Solution for Hidden Terminal Problem in New ITS Radio Communication System

Hideaki SHIRANAGA*, Masaya YAMADA, Hirofumi URAYAMA and Syouhei OGAWA

The Japanese government has planned to operate a new radio communication system for improving vehicle safety. In this system, on-car units send packets including information of their location and speed using the Carrier Sense Multiple Access (CSMA) method. However, when radio wave sent by a unit is blocked by a building and the unit cannot be detected by others, two or more units can send their packets nearly simultaneously. This can cause a packet collision called "hidden terminal problem," leading to a serious defect in the new ITS (Intelligent Transport System) radio communication system. The authors have developed a new method for improving the receiving rate of packets when the collision occurs by selectively receiving a packet with a stronger power level, and have successfully verified the performance in a field experiment.

Keywords: ITS, radio communication, hidden terminal

1. Introduction

A new radio communication system to assist safe driving is being planned to enter practical use, in line with the Japanese government's new strategy on information and communications technology, with a goal of reducing road traffic-related fatalities to fewer than 2,500 in fiscal 2018. The new ITS radio communication system enables each vehicle to transmit and receive information, such as position and speed, via communication among on-car units (vehicle-to-vehicle communication) as well as between roadside and on-car units (road-to-vehicle communication). This approach is intended to avoid accidents by, for example, voice warnings to drivers about an approaching vehicle in the blind spot. Vehicle-to-vehicle communications use the Carrier Sense Multiple Access (CSMA) method, in which each on-car unit checks whether it receives radio wave from another unit before transmission and, when it detects no carrier, the on-car unit transmits a packet containing the vehicle's position and other information. Therefore, when on-car units whose intercommunication is blocked by a building standing between them, as shown in **Fig. 1**, the units detect no carrier and transmit packets nearly simultaneously. As a result, the receiver (roadside unit in **Fig. 1**) fails to demodulate the packets due to jamming. On crowded urban roads, more than 200 on-car units would individually transmit packets, and therefore this "hidden terminal problem" is anticipated to be a serious issue. As a solution to this problem, we have refined the logic used in such radio units. The goal is to demodulate correctly the packet of the highest received power level when multiple packets arrive nearly simultaneously. A packet with a higher received power level is more important than others in terms of providing driving safety support since it is sent from an on-car unit that is closer to the receiver. The newly developed logic and prototype testing are detailed below.

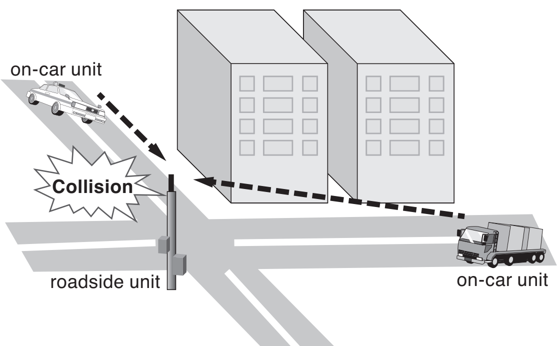

Fig. 1. Collision by hidden terminal problem

2. Radio Communication Specifications and Radio Unit Configuration

2-1 Radio communication specifications

Analog broadcasting is scheduled to end in 2011, freeing the 700 MHz band for other uses. The ITS radio communication system uses 10 MHz bandwidth in the freed band. The system complies with the IEEE 802.11 specifications in physical layer such as modulation and demodulation. The communication protocol is under consideration by the Association of Radio Industries and Businesses. The format shown in **Fig. 2** is used to form packets and convey data containing vehicle position, speed and other information. Each on-car unit transmits such packets approximately every 100 ms, checking the absence of carrier wave. Unlike cellular phones, which establish a link with the receiver before transmission, on-car units broadcast the packets to other units. The receiver is required to demodulate as many packets as possible, which are sent in rapid succession, sometimes concurrently, from many on-car units.

Preamble*1	Header	Data	CRC*2

Fig. 2. Frame format

2-2 Radio unit configuration

Photo 1 and **Fig. 3** show the exterior of the newly developed radio unit and its block diagram, respectively. Packets received via an antenna undergo amplification and other processes carried out by RF circuits for generating an IF signal containing the data and an RSSI signal indicating the packet's received power level. After A-D conversion, these signals enter the demodulator. The demodulator maintains the amplification factor of the RF circuits at an optimal value according to the RSSI signal level. The demodulator starts to demodulate the received packet, and if the demodulation is successful, the demodulator sends the data to the application processor.

Photo 1. Exterior of radio unit

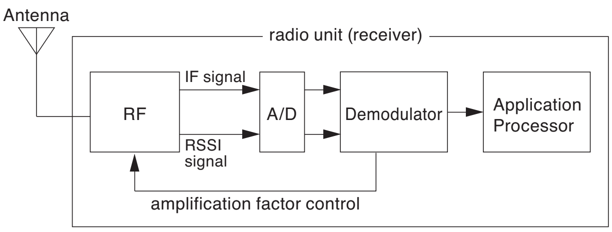

Fig. 3. Block diagram

The demodulator receives packets through the following steps (1) through (5) (**Fig. 4**).

(1) In its idle state, the demodulator awaits an RSSI signal. When it receives a signal higher than the reference level, it deems that a carrier wave is present.
(2) Demodulator coarsely adjusts the RF circuit amplification factor according to RSSI signal value.
(3) While finely adjusting the RF circuit amplification factor, demodulator tries to detect the preamble prefixed to the packet.
(4) Having detected the preamble correctly, the demodulator deems the packet legitimate and establishes synchronization. Then it fixes the RF circuit amplification factor, and continues with data demodulation.
(5) Lastly, the demodulator carries out CRC calculation. If the data is error-free, the demodulator transfers it to the application processor.

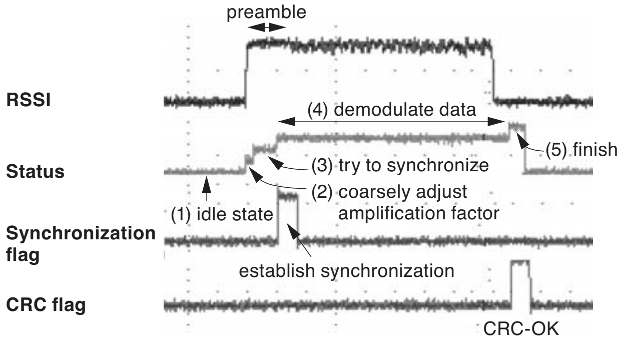

Fig. 4. Demodulation procedure

3. Measures against Hidden Terminal Problem

This section examines operations that take place upon nearly simultaneous receipt of packets from multiple on-car units when they are regarded as hidden terminals. Assume that preceding packet A arrives with higher received power level than that of following packet B, as shown in **Fig. 5**. In this case, packet B is perceived as noise. If packet A has substantially high power relative to noise (packet B), packet A can be demodulated via conventional operations. Packet B will not be demodulated, because its first portion is blurred by packet A, without the establishment of synchronization.

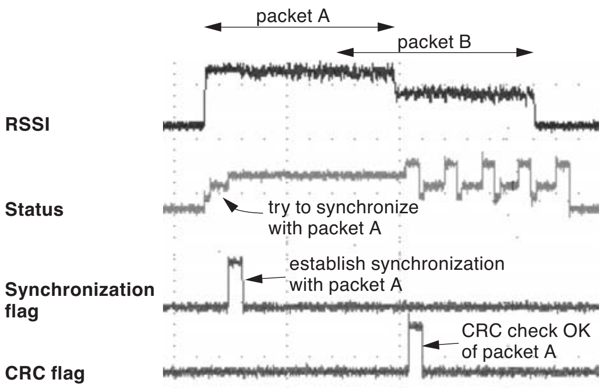

Fig. 5. The situation stronger packet arrives first

In another case, packet A with lower received power level may arrive earlier than packet B, with a higher received power level, as shown in **Fig. 6**. In such case, the conventional procedure tries to receive packet A and misses packet B. Moreover, packet A is not properly demodulated, due to the effects of noise (packet B) overpowering packet A.

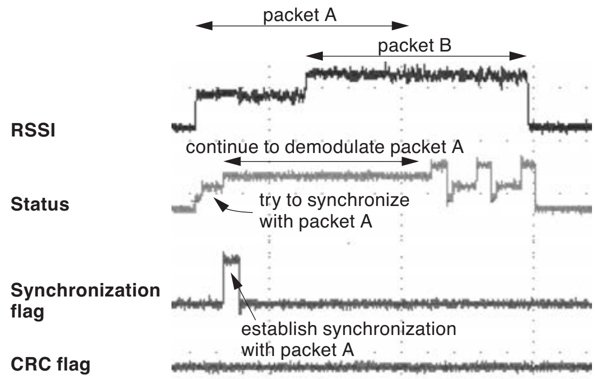

Fig. 6. The situation stronger packet arrives last

One possible solution to this problem is to separately perform a logical operation to monitor the preamble for synchronous detection, given the possibility of receiving another packet during packet A demodulation(1). However, this method may fail to make a correct judgment due to excessively high amplification factor relative to one suitable for determining packet B synchronization, since when packet A is demodulated the RF circuit amplification factor is set high in response to the received power level of packet A.

If the subsequently received signal, even if noise, is substantially strong, it becomes impossible to demodulate packet A. We therefore tested a method in which, when the level difference exceeds the reference value, the RF circuit amplification factor is optimized for the subsequently received signal, while immediately terminating the ongoing packet demodulation. In other words, this method relies only on the RSSI signal for the selection of the packet to be demodulated. One merit of this method is that it enables demodulator downsizing to smaller circuits than is required by the aforementioned method of concurrent detection of another preamble. **Figure 7** shows demodulator

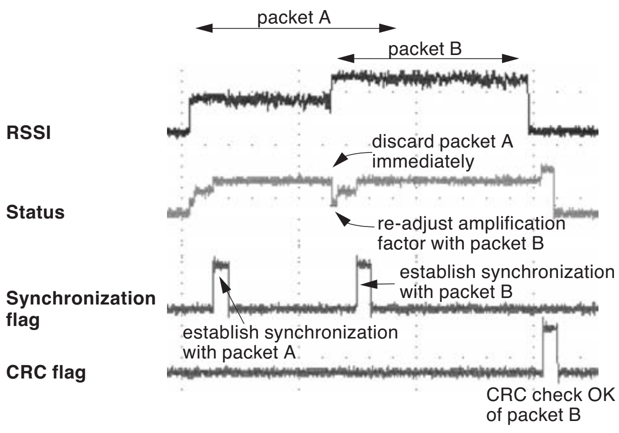

Fig. 7. Newly developed method

status changes resulting from the newly developed method. Upon receipt of a high RSSI level signal during packet A data demodulation, the new method immediately discards packet A and tries synchronization at the optimal amplification factor for the received power level of packet B, thereby achieving correct demodulation of packet B.

Next we tried to optimize the criteria used to determine whether to discard packet A upon receipt of a stronger signal during the receipt of packet A. When a packet is being received, the RSSI signal is subject to substantial variations over time. If the system erroneously interprets a variation as the arrival of another radio wave, it might unnecessarily discard packet A. Alternatively, the average of long-term RSSI signal variations may be used as a criterion for mitigating the effects of the variations. However, this is subject to failure in synchronization determination, due to delayed detection of packet B arrival. We noticed that, with packets compliant with IEEE 802.11 specifications, the RSSI signal is more stable during the preamble than during the subsequent portion of data. Consequently, as shown in **Fig. 8**, our solution was to store the average RSSI level determined when receiving the low-variation preamble of packet A and discard packet A upon receipt of an RSSI signal of substantially higher level than that stored. This prevents the unnecessary discarding of packets due to temporal RSSI signal variations when receiving data. The result is stable operation and successful demodulation of more packets.

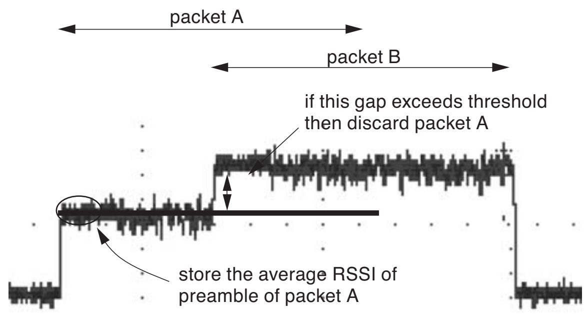

Fig. 8. Criteria to determine whether to discard packet A

4. Verification Tests

We conducted radio communication tests in Toyota, Aichi Prefecture to verify the effects of the implemented logic. To efficiently acquire data from the test, roadside radio transmitters a and b were installed and fixed respectively at positions (1) and (2) in **Photo 2**. We drove a vehicle with on-car unit c installed as a radio receiver. On-car unit c collected data such as the received power level of packet A, transmitted from roadside unit a; that of roadside unit b, and packet arrival rate (demodulation success rate) of B. **Table 1** shows test parameters. Roadside unit a, used as a hidden terminal, was set up to transmit packets almost without interruption, so that packet B always arrived during the receipt of packet A, as shown in **Fig. 9**. The goal was to evaluate the packet arrival rate of B under these conditions.

Photo 2. Verification tests

Table 1. Test parameters

Items		Parameters
roadside unit a	output power (EIRP)	19 dBm
	packet length	1000 B
	modulation	QPSK (R 1/2)
	transmission interval	1.5 ms
	antenna type and height	omni directional, 6 m
roadside unit b	output power (EIRP)	19 dBm
	packet length	100 B
	modulation	16 QAM (R 1/2)
	transmission interval	5 ms
	antenna type and height	omni directional, 6 m
On car unit c	antenna type and height	omni directional, 1.5 m

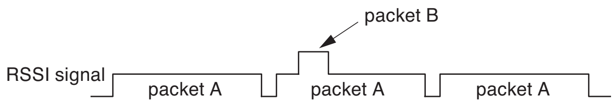

Fig. 9. RSSI signal near roadside unit b

Figure 10 shows the test results. The position of roadside unit b is at 0 m on the horizontal axis in **Fig. 10**. The cumulative packet arrival rate represents the probability of success in receiving at least one of the packets transmitted within a 5 m section while driving at 70 km/h[(2)].

$$1-(1-P_X)^{N_X}$$

where

P_X : packet arrival rate per transmission session within X [m] section

N_X : average number of packets transmitted within X [m] section (N_X = 2.6 when X = 5 and driving at 70 km/h)

The field tests demonstrated that during the receipt of packet A, when the received power level of incoming packet B is substantially high, the proposed method successfully demodulates packet B, as shown in **Fig. 10**.

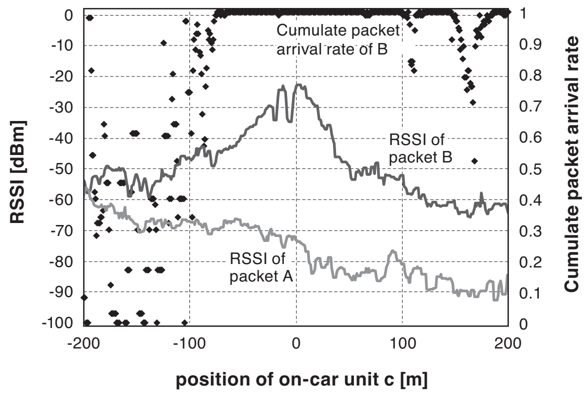

Fig. 10. Test results

5. Conclusion

The ITS radio communication system is subject to the serious hidden terminal problem. We implemented necessary logic circuitry as a solution to the hidden terminal problem and conducted tests to verify its effects. The newly developed method is expected to be useful in support of driving safety, since it improves the receiving rate of particularly important packets which are sent from on-car units proximal to the receiver, even when many of those radios transmit their packets nearly simultaneously.

Technical Term

*1 Preamble: A known code prefixed to a frame. By detecting this code, the receiver establishes synchronization for communication.

*2 CRC: cyclic redundancy check
A code provided for determining the occurrence of errors in data. The transmitting unit appends a value calculated in accordance with a given rule. The receiving unit follows the same rule for calculation and checks whether the calculation result equals the correct value to determine that the data is error-free.

References

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Contributors (The lead author is indicated by an asterisk (*).)

H. SHIRANAGA*

- Assistant Manager, Information & Communications Laboratories
  He is engaged in the development of radio communication systems for safe driving.

M. YAMADA

- Manager, Information & Communications Laboratories

H. URAYAMA

- Assistant Manager, Information & Communications Laboratories

S. OGAWA

- Information & Communications Laboratories