I2V Multi-Hop Broadcast Communication by TC-BF Method

Ryousuke Katsumata, Yasushi Yamao#1

#Advanced Wireless & Communication Research Center, the University of Electro-Communications

1yamao@ieee.org

***Abstract*— A novel Infrastructure to Vehicle (I2V) multi-hop broadcast communication technique is proposed. The proposed Time-Controlled Broadcast Forwarding (TC-BF) method enables more efficient information delivery on the road compared to the existing broadcast packet forwarding schemes such as flooding and Irresponsible Forwarding (IF) methods. Packet delivery rate (PDR) and forwarding efficiency of the proposed scheme are evaluated by computer simulation. It is concluded that the proposed TC-BF can cut unnecessary forwarding and keep high PDR with extended communication range.**

Keywords— I2V, broadcast, forwarding, congestion, 802.11p

I. Introduction

Vehicular communications are expected to be essential means in future Intelligent Transport System (ITS) not only for safe and automated driving, but also for achieving smooth and energy-efficient traffic [1]. Infrastructure to vehicle (I2V) communication plays an important role that it can provide cars with wider area information than that obtained by onboard sensors of each vehicle. At the same time, the road infrastructure can collect information from vehicles through the reverse (V2I) links. Although collected data are quite valuable as "big data," the coverage of I2V/V2I communication is limited near the roadside radio units.

In order to expand the service area of I2V/V2I communication, ad hoc forwarding between vehicles is effective [2][3]. In this paper, we focus on I2V communications, where most of applications are broadcast services such as road information delivery. In the broadcast services, packet delivery rate for all vehicles is the most important index. It depends on the location of vehicle and the evaluation should include location dependency.

The next important index is the forwarding efficiency. For example, if very common flooding method [4] is used, inefficient inter-vehicle forwarding with a short link distance will frequently happen. It increases the packet traffic density and causes packet congestion. In order to mitigate this issue, the Irresponsible Forwarding (IF) method has been proposed [5]. It determines forwarding probability depending on the communication distance. Although it can reduce the generation of inefficient forwarding, PDR performance is not always better than flooding method.

In this paper, we propose a Time-Controlled Broadcast Forwarding (TC-BF) method that employs a waiting time control scheme based on transmission distance. By comparing simulated performance of the proposed method with that of conventional flooding and IF methods, we show that higher PDR can be achieved in the extended coverage area, while saving the total number of forward packet transmission.

II. Multi-Hop Broadcast Communication and Existing Forwarding Methods

Fig. 1 shows a concept of multi-hop road to vehicle broadcast communication system. Information from road and traffic management systems is transmitted by Road Side Units (RSUs). We assume that the localized information is different among RSUs. Distance between two adjacent RSUs is basically set longer than their direct communication range. This is desirable to enable cost effective deployment of I2V services as well as mitigating interference between RSU's using the same radio channel. Ad hoc forwarding via vehicles extends the service area of RSUs as shown in the figure. If the inter-distance of RSUs is longer, ad hoc forwarding should be multi-hop. Therefore, reliable and efficient broadcast forwarding scheme is a key technique in this system.

In order to avoid packet collision among vehicles, current Vehicle to Vehicle (V2V) communication standards such as IEEE 802.11p [6] and ARIB STD-T109 [7] employ Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). The candidates of existing forwarding methods that can be employed in the CSMA/CA environment are flooding and IF.

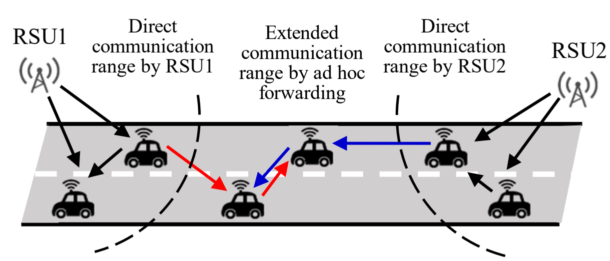

Fig. 1 Multi-hop road to vehicle broadcast communication.

A. Flooding

Flooding is a well-known technique to find a destination node in an ad hoc network [4]. For this goal, a route request packet is sent as flooding packet and the nodes that receive it forward the packet. This is repeated until it arrives at the destination, or the Time to Live (TTL) counter reaches zero.

The TTL is mandatory to avoid broadcast storm in flooding. In addition, if a node receives the same packet that has been forwarded by the node, the packet is discarded to prevent loop. Nevertheless, flooding is not always efficient as multi-hop forwarding method because so many duplicated packets are forwarded by short-distance neighbors.

B. Irresponsible Forwarding (IF)

The IF method handles the issue of flooding by introducing the "forwarding probability". The forwarding protocol of IF is shown in Fig. 2. After the inspection of TTL, the forwarding probability p is calculated based on the link distance of received packet. This is possible if every vehicle node knows its location by GPS and the location data is attached to the forwarded packet. The decision of forwarding or discarding the received packet follows the result of trial with success probability of p.

The p is calculated as;

$$p = \begin{cases} \exp\left\{-\dfrac{\rho_s(z-d)}{c}\right\} & (d < z) \\ 1 & (d \geq z) \end{cases} \tag{1}$$

where z is reliable communication range, d is the distance between sending and receiving nodes, ρ_s is vehicle traffic density. c is magnifier for p. Fig. 3 shows some example curves of p. Regardless of z and c, p decreases as d approaches to zero. By controlling the forwarding probability according to the link distance, short-distance forwarding can be reduced on the decision of receiving node.

III. Time-Controlled Broadcast Forwarding

Proposed forwarding method introduces priority control by differentiating transmission waiting time according to link distance. The proposed flowchart of TC-BF is shown in Fig. 4. After the inspection of TTL and self-duplication, a waiting time T_W is calculated based on the link distance of received packet. The waiting time T_W is given by

$$T_W = n\ W\ T_{max} \tag{2}$$

where n is a multiplier and T_{max} is the maximum back-off time determined by 802.11 CSMA/CA standard. W is calculated as

$$W = \frac{1}{p} = \begin{cases} \exp\left\{\frac{\rho_s(z-d)}{c}\right\} & (d < z) \\ 1 & (d \geq z) \end{cases} \tag{3}$$

Fig. 5 shows example curbs of W. As shown in the figure, W increases rapidly as d decreases.

Although both IF and TC-BF are based on the link distance control, significant difference between IF and TC-BF is that the IF differentiates the forwarding priority in probability, whereas TC-BF employs time order prioritization and prohibits duplicate forwarding by multiple nodes in the communication range. During the waiting time of T_W, the waiting node monitors other nodes whether they forward the same packet or not. If no other node forwards the same packet, the node can forward the packet as the first forwarder. This is important to suppress unnecessary second forwarding by the shorter distance node after the longer distance node has completed forwarding.

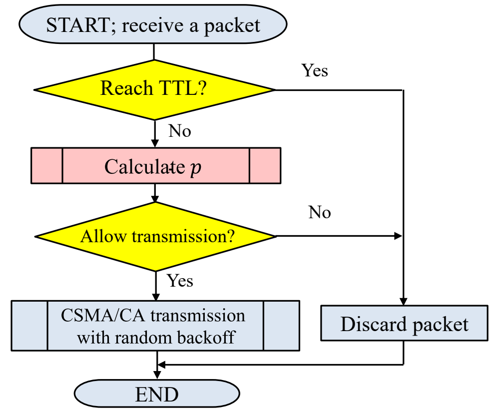

Fig.2 Flowchart of IF method.

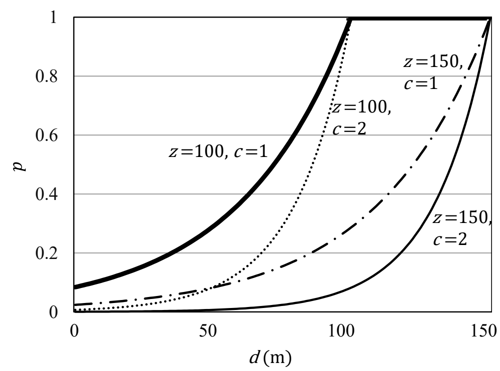

Fig.3 Forwarding probability p vs. link distance.

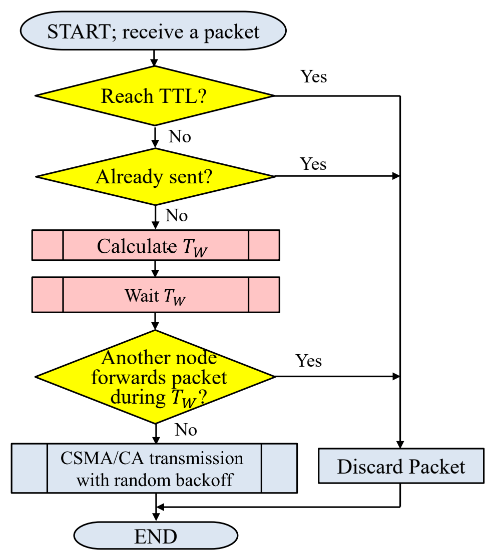

Fig. 4 Flowchart of proposed TC-BF.

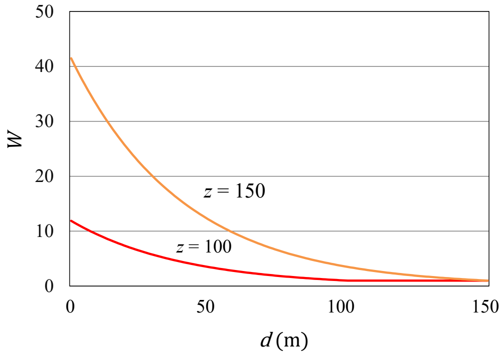

Fig.5 Waiting time coefficient W vs. link distance.

IV. Performance Evaluation

The performance of proposed TC-BF is evaluated by computer simulation using Scenargie network simulator [8]. Table I shows radio transmission parameters. Node layout is assumed as Fig. 6, in which vehicle nodes are indicated as VS_X. Node layout and forwarding parameters are listed in Table II. We suppose a straight load and all vehicles are on the load with inter-vehicle spacing of 40 m (normal traffic) or 20m (dense traffic). 50 or 100 vehicles are between two RSUs that are apart each other by 2 km. Vehicle speed is set 40km/h assuming urban city, which causes Rayleigh fading with the Maximum Doppler frequency of 28 Hz at 760 MHz.

Fig. 7 shows PDRs for V2V and V2I links that are calculated by the antenna heights and propagation model in Table I [9]. When the node distance is 1000 m, V2I PDR becomes zero. Therefore, communication areas of two RSUs do not overlap. For the area apart from the RS more than 500m, direct I2V link PDR rapidly decreases, then ad hoc forwarding is necessary to achieve high PDR. Since PDRs for V2V links gradually decrease when node distance is larger than 100 m, the reliable communication range z is set 100 or 150 m as the parameter of IF and TC-BF.

A. Performance for normal traffic

Since the performances for RSU1 and RSU2 have line symmetry, we only show the results for RSU1. Fig. 8 shows PDR of 50 vehicle nodes for Δx_{VS} = 40 m. Forwarding parameters z and c are set 100 m and one, respectively. PDRs of flooding and IF with the same z and c are also shown as references. For all forwarding methods, PDR is higher than 90 % when the distance from RSU1 is less than 1000 m. However, it decreases when the distance is more than 1000 m for flooding and IF method. On the other hand, TC-BF with n of 1.5 and 3 have the higher PDR in all distance. The PDR keeps more than 90 % until the distance of 1750 m.

Although required PDR depends on the service, important I2V information such as road information is repeatedly transmitted several times. In this case, the required PDR depends on the acceptable delay [10]. If the transmission repeat interval is 100 ms and acceptable average transmission delay is 40 ms, required PDR is around 80 % in the channel

TABLE I Radio Transmission Parameters.

Radio Frequency (Bandwidth)	760 MHz (10 MHz)
Propagation Model	ITU-R P.1411(LOS) + Rayleigh fading
Access Protocol	IEEE 802.11p (CSMA/CA)
Transmitting Power	18 dBm
Carrier Sense Threshold	-85 dBm
Receiver Noise Figure	11.8 dB
Contention Window Size	63
VS Antenna Height	1.5 m
RSU Antenna Height	6 m
Packet payload size	100 byte
Number of packet transmissions by RSU	100
Packet transmission interval	10 ms

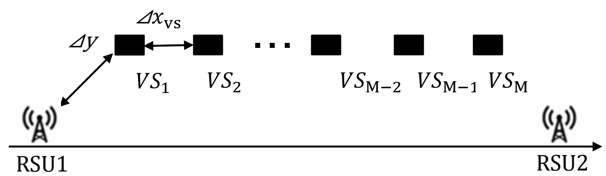

Fig. 6 Node layout for simulation.

TABLE II Node Layout and Forwarding Parameters.

Parameters	Variable	Value	
Number of vehicles	M	50	100
Inter-vehicle distance (m)	Δx_{VS}	40	20
Vehicle density (vehicles/km)	ρ_S	25	50
Distance between RSUs (m)	d_{I2I}	2000	
Distance between RSU and the nearest vehicle (m)	Δy	5	
Communication range for p (m)	z	100, 150	
Magnifier for p	c	1, 2	
Multiplier for adjusting T_{w}	n	1.5, 3, 5	
Maximum back-off time defined by CSMA/CA (ms)	T_{MAX}	864	
Time to live (hops)	TTL	8	

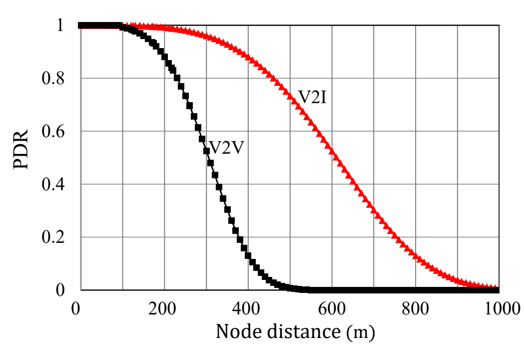

Fig. 7 Link PDR vs. node distance.

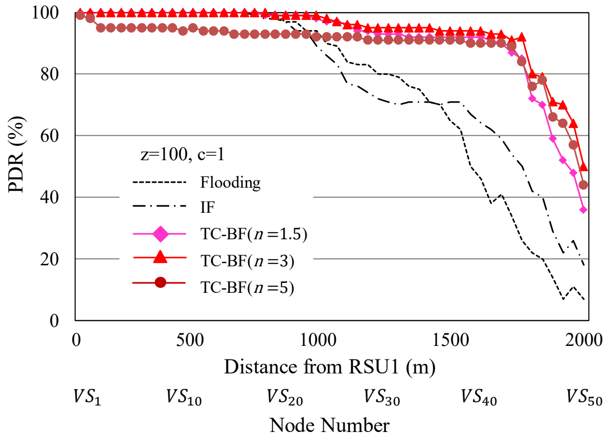

Fig. 8 PDR of 50 vehicle nodes for Δx_{vs}= 40 m.

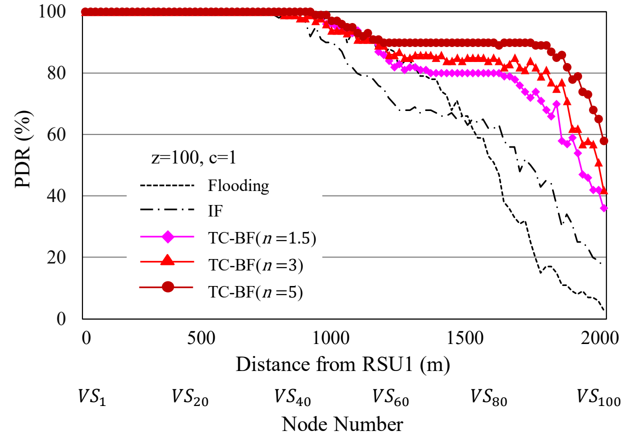

Fig. 10 PDR of 100 vehicle nodes for Δx_{vs}= 20 m.

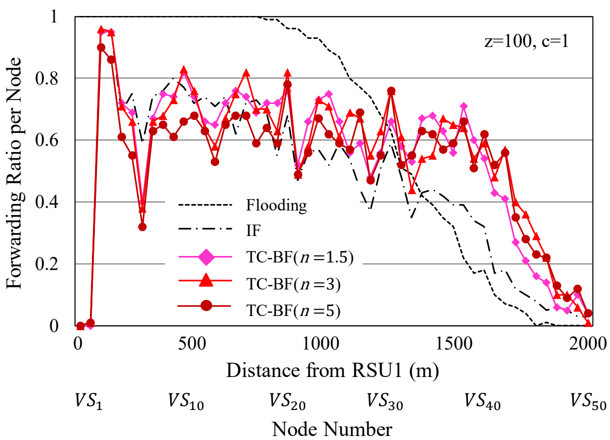

Fig. 9 Forwarding ratio of 50 vehicle nodes for Δx_{vs}= 40 m.

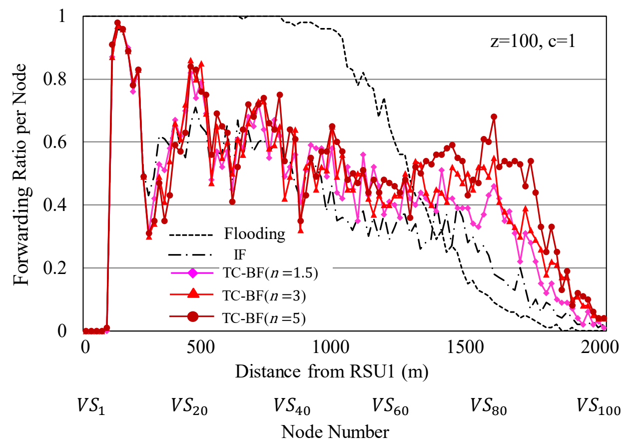

Fig. 11 Forwarding ratio of 100 vehicle nodes for Δx_{vs}= 20 m.

air-time occupancy ratio of 60%.

Fig. 9 shows the forwarding ratio of 50 vehicle nodes in the same condition as Fig. 8. The forwarding ratio of flooding is close to 1 when the distance from RSU1 is less than 750 m. However, it decreases rapidly when the distance is more than 750 m. This is because most of TTL numbers in forwarded packets reach eight at distance more than 750 m. On the other hand, the forwarding ratio of TC-BF is high at distance of around 150 and 200 m, however, it decreases to around 0.6 to 0.7 for the wide distance range from 250 to 1600 m. This is because TC-BF stops unnecessary forwarding and discards the received packet if it detects another node forwards the same packet.

Although the forwarding ratio of IF is close to that of TC-BF up to 900 m, it decreases after 900 m. PDR of IF also decreases after 900 m. The reason of forwarding ratio and PDR decrease after 900 m is that the number of arrived packets decreases after multi-hop IF forwarding. This loss depends on the forwarding probability of p. Since TC-BF does not employ forwarding probability, there is no forwarding loss and high PDR is obtained in wide area. Comparing Fig. 8 and 9, it is said that the forwarding ratio per node is the good measure for predicting PDR.

Fig. 10 and 11 show PDR and forwarding ratio for the dense traffic condition, respectively. The number of vehicles is doubled to100 by halving the inter-vehicle distance. Basic trends are similar to those of Fig. 8 and 9. However, n =5 provides the best PDR for TC-BF in this condition. It is understood that longer waiting time is required in higher node density condition where contention is more severe.

Comparing Fig. 11 with Fig. 9, forwarding ratios of IF and TC-BF in dense traffic are lower than those in normal traffic. Nevertheless, PDR values are similar. It is because total number of forwarded packets is sufficient to cover the area and keep the PDR.

Next, we discuss broadcast PDR and averaged forwarding ratio throughout the simulation area. Broadcast PDR (B-PDR) is the average of PDR for all vehicles (50 or 100 vehicles). Averaged forwarding ratio is the average value of forwarding ratio among all vehicles, which represents consumed network resource per node. Table III show the broadcast PDR and averaged forwarding ratio in normal traffic condition for various forwarding parameter set. As mentioned before, TC-IF with z = 100, c = 1, n = 3 achieves the best B-PDR. IF method can reduce forwarding ratio with little penalty of PDR from flooding.

TABLE III BROADCAST PDR AND FORWARDING RATIO.

Forwarding method (parameters)	Broadcast PDR	Averaged forwarding ratio
FL	75.6 %	0.648
IF(z =100, c =1)	78.7 %	0.469
IF(z =100, c =2)	76.4 %	0.420
IF(z =150, c =1)	72.5 %	0.286
IF(z =150, c =2)	73.4 %	0.261
TC-IF(z =100, c =1, n =3)	94.0 %	0.557
TC-IF(z =100, c =2, n =3)	93.7 %	0.5
TC-IF(z =150, c =1, n =3)	84.4 %	0.329
TC-IF(z =150, c =2, n =3)	77.6 %	0.271

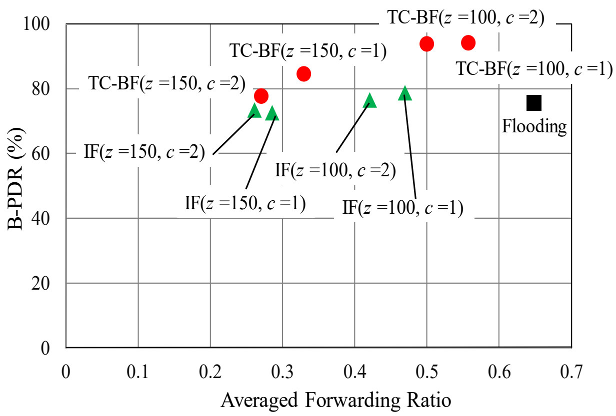

Fig. 12 Relationship of broadcast PDR and forwarding ratio.

Fig. 12 shows the relationship of broadcast PDR and forwarding ratio for three methods with various parameters in Table III. The proposed TC-BF can achieve the highest B-PDR with the reduced network resource. Therefore, it is promising as the forwarding protocol for I2V multi-hop broadcast communications.

IV. CONCLUSION

A novel I2V multi-hop broadcast communication technique is proposed. The proposed Time-Controlled Broadcast Forwarding (TC-BF) method enables more efficient information delivery on the road compared to the existing broadcast packet forwarding methods such as flooding and Irresponsible Forwarding. PDR and forwarding efficiency of the proposed scheme are evaluated by using computer simulations. It is concluded that the proposed TC-BF can reduce unnecessary forwarding and achieve high PDR with extended communication range.

Acknowledgement

Part of this work is supported by JSPS KAKENHI Grant Number 16H02344.

REFERENCES

[1] E. Uhlemann, “Introducing connected vehicles,” IEEE Vehicular Technology Magazine, vol. 10, no. 1, pp. 23-31, Feb. 2015.

[2] W. Chen, et al., “Ad hoc peer-to-peer network architecture for vehicle safety communications,” *IEEE Communication Magazine*, Vol.43, pp.100-107, Apr. 2005.

[3] R. Atallah, M. Khabbaz, C. Assi, “Multihop V2I Communications: A Feasibility Study, Modeling, and Performance Analysis," Proc. IEEE Transactions on Vehicular Technology, pp. 2801-2810, June. 2016.

[4] C. Perkins and E. Royer, “Ad Hoc On-demand Distance Vector Routing,” Proceedings of the 2nd Annual IEEE International Workshop on Mobile Computing System and Applications, pp. 90-100, Feb. 1999.

[5] S. Panichpapiboon, G. Ferrari, “Irresponsible forwarding,” Proc. Intelligent Transport System Telecommunication (ITST), pp. 311–316, Oct. 2008.

[6] IEEE 802.11p, version 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, 2010.

[7] ARIB STD-T109, “700 MHz Band Intelligent Transport Systems,” English translation, STD-T109-v1.2, Dec. 2013.

[8] https://www.spacetime-eng.com/en/

[9] Rec. ITU-R P.1411-6, “Propagation data and prediction methods for the planning of short-range outdoor radio communication systems and radio local area networks in the frequency range 300 MHz to 100 GHz,” 2012.

[10] L. T. Trien and Y. Yamao, “Information Delivery Delay Reduction by Relay-Assisted Broadcast Transmission for ITS V2V communications,” IEICE Trans. Fundamentals, Vol. E101-A/ 9, pp.1290-1297, Sept. 2018.