]. The AL-FEC method has been widely used to improve the reliability of broadcast or multicast transmission [11] [12]. Figure 5 shows detailed structures and flows of the LDDP.

A. Transmission and Reception Flow

The application starts the transmission by sending the data blocks to the AL-FEC encoder. The AL-FEC module encodes the repair block based on the received data blocks from the application. Then, it transmits all blocks, i.e., the repair block and the data blocks, to wpa_supplicant. These repair block and data blocks become a payload of a data frame. Wpa_supplicant constructs a data frame with this payload and forwards it to cfg80211, mac80211 on a kernel layer through a netlink socket. Finally, it broadcasts over the air via the WLAN chipset by the WLAN device driver and the WLAN firmware.

On the other hand, the data reception flow is as follows. For every received frame in the WLAN chipset, the frame is forwarded directly to wpa_supplicant via the WLAN device driver, mac80211, and cfg80211. Wpa_supplicant extracts a payload from the received data frame and transfers it to the AL-FEC decoder. After decoding, the AL-FEC module sends the decoded data to the application. In the case of a relay node, the AL-FEC module re-encodes the decoded data and sends it to the lower layers for a relay.

B. Change of the Default Data Rate

To be able to transmit management frames using a desired transmission rate, we modified the Intel WLAN device driver. According to the WLAN chipset model, the driver determines the function for building transmission rate, i.e., iwlagn_tx_cmd_build_rate() and il4965_tx_cmd_build_rate(). The transmission rate can be adjusted by setting the parameter value of rate_idx, and this value is set to the intended transmission rate for the LDDP.

C. Fixing the Working Channel

From an implementation point of view, the way to fix the working channel is quite different between transmission and reception. For transmission, we pass a channel information parameter to the wpa_driver_nl80211_send_frame() function of wpa_supplicant. For reception, we modified the __nl80211_set_channel() and nl80211_can_set_dev_channel() functions of cfg80211, which prevent WLAN in the STA mode from fixing its working channel. Then, by executing “iw dev <devname> set freq <freq>” command, the WLAN chipset of the device in the STA mode is set to listen on a specific channel. In addition, a mac80211 filter flag is modified to receive LDDP frames on the channel at any time.

Chapter 5

Performance evaluation

The LDDP has the characteristic that a connection is not required for data communications as compared with the conventional WLAN. Whereas in the conventional WLAN, a connection process such as a device scanning, an association process, and an IP assignment are required, and these take considerable time for a link setup. Accordingly, since the structures of the conventional WLAN and the LDDP for data communications are fundamentally different, we focus on measuring the performance of the LDDP rather than the direct comparison with the conventional WLAN. On the other hand, various types of contents such as a text, an audio, and a video can be supported by the LDDP. Among these contents, a text and an audio are not burdened even if they are transmitted several times due to its relatively small size. However, for a video, it is challenging because of its big size. For this reason, to validate the feasibility of the LDDP, we evaluate the performance by transmitting a video content in a vehicular environment.

A. Experiment Settings

The experiment is conducted by driving three or four cars on the road where the external WLAN signals have little effect. A laptop is put inside each car, which is equipped with WLAN (IEEE 802.11b) and is connected with a smartphone device which has a GPS receiver. The lowest transmission rate of IEEE 802.11b is 1 Mbps, which is used to transmit the survey request, response, and ACK frames. The transmission range of WLAN in each car is approximately 80 m. The 2.4 GHz band is selected for operations, and the working channel is set to a channel 6 (2.437 GHz). During the experiment, Node 1 acts as a source node which broadcasts a windows media video (WMV) file continuously with an 11 Mbps PHY rate. The application sends the data blocks to the AL-FEC encoder with an interval of 10 ms, approximately 1 Mbps, which is close to the bit rate of a SD 480p video. In addition, initial T_{RF} = 40 ms, T_{RS} = 5 s, T_{CI} = 30 s, A_{TH} = 70, $RSSI_{\mathrm{TH}}$ = -70 dBm, T_{ACK} = 1 ms, and M_{rtr} = 3. For data transmission, we test the scenarios for one-hop (TTL = 0), two-hops (TTL = 1) and three-hops (TTL = 2) communications. For one-hop and two-hops communications, two kinds of ratios are used for AL-FEC: one repair block for every two source data blocks, namely AL-FEC 2:1 and one repair block for every three source data blocks, namely AL-FEC 3:1. For three-hops communication, one more AL-FEC ratio is tested according to the increase in hop count: one repair block for every one source data block, namely AL-FEC 1:1. The performance metrics are data block receiving intervals on the application layer, a packet loss rate, and a peak signal-to-noise ratio (PSNR) which expresses the quality of a transmitted video. The data block receiving intervals on the application are the time intervals that the application receives data blocks from the AL-FEC decoder. For the experiment purpose, a number is embedded in each data block to track the sequence of data blocks on the application.

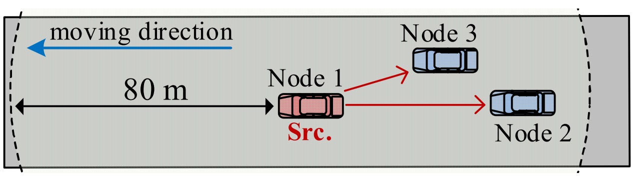

Figure 6. Scenario I - All receivers are within a transmission range of the source node (one-hop communication).

The experimental scenarios are as follows. At the beginning, three cars move according to Figure 6. Node 1 is the source node which intends to broadcast a video file. Node 2 and Node 3 are the receivers of this broadcasted file. All cars move with speed between 30-40 km/h. At first, the location of Node 2 and Node 3 are maintained to be always within a transmission range of Node 1 by controlling their moving speed. Thus, Node 2 and Node 3 may receive the broadcasted message directly from Node 1. At this point, Node 2 is selected to be a relay node.

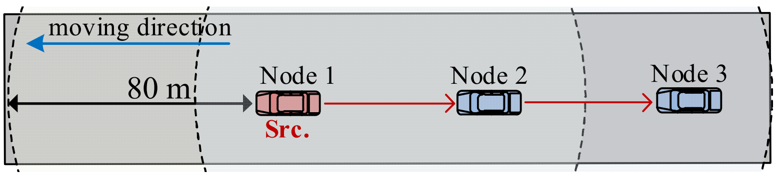

Figure 7. Scenario II - One receiver is out of a transmission range of the source node (two-hops communication).

Then, after a certain time, Node 3 slows down and moves away from Node 1 and Node 2 as shown in Figure 7. Thus, the location of Node 3 is out of the transmission range of Node 1, but within a transmission range of Node 2. While moving away from Node 1, Node 3 experiences the weak signal strength from Node 1. So it receives broadcasted data from Node 2, not from Node 1.

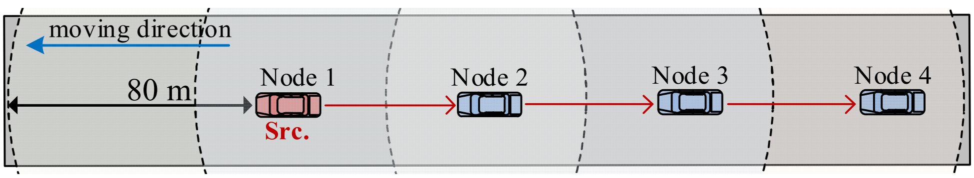

Figure 8. Scenario III - One receiver enters a transmission range

of Node 3, the second relay node (three-hops communication).

After scenario II, one more node, Node 4 follows Node 3 as shown in Figure 8. Node 4 is out of the transmission range of Node 1 and Node 2, but within a transmission range of Node 3. So it receives broadcasted data from Node 3, not from Node 1 and 2.

B. Experiment Results

The first result is the intervals of data blocks that the application of Node 3 received right before and after it leaves the transmission range of Node 1. The result is derived from AL-FEC 2:1. With this AL-FEC ratio, the decoding process results in two blocks of data. Therefore, on the application layer, two blocks of data arrive almost at the same time. The data block receiving intervals on the application of Node 3 are depicted in Figure 9, and one dot means reception of two data blocks.

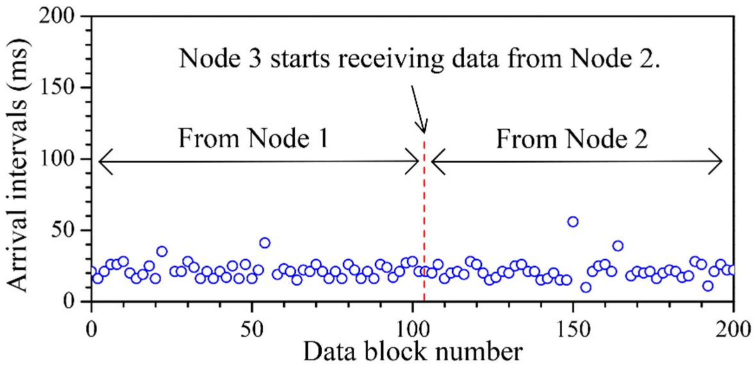

Figure 9. Data block receiving intervals on the application of Node 3 right before

and after out of range from Node 1 (AL-FEC 2:1).

As the location of Node 3 is changed, the signal strength from Node 1 gets worse. As the signal weakens gradually, Node 3 receives the data from Node 2. Although the sender node is changed, data reception takes place smoothly. This is because Node 3 has flexibility in receiving data frames without incurring overhead like a link setup process. Note that there are slight fluctuations observed on the graph due to the contention of WLANs.

Table I. PSNRs and Packet loss rates of Node 2 and Node 3 on scenario I

	Without AL-FEC	**AL-FEC 3:1**	**AL-FEC 2:1**
Node 2	16.85 dB (5.1 %)	31.69 dB (2.6 %)	33.10 dB (1.6 %)
Node 3	17.26 dB (4.8 %)	31.71 dB (2.4 %)	33.62 dB (1.5 %)

Table II. PSNRs and Packet loss rates of Node 2 and Node 3 on scenario II

	Without AL-FEC	**AL-FEC 3:1**	**AL-FEC 2:1**
Node 2	17.49 dB (4.8 %)	30.41 dB (2.6 %)	34.20 dB (1.6 %)
Node 3	15.25 dB (11.4 %)	25.69 dB (6.3 %)	27.74 dB (3.5 %)

As the second result, PSNRs and packet loss rates under the scenario I (Figure 6) and the scenario II (Figure 7) are presented in Tables I and II, respectively. Without AL-FEC, all results of PSNR are less than 18 dB, and packet loss rates are over 4.8%. While, with AL-FEC, all results of PSNR are greater than 25 dB, and packet loss rates are under 6.3%. The results with AL-FEC show the lower loss rates and the higher PSNRs because of the recovery mechanism. According to [13], based on PSNR, the video quality can be classified into 5 categories i.e., excellent (> 37 dB), good (31-37 dB), fair (25-31 dB), poor (20-25 dB), bad (< 20 dB). Thus, it confirms that the LDDP with AL-FEC results in acceptable video qualities.

Generally, the higher packet loss results in the lower PSNR. However, in Node 3 with AL-FEC 3:1 and Node 2 without AL-FEC under scenario II, even though the packet loss rate of Node 3 is higher, the result shows that PSNR is also higher. With AL-FEC 3:1, the packet loss rate of 6.3% results in PSNR 25.69 dB. On the other hand, without AL-FEC, even the packet loss rate of 4.8 % results in PSNR 17.49 dB. This is due to the structure of the WMV video file which consists of I- and P-frames. I-frame is the most important frame to display the video. The loss of this frame may cause a severe drop in the video quality. In some cases, there can be more missing of I-frames relatively. Therefore, even if packet loss is lower, PSNR can be lower.

Table III. PSNRs and Packet loss rates of Node 2, Node 3 and Node 4 on scenario III

	AL-FEC 2:1	**AL-FEC 1:1**
Node 2	34.00 dB (1.5 %)	39.96 dB (0.8 %)
Node 3	30.78 dB (2.4 %)	35.40 dB (1.5 %)
Node 4	23.63 dB (7.5 %)	27.93 dB (4.2 %)

As the final result, PSNRs and packet loss rates under the scenario III (Figure 8) is presented in Tables III. Even though AL-FEC 2:1 is acceptable in one-hop and two-hops communications, it cannot guarantee the quality of video in three-hops communication. By adjusting the ratio of AL-FEC, we can send a good quality video farther in spite of increased hop count (TTL).

In summary, the results of Figure 8, Tables I, II and III demonstrate that the LDDP with AL-FEC can provide the reasonable performance to support V2V communications.

Chapter 6

Conclusion

In this paper, we have designed and implemented the lightweight data dissemination protocol (LDDP) for WLAN based multi-hop V2V networks. The LDDP can be implemented on the commercial devices by software modifications. The experimental results show that the LDDP with AL-FEC offers good performance even though the IEEE 802.11b is not particularly designed for VANET. Therefore, the LDDP is useful in enabling V2V networks using widely available commercial devices to support better driving experiences.

Bibliography

[1] IEEE. (2010). *802.11p-2010 - IEEE standard for information technology part 11: Wireless lan medium access control (MAC) and physical layer (PHY) specifications amendment 6: Wireless access in vehicular environments* [Online]. Available: http://standards.ieee.org/findstds/ standard/802.11p-2010.html.

[2] D. Jiang and L. Delgrossi, "IEEE 802.11p: Towards an international standard for wireless access in vehicular environments," in *Proc. IEEE Veh. Technol. Conf. (VTC Spring '08)*, Singapore, May 2008.

[3] M. Barradi, A. S. Hafid, and S. Aljahdali, "Highway multihop broadcast protocols for vehicular networks," in *IEEE Int. Conf. Commun. (ICC '12)*, Ottawa, Canada, June 2012.

[4] S. Ucar, S. C. Ergen, and O. Ozkasap, "Multihop-cluster-based IEEE 802.11p and LTE hybrid architecture for VANET safety message dissemination," *IEEE Trans. Veh. Technol.*, vol. 65, no. 4, pp. 2621–2636, Apr. 2016.

[5] C. Y. Chang, H. C. Yen, and D. J. Deng, "V2V QoS guaranteed channel access in IEEE 802.11p VANETs," *IEEE Trans. Depend. Sec. Comput.*, vol. 13, no. 1, Feb. 2016.

[6] F. Librino, M. E. Renda, and P. Santi, "Multihop beaconing forwarding strategies in congested IEEE 802.11p vehicular networks," *IEEE Trans. Veh. Technol.*, vol. 65, no. 9, Sept. 2016.

[7] IEEE. (2017). “Official IEEE 802.11 working group project timelines,” [Online]. Available: http://www.ieee802.org/11/Reports/802.11_Timelines.htm. [Accessed: 10-Mar-2017].

[8] K. C. Su, H. M. Wu, W. L. Chang, Y. H. Chou, “Vehicle-to-vehicle communication system through wi-fi network using android smartphone,” in *Proc. IEEE Int. Conf. Connected Vehicles and Expo (ICCVE ’12)*, Beijing, China, Dec. 2012.

[9] C. Satish, “Inter vehicular communication for collision avoidance using Wi-Fi direct,” Master Thesis: Rochester Institute of Technology, 2014.

[10] OpenRQ open source project, [Online]. http://www.lasige.di.fc.ul.pt/openrq/. [Accessed: 10-Mar-2017].

[11] M. Luby, T. Stockhammer, M. Watson, “IPTV systems, standards and architectures: Part II – application layer FEC in IPTV services,” *IEEE Wireless Commun. Mag.*, vol. 46, no. 5, pp.94–101, May 2008.

[12] H. S. Oh, J. G. Shin, W. S. Jeon, and D. G. Jeong, “Reliable video multicast based on AL-FEC and H.264/AVC video traffic characteristics,” in *Proc. IEEE CCNC 2017*, Las Vegas, USA, Jan. 2017.

[13] J. Klaue, Jirka, B. Rathke, and A. Wolisz, “EvalvidA framework for video transmission and quality evaluation,” in *Proc. Computer Performance Evaluation, Modelling Techniques and Tools*, pp. 255-272, 2003.

요 약

일상적으로 무선 네트워크 구성을 위해 IEEE 802.11 기술이 널리 사용된다. 해당 기술은 관련 기기들이 대중화되어 있고 통신을 위해 별도의 비용이 들지 않는다는 것이 특징이다. 이에 따라 차량간 무선 네트워크 구성에 있어서도 해당 기술의 적용이 종종 고려된다. 하지만 100m의 짧은 신호 범위와 장비간 연결에 걸리는 시간 문제로 네트워크 토폴로지가 지속적으로 변하는 도로 상의 차량에서는 사용에 어려움이 있다.

이와 같은 상황을 개선하기 위해 본 논문에서는 차량간 통신을 위한 경량 데이터 전송 프로토콜을 제안한다. 해당 프로토콜은 IEEE 802.11의 management frame 기반으로 데이터를 전송하기 때문에 기기간 별도의 연결이 필요 없어 실제 통신 가능 시간을 증가시키고, relay node를 통한 multi-hop 전송을 지원하여 송신자의 신호 범위 보다도 멀리 데이터를 전달할 수 있도록 한다.

위 제안 프로토콜의 실현 가능성 확인을 위해 상용 기기 상에서 관련 코드를 구현하였다. 이를 바탕으로 실제 도로 주행 실험을 진행하였고, 제안 프로토콜을 통해 송수신한 비디오 컨텐츠의 품질이 충분히 인지 가능한 수준임을 확인하였다. 또한 네트워크 토폴로지가 변화하는 도로 주행 중이더라도 차량간 끊김없는 multi-hop 전송이 가능함을 확인하였다. 본 논문에서 제안하는 프로토콜을 통해 보다 나은 차량간 통신이 가능해지리라 기대한다.

주요어 : IEEE 802.11, 차량간 통신,
경량 데이터 전송 프로토콜, multi-hop

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