Road side unit coverage extension with OFDM Cooperative Transmission

Katsuhiro Naito, Atsushi Ono, Kazuo Mori, and Hideo Kobayashi
Department of Electrical and Electronic Engineering, Mie University,
1577 Kurimamachiya, Tsu, 514-8507, Japan
Email: {naito, kmori, koba}@elec.mie-u.ac.jp, atsuono@com.elec.mie-u.ac.jp

Abstract— **Intelligent Transport System (ITS) has drawn attention as new important technologies for vehicular safety. Additionally, roadside to vehicle communication is also focused because it provides network services such as an Internet access from vehicles. It is well known that communication environment in ITS is severe due to fading, blocking etc. Therefore, service quality of the Internet access from vehicles deteriorates due to transmission errors. Additionally, transmission range extension mechanisms of roadside unit is important for reducing implementation costs. In this paper, we focus on an Orthogonal Frequency Division Multiplexing (OFDM) transmission technology, which is employed in IEEE 802.11p for ITS networks. In OFDM communication, vehicles can demodulate multiple OFDM signals within Guard Interval (GI) period without inter-symbol interference. In the proposed system, vehicles forward packets from roadside units at a same allocated slot. Therefore, a destination vehicle can receive multiple OFDM signals from neighbor forwarder vehicles within GI period. From the numerical results, we show that the proposed scheme can extend the transmission range of roadside units.**

Keywords— **Intelligent Transport System, Roadside to vehicle communication, Orthogonal Frequency Division Multiplexing, Multi-hop communication**

I. Introduction

Intelligent Transport Systems (ITS) have drawn attention as important mechanisms to achieve a safety driving and useful applications in vehicles [1], [2]. Communication types in ITS are classified into roadside to vehicle communication and inter-vehicle communication. The roadside to vehicle communication is an infrastructure system. Therefore, some roadside units are installed along a road. The inter-vehicle communication is an autonomous system. As the results, each vehicle communicates with neighbor vehicles autonomously [3], [4]. Additionally, the inter-vehicle communication is suitable mechanisms to extend transmission range of roadside unit to reduce installation costs [5] .

In the roadside to vehicle communication, Internet access services will be considered as useful application services in vehicles [6], [7]. It is well known that communication environment in ITS is quite severe due to fast movement of vehicles, fading, blocking etc. Especially, distance between a roadside unit and a vehicle changes due to a location of vehicles. Therefore, a signal intensity changes dynamically due to these reasons. As the results, vehicles suffer from transmission errors due to a weak signal intensity. Additionally, almost all Internet applications employ Transmission Control Protocol (TCP) to achieve reliable communication. However, TCP performance deteriorates when a segment error ratio is increased [8].

To reduce transmission errors, we have considered diversity mechanisms at roadside units [9]. Therefore, our system employs multiple transmission mechanisms from some roadside units. Additionally, we focus on Orthogonal Frequency Division Multiplexing(OFDM) which is used in IEEE 802.11p for ITS networks. In OFDM, vehicles can demodulate multiple OFDM signals within Guard Interval (GI) period without intersymbol interference (ISI). As the results, multiple OFDM signals can be transmitted simultaneously at roadside units [10]. Additionally, we have confirmed that the multiple OFDM signal transmission is effective in multi-hop communication [11], [12]. In this paper, we employ multi-hop mechanisms to extend transmission range of roadside units. Therefore, forwarder vehicles transmit a same OFDM signal simultaneously to forward data from roadside units. From numerical results, we can find that the proposed technique can extend the transmission range of roadside units with high TCP throughput performance.

II. Range extension with OFDM cooperative communication

A. OFDM cooperative communication

In this paper, we focus on the characteristics of OFDM scheme. A transmitter of OFDM generally adds a guard interval (GI), which is a part of an OFDM symbol, to the OFDM symbol. The general purpose of GI is to mitigate the multi-path effect due to fading. Therefore, GI period is set according to maximum propagation delay in assumed

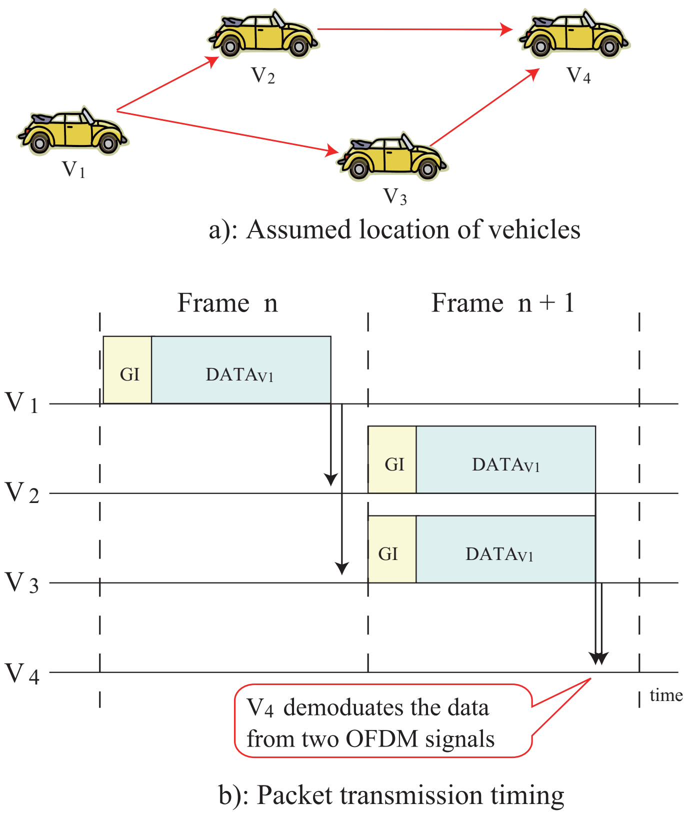

Fig. 1. Overview of the OFDM cooperative communication.

wireless communication environment. An OFDM receiver can demodulate received signals accurately when the signals arrive within GI period.

Fig. 1 shows the overview of the OFDM cooperative communication. Fig. 1 a) shows the assumed vehicle location , and Fig. 1 b) shows the overview of transmission timing at each vehicle. In the assumed system, we employ Time Division Multiple Access (TDMA) to synchronize transmission timing because arrival difference timing between signals should be within GI period. The cooperative communication processes are the followings.

- The vehicle V_1 transmits the OFDM packet including the OFDM symbol and GI in the frame n. This process is typical operation in OFDM with TDMA.
- The vehicle V_2 and V_3 receive the OFDM packet normally. Then they transmit the received OFDM packet simultaneously in the frame $n+1$. Generally, duplicated transmissions are avoided in wireless communication systems because they cause packet reception error. However, the vehicle V_4 can demodulate the duplicated OFDM packets when the arrival difference timing between the OFDM packet from V_2 and that from V_3 is less than the GI period in OFDM systems because OFDM is high tolerant of multiple signals within GI period.
- The vehicle V_4 can receive the two OFDM packets from V_2 and V_3, and can demodulate the signals more reliably because it obtains the diversity effect according to multiple transmission at different points. From the previous evaluation in our research, we could find that the total signal power is the summation of signal power of each OFDM packet. Fig. 2 is the reference bit error ratio performance with the Tab. I [11].

TABLE I

SIMULATION PARAMETERS IN PHYSICAL LAYER SIMULATION

Simulator	Matlab 6.5
Number of FFT points	64
Number of Subcarriers	52
Number of pilot subcarriers	14
Bandwidth	20 [Mhz]
Modulation scheme	16QAM
Symbol period	2.6 [μs]
GI period	0.52 [μs]
Channel model	Rayleigh fading
Number of multi-path	5

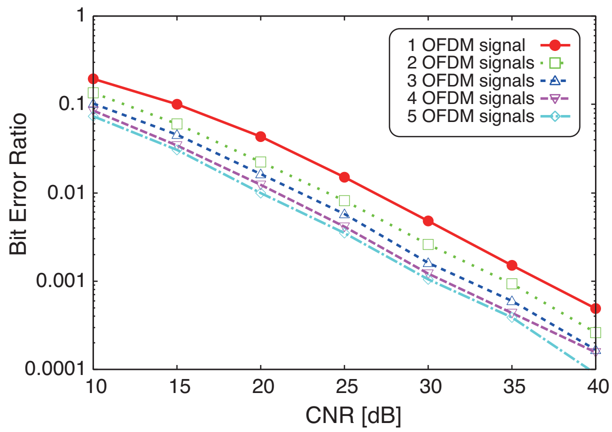

Fig. 2. BER performance in OFDM cooperative communication.

The features of the proposed cooperative communication scheme are to obtain the diversity effect according to multiple routes and to achieve effective wireless resource usage by transmitting a same OFDM signal simultaneously. As the results, our scheme can obtain the benefit of cooperative communication without the demerit.

B. Road side unit coverage extension

In the proposed system, we employ the proposed OFDM cooperative communication to extend the transmission range of roadside units. Therefore, we employ hybrid transmission

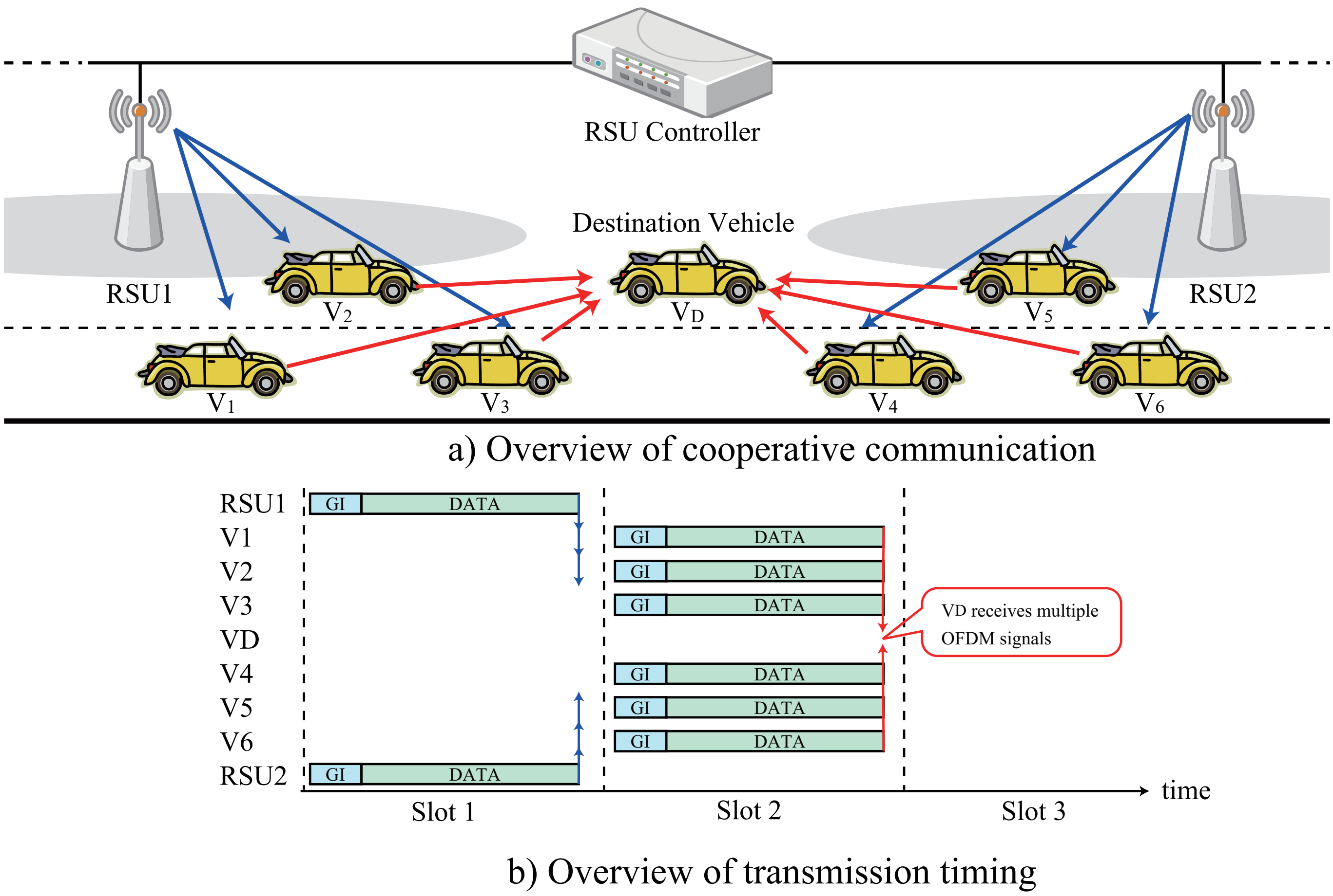

Fig. 3. Overview of the proposed communication.

of roadside to vehicle communication and inter-vehicle communication. A roadside unit has an Omni directional antenna. Vehicles near the roadside unit can receive the packet directly when it exists within the transmission range of the roadside unit. On the contrary, vehicles near a roadside unit forward a packet to a vehicle at an outer area of roadside unit transmission range when the destination vehicle exists in out of the transmission range of the roadside unit. The hybrid concepts have been proposed in the conventional researches. Then, it is well known that the concepts can improve the communication performance. However, traffic increasing due to multiple forwarding of packets is a big issue. The proposed system solves this issue to employ OFDM cooperative communication techniques because vehicles can transmit a same packet simultaneously in our techniques.

Fig. 3 shows the overview of the proposed communication. Fig. 3 a) shows the overview of the cooperative communication, and Fig. 3 b) shows the overview of transmission timing at each vehicle. In the figures, the roadside unit RSU$_1$ and RSU$_2$ transmit a packet to the vehicle V_D. However, the vehicle V_D exists in the outer area of transmission range of roadside unit RSU$_1$ and RSU$_2$. Therefore, multi-hop communication is required to deliver the packet to the vehicle V_D.

The proposed system employs Time Division Multiple Access (TDMA) mechanisms for the access control. Therefore, the roadside unit controller assigns slots based on traffic and a vehicle location. In assignment rules, it tries to find one slot for roadside units and some slots for forwarder vehicles according to the required hop counts. The important rule is that forwarder vehicles should transmit a same OFDM signal at same slot. Fig. 3 assumes multi hop communication with one hop. In Fig. 3, the roadside units RSU$_1$ and RSU$_2$ transmit the OFDM signal at the slot 1 The vehicles V_1, V_2 and V_3 receive the OFDM signal from the roadside unit RSU$_1$ and the vehicles V_4, V_5 and V_6 receive it from the roadside unit RSU$_2$. Then, these vehicles transmit the OFDM signal at the slot 2. As the results, the destination vehicle can receive six OFDM signals from neighbor vehicles. Finally, it can obtain the diversity effect and can improve packet reception performance without redundant wireless resource consumption.

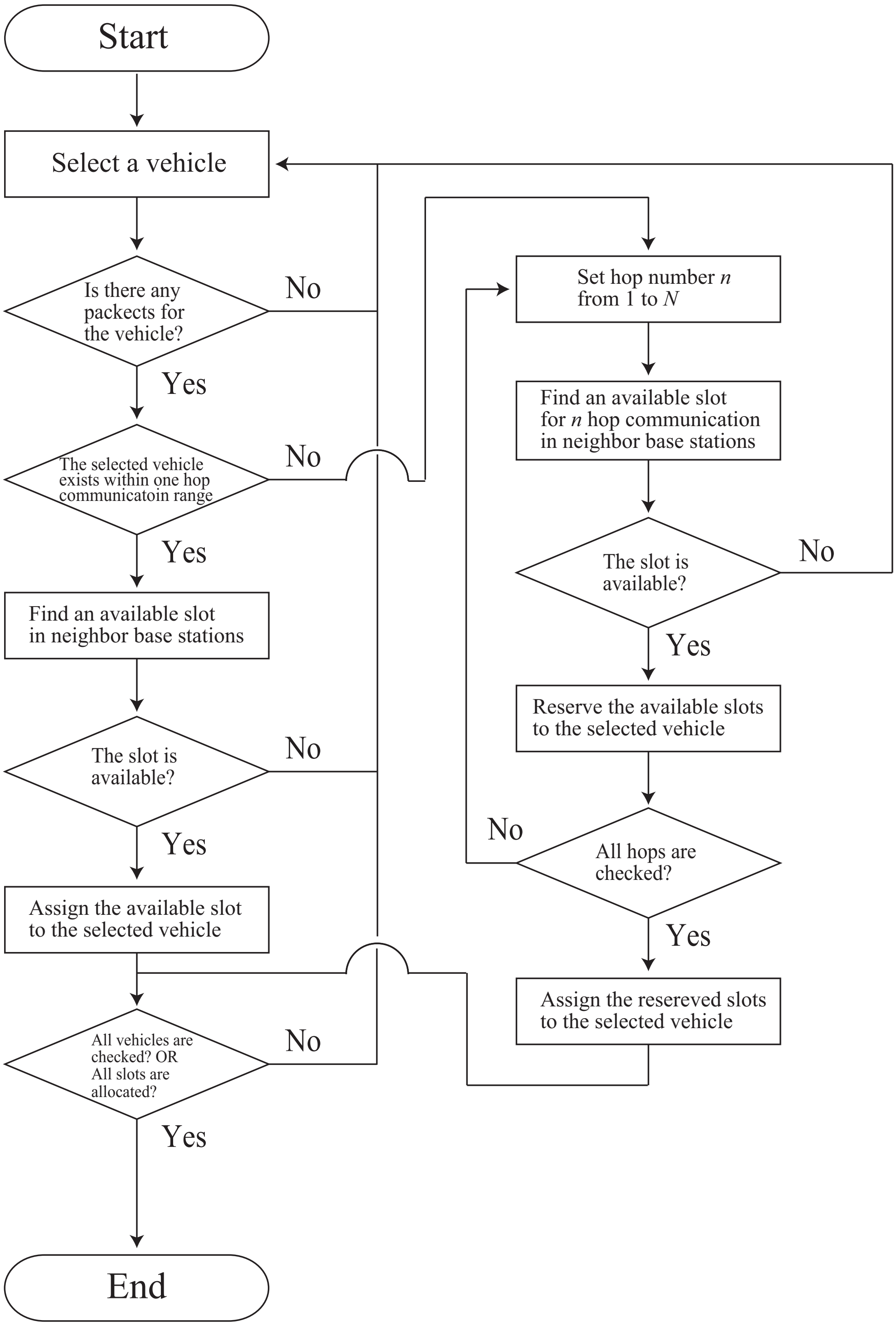

Fig. 4. Flowchart of slot allocation.

C. *Slot allocation algorithm*

Fig. 4 shows the flowchart of the slot allocation algorithm for the proposed scheme. The slot allocation algorithm is performed for each frame. Therefore, all slots in the frame will be assigned according to the following processes.

- The road side unit controller (RSUC) starts the allocation process when a new frame is started.
- The RSUC checks a number of vehicles in a service area. Then, it selects one vehicle.
- The RSUC checks a packet buffer to find packets for the

selected vehicle. It starts the slot allocation process for the selected vehicle when packets arrive in the packet buffer.

- The RSUC checks the location of the selected vehicle. It finds the nearest base station when the selected vehicle exists within the transmission range of RSU or it starts the allocation process for multi-hop communication when the selected vehicle exists in out of the transmission range of RSU.
- The RSUC checks the slot allocation status and allocates the free slot for the selected vehicle when the direct transmission from RSU is available. Then, it will select a next vehicle.
- The RSUC initializes the hop number n to find the free slots for the selected vehicle when the multi hop communication is required. Generally, we assume the maximum hop count N according to the distance between RSU.
- The RSUC checks the slot allocation status and reserve the free slot for nth hop communication. The 1st hop communication is used for transmission from RSUs. The later than the 2nd hop communication is used for forwarding packets from vehicles to vehicles.
- The RSUC checks the reservation status of the slots for the selected vehicle. It allocates the all slots when all of required slots are reserved.
- The RSUC ends the process when slots for all vehicles are checked or all slots are allocated.

TABLE II

SIMULATION PARAMETERS.

Simulation time	500 [s]
Simulation trial	100 [times]
Number of vehicles	100 [vehicles]
Number of communication vehicles	10 - 40 [vehicles]
Vehicle movement	Autonomous running model [13] Object speed : Random from 80, 90, 100, 110, 120[km/h] Average speed : 100 [km/h] Acceleration velocity : 0.3 [G] Breaking velocity(1st) : - 0.3 [G] Breaking velocity(2nd) : - 0.6 [G]
Initial vehicle position	Random
Number of lanes	2 [lanes]
Width of lane	3.5 [m]
Length of lanes	2000 [m]
Interval distance between RSU	100, 120, 140, 160 [m]
Communication device	IEEE 802.11p
Transmission rates	3 [Mbps]
Transmission power	50 [dB] at 1[m] from RSU
Channel frequency	5.9 [GHz]
Antenna gain	0 [dB]
Antenna type	Omni directional
Antenna height	8[m]
Propagation path loss model	Free Space
Wireless environment	Rayleigh fading
Guard interval	1.6 [μ s]
Access control	TDMA
Number of slots	24 [slots]
Packet length	1.5 [kbytes]
Maximum hops	2 [hops]
Application	FTP

III. NUMERICAL RESULTS

To evaluate the proposed system, we perform the computer simulations. In the simulations, we assume that 2,000 [m] straight highway with two lanes. Road side units are installed with 100 [m] interval for only RSU transmissions, and are installed with 120, 140, and 160 [m] intervals for RSU transmission and multi-hop transmission. Each RSU has an omni directional antenna whose height is 8 [m]. The transmission power is set to 50 [dB] at 1 [m] from RSU. Each vehicle is located randomly on the road, and selects the velocity from 80, 90, 100, 110, 120 [km/h] randomly. The average speed is set to 100 [km/h] The vehicle runs on the cruising lane principally. If there is no vehicle on the passing lane, the vehicle moves to the passing lane from the cruising lane to overtake a forward vehicle. After overtaking, the vehicle moves to the cruising lane when there is no vehicle on the cruising lane. As the wireless device, we employ the IEEE 802.11p device. The transmission speed is set to 3M [bps] and GI period is 1.6 [μ s]. In the simulations, we assume Rayleigh fading as the wireless channel model, and the assumed application is a file transfer application such as FTP.

Fig. 5 shows the throughput performance. From the results, we can find that the cooperative communication scheme with only RSU can achieve good throughput according to the increasing of vehicles. In the proposed scheme, neighbor RSUs of a vehicle transmit a same OFDM symbol simultaneously in a same slot. Therefore, the vehicle can receive the two OFDM signals through different routes, and obtain the diversity effect. As the results, the vehicle can continue to communicate with neighbor RSUs, and can achieve high throughput performance.

Additionally, The proposed range extension method can extend transmission range with almost similar throughput performance within 140m. The destination vehicle can receive many same OFDM signals from neighbor forwarder vehicles because RSUC reserves two slots for roadside-to-vehicle communication and vehicle-to-vehicle communication respec-

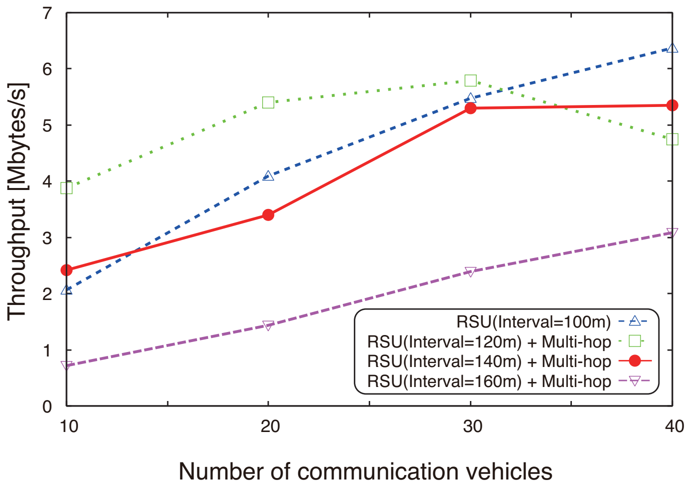

Fig. 5. Throughput performance.

tively. As the results, the vehicle can continue to communicate with RSUs even if it exists in the out of transmission range of the RSUs. Generally, the multi-hop transmission consumes a wireless resource due to multiple forwarding of packets. On the contrary, forwarder vehicles can transmit a same OFDM signal simultaneously in the proposed system. As the results, the proposed system can improve transmission error ratio without redundant wireless resource consumption.

IV. Conclusion

In this paper, we have proposed range extension mechanisms for roadside units in ITS networks. The feature of the proposed system is to employ cooperative OFDM transmission mechanisms. In the proposed scheme, neighbor RSUs of a vehicle transmit a same OFDM symbol simultaneously in a same slot. Additionally, neighbor vehicles also transmit the same OFDM symbol simultaneously in the same slot. Therefore, the vehicle can receive the some OFDM signals through different routes, and obtain the diversity effect. As the results, the vehicle can continue to communicate with neighbor RSUs, and can achieve high throughput performance. Additionally, The proposed range extension method can extend transmission range with high throughput performance. As the results, our scheme can extend transmission range without throughput degradation and redundant consumed wireless resource.

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