# An Experimental Study of Reliable Wireless Communications in Vehicles

Tadahide KUNITACHI
YAZAKI Research and Technology Center
YAZAKI CORPORATION
Yokosuka-shi, Japan
tadahide.kunitachi@jp.yazaki.com

Kazuhiko KINOSHITA
Graduate School of Technology and Science
Tokushima University
Tokushima-shi, Japan
kazuhiko@is.tokushima-u.ac.jp

Takashi WATANABE
Graduate School of Information Science and Technology
Osaka University
Suita-shi, Japan
watanabe@ist.osaka-u.ac.jp

***Abstract*— Recent works on enhancing comfortability and convenience in vehicles reveal that information collections by various wireless sensor nodes have the potential due to their easiness of install and their small size. However, the conventional wireless network standards achieve insufficient reliability for practical in-vehicle communications. In this paper, through implementing 2.4GHz devices in an actual vehicle with crews in the cabin. Based on the results, we propose a method to provide reliable multi-hop communications in a vehicle using overhearing. In the proposed method, the neighbor nodes overhear a packet sent from a source node. If the destination node does not receive the packet, neighbor nodes send the overheard packet as proxies of the source node. We evaluate the performance of the proposed method by computer simulation and experimental implementation. One of the results shows that the proposed method achieves 99.9% packet arrival ratio within 20ms.**

***Keywords*— *reliability; sensor node; overhearing***

## I. Introduction

In recent years, driving support in a vehicle by sensing characteristics and awakening state of the driver is studied actively [1, 2]. It is expected to be a critical technology to reduce the number of traffic accidents. In such studies, sensors play an important role for safe and comfortable driving [3].

There are a lot of devices in a cabin. They are expected to be connected via wireless links, since wired harness is heavy and inflexible.

By avoiding wiring, ICT equipments try to achieve saving metal resources, reducing CO2 emission and improving the service response [4-6]. In a satellite system, hard wiring and launching cost are reduced by using light-weight wireless links [6, 7]. A vehicle engine compartment can improve its fuel efficiency by using light-weight systems, too [5, 8].

These systems can be considered as a kind of wireless multihop network. Therefore, some existing methods may be applied. Note here that, however, the application assumed in this paper requires reliable communications with very low delay in a very unstable radio propagation environment.

Optimized Link State Routing (OLSR) is effective for low delay [9]. OLSR can send a packet quickly since any routes are established before communication. It is available for some systems with fixed equipments, since the change of radio wave environment is not so drastic. But it is not useful in a vehicle due to fluctuation.

Ad hoc On-demand Distance Vector routing (AODV) selects the suitable route when a transmission starts [10-12]. This is robust for drastic environment. But communication delay tends to be large due to route setup overhead.

Dynamic Multi-Hop Shortcut (DMHS) adjusts the average number of hops of a created route [13]. This is effective when a previous route is available, since the influence of radio wave environment is insignificant. However, communication delay tends to be still large.

Energy Delay Index for Trade-off (EDIT) is a routing method to use a distance and a Hop-count for an energy-efficient clustering. [14] It considers delay-constrained applications, but it does not discuss the success ratio.

Network coding improves the throughput by coding several packets from different source nodes into one and relaying it to other nodes [15]. It incurs additional delay due to waiting for packets from the source nodes.

In this paper, we propose a new method to provide reliable communications in a vehicle by sending overheard packet without selecting the route. Then, the performance is evaluated by computer simulation and experimental implementation.

The reminder of this paper is organized as follows. Section II shows the target system, section III describes the problem of radio wave environment with narrow space. We discuss the reliability of the proposed method in section IV. Section V evaluates the performance of the proposed method and section VI makes some conclusions.

## II. System Model

This paper assumes the following system. There are many sensors detecting the state of crews in a vehicle. Communications between these sensors must be reliable even affected by the crews. The type of the assumed vehicle is minivan. Its cabin size is 1,470mm × 2,690mm. There are 9 sensor nodes in the cabin as shown in Fig. 1.

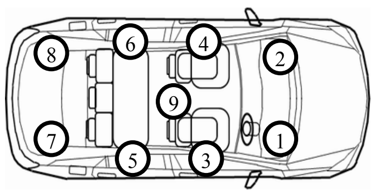


Fig.1. Nodes arrangement.

Fig. 2. Experimental setup

Since the transmission between these sensors requires high reliability equivalent to conventional wire harness, target success ratio is 99.9%. In addition, required delay constraint is 20ms in the reference of SAE (Society of Automotive Engineers) [16].

For the practical use of sensor nodes in a vehicle, the operating frequency is within the unlicensed Industrial Scientific Medical (ISM) band of 2.4GHz.

## III. Problematic issues of wireless communications in narrow space

Theoretical propagation loss [17] is

$$L = 20\log\left(\frac{4\pi r}{\lambda}\right), \tag{1}$$

where *r (m)* is distance from a transmission node and *λ(m)* is wavelength.

But, the inside of vehicle is a small space covered with metal. Moreover, a radio wave is interrupted by some equipments. Therefore, we measured the radio wave propagation in the cabin.

Fig. 2 shows a carrier wave generator located 40 cm far from the floor. All windows were closed. Its antenna is omnidirectional. We measured radio wave propagations for three parts of the cabin space, there are driver's seat, passenger's seat, and back seat. Fig. 3 illustrates the fluctuation of radio wave propagations by position while crews performed general movement.

Fig. 4 shows a case that there are crews between the source node and the destination node. It clarifies a significant propagation loss. In addition, Fig. 5 shows another case that there are no crews between nodes. In this case the propagation loss is relatively stable.

Sensor nodes in a vehicle have to communicate with high success ratio and low delay time under such a severe environment.

## IV. Reliable wireless communication in vehicles

In this section, we discuss to achieve high success ratio and low delay time by using data link layer and network layer technologies.

### *A. Overview*

As described in section III, a packet loss may occur in a fluctuate condition. Generally, it should be recovered by retransmission. However, our assumed applications require very low delay time. Therefore, a traditional retransmission is not effective.

It is better to use common equipments for early development. Consequently, we try to achieve the required reliable communications using standard devices.

### *B. Proposed Method*

In this paper, we propose to reduce the packet loss ratio based on overhearing as follows.

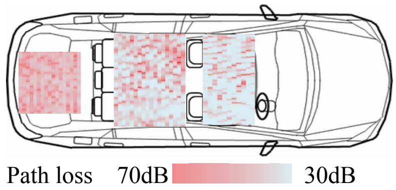

Fig. 3. Measured path loss in the vehicle.

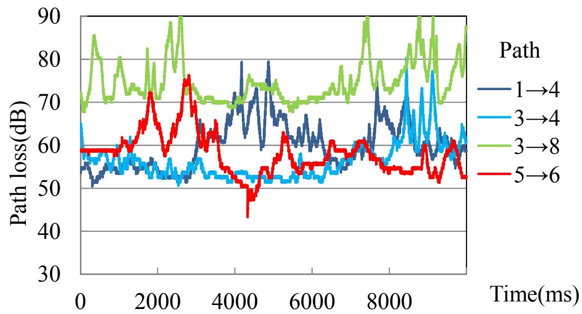

Fig. 4. Path loss fluctuation of a path traversing passengers.

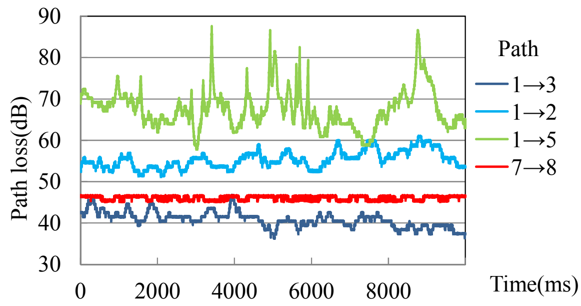

Fig. 5. Path loss fluctuation of line-of-sight path.

When a source node sends a packet to a destination node, neighboring nodes overhears the packet. If the destination node receives it, this communication is completed. Otherwise, if the destination node does not receive the packet, one of the neighboring nodes sends the overheard packet to the destination node. We call it "substitute forwarding".

If the destination node receives the packet by the substitute forwarding, the neighboring node sends a message which means a success of substitute forwarding to the source node. We call it "confirmation message". It is also delivered by substitute forwarding.

In this method, a source node makes retransmission if a source node does not receive an acknowledgement packet from the destination node or the confirmation message from neighboring node. To the contrary, a neighboring node never makes retransmission. In addition, even if it misses a confirmation message, it never retransmits. Once it has made substitute forwarding, it discards the overheard packet. However, this node makes substitute forwarding when it overhears the substitute forwarding of another node. Note again that this paper assumes a delay constraint, so that a packet is discard when its TTL (Time to Live) expires.

The proposed method is based on the CSMA/CA manner. A packet form a source node sets CWmin=2, and a packet by substitute forwarding sets CWmin=1. This means that the priority of packet by substitute forwarding is higher than retransmission packet from source node for back-off time. A packet from source node increases CW size every retransmissions. The maximum size is CWmax=32.

Fig. 6 shows communication between node A and node F.

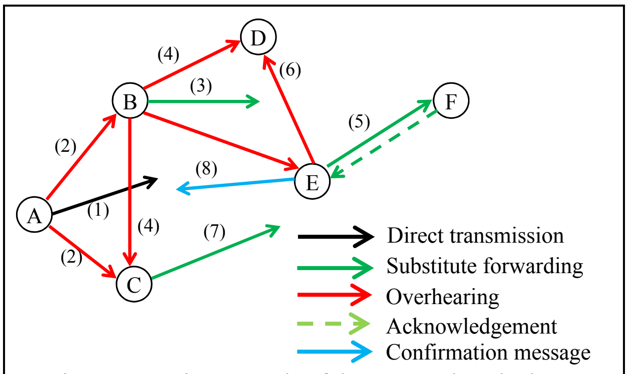

Fig. 6. Execution example of the proposed method.

(1) A source node (node A) sends a packet to a destination node (node F) directly.
(2) Neighboring nodes of node A (node B and C) overhear the sent packet at the same time.
(3) As the sent packet from node A is not received by node F, node B recognizes the fail and sends the overheard packet to the destination node as a substitute forwarding.
(4) Node B which has made the substitute forwarding has failed. Nodes C, D and E overhear the substitute forwarding from node B.
(5) Node E sends the packet as a substitute forwarding to the destination node. Node F receives it and replies its acknowledgement.
(6) Node D cancels its substitute forwarding, since it can confirm the completion by the substitute forwarding.
(7) Node C makes substitute forwarding.
(8) Node E sends a confirmation message to the source node, since the substitute forwarding of node E was received by the destination node.

## V. PERFORMANCE EVALUATION

### *A. Simulation Experiments*

We evaluated the performance of the proposed method with the experimental data shown in section III.

We implemented the method based on IEEE802.15. It has a simple structure with necessary elements as shown in Fig. 7.

We placed 9 nodes as shown in Fig. 1. A source node sent 400bits data frame with 20ms interval as a single flow. Its delay constraint was 20ms. A destination node replied 176bits ACK frame immediately when it received the data frame. Transmission power was changed from −30dBm to −42dBm. Bitrate was 1Mbps.

As a radio propagation model, the path loss described in section III was used in addition to standard white noise.

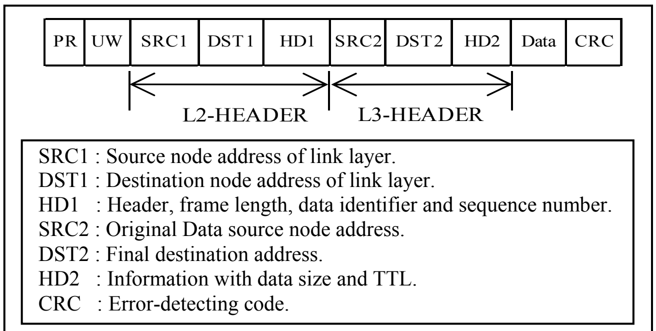

Fig. 7. Frame format.

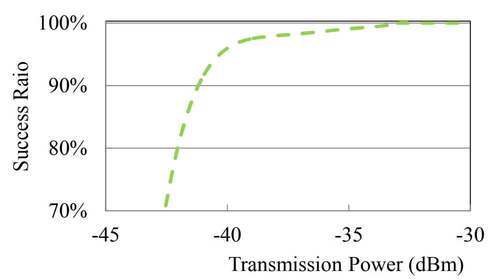

Fig. 8. Success ratio in simulation.

Fig. 8 shows the success ratio as a function of transmission power. It indicates that 100% of packets were successfully received with transmission power more than −33dBm. The success ratio of each path with transmission power −36dBm achieved that 100% of packets were received except between node 6 and node 8.

### *B. Implementation*

We also evaluated the performance of the proposed method by experimental implementation. We adopted a general module, ADF7242, made by Analog Devices, Inc. [18]. Then we implemented the proposed method in the same manner of simulation experiments. Modulation is GFSK. Bitrate is 1Mbps. Receiving sensitivity for loss factor is −86dBm.

1000 packets were sent from the driver's position (node 1). Experiments were conducted with changing transmission power from −32dBm to −44dBm.

Fig. 9 shows the success ratio in the transmission power. It was confirmed that the high success ratio and low delay were achieved by substitute forwarding. Moreover, an approximate curve between success ratio and transmission power was also plotted in Fig. 9. It shows the success ratio of more than 99.9% can be achieved by transmission power over −36dBm.

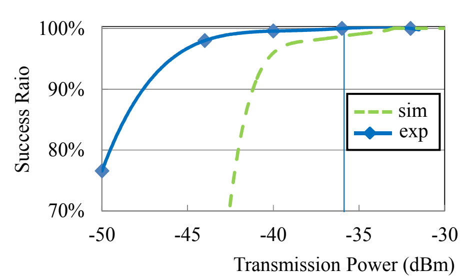

Fig. 9. Success ratio in implementation.

Fig. 10 shows the CDF (cumulative distribution function) of the end-to-end delay with the −36dBm transmission power. It shows that almost all transmissions were completed within 5ms.

Fig. 11 shows the CDF of the number of hops with the −36dBm transmission power. It confirms that more than 70% of communications made substitute forwarding. Although more than 95% of communications were within 3 hops, a few communications were delivered by virtue of 4 times or more substitute forwarding. Specifically, 3 trials used 6 hops and just one trial used 7 hops.

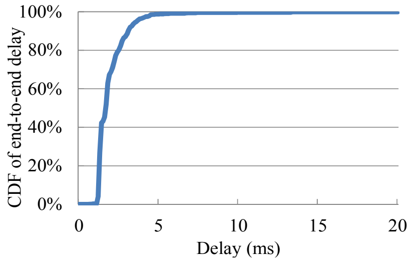


Fig. 10. End-to-end delay.

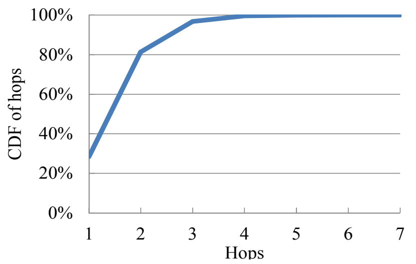


Fig. 11. The number of hops.

Table1 shows how many times each node made substitute forwarding. It is found that node 2, node 3 and node 9 were often used with first substitute forwarding. They were near the source node.

Table1 Number of substitute forwardings.

| Node \ Hops | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 2 | 486 | 22 | 14 | 3 | 0 | 1 |
| 3 | 624 | 10 | 5 | 0 | 0 | 0 |
| 4 | 4 | 93 | 3 | 0 | 2 | 0 |
| 5 | 198 | 84 | 20 | 2 | 1 | 0 |
| 6 | 243 | 165 | 53 | 0 | 0 | 0 |
| 7 | 6 | 131 | 18 | 5 | 0 | 0 |
| 8 | 0 | 122 | 14 | 1 | 0 | 0 |
| 9 | 433 | 53 | 14 | 3 | 0 | 0 |

Some neighboring nodes overhear the packet from source node. Therefore, we expected that relay nodes were distributed all over the network due to randomized back off in CSMA/CA. This is an unexpected result.

We investigated other cases. We also confirmed that neighboring nodes of source node were often used. For example, node 3 and node 9 were used when source node was node 2. In another case that source node was node 3, node 4 and node 5 were used.

## VI. CONCLUSION

In this paper, we proposed the method to provide reliable communications in a vehicle by substitute forwarding. The results of performance evaluation by computer simulation and experimental implementation showed that 99.9% of packets were received within 20ms. It indicated the proposed method was effective under the various change of radio wave environment in narrow space.

A future work will consider interferences by other equipments and/or systems.

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