Fast Alarm Message Broadcasting in Vehicular Ad Hoc Networks (VANETs)

Pakornsiri Akkhara pakornsiri@cnl.k.u-tokyo.ac.jp
Yuji Sekiya sekiya@wide.ad.jp
Yasushi Wakahara wakahara@nc.u-tokyo.ac.jp

Department of Frontier Informatics, Graduate School of Frontier Sciences, The University of Tokyo

Information Technology Center, 2-11-16 Yayoi, Bunkyo-ku,Tokyo 113-8658

Abstract – Presently, as a part of Intelligent Transport System (ITS), many applications in Vehicular Ad Hoc Networks (VANETs) attract a lot of research attention from academic community and industry, especially car industry. One important feature of the applications in VANETs is the ability to extend line-of-sight of the drivers and exploit on-board devices in order to improve the safety and efficiency of road traffic. However, due to mobility constraints, driver behavior and high mobility, characteristics of VANETs are dramatically different from those of general Mobile Ad Hoc Networks (MANETs). Moreover, the broadcasting approaches used in MANETs cannot be properly applied to the safety application in VANETs. Thus, we propose new broadcasting approaches in VANETs with respect to alarm message dissemination scenarios. This paper is focusing on the broadcasting methods which provide an efficient dissemination of alarm message in the aspect of broadcasting time. Related works, basic idea of the proposed methods, their evaluation results and some directions of the further researches are also discussed.

Keyword – alarm message, broadcasting method, vehicular ad hoc networks, multiple interfaces, multiple channels

1. Introduction

There has been increasing interest in the exploitation of advanced information technology in transportation systems for providing improved comfort and additional safety in driving. Existing ITS deployments mainly rely on networks in the roadside infrastructure or Road-Vehicle Communication (RVC). In Japan, one example of this system is Advanced Cruise-Assist Highway System, referred to as ASH. The main target of this system is to prevent collision with forward obstacles, e.g. a vehicle that has stopped at some blind spots such as at a curve on a highway, by using some sensors deployed along the highway. After detecting the obstacles, these sensors will notify the vehicles, which are equipped with Vehicle Information and Communication System (VICS), one kind of navigation systems widely used in Japan, in their transmission range. While such systems provide substantial benefits, their deployment is very costly, which prevents them from reaching their full potential. Due to this problem, there is a trend of equipping vehicles with the communication technology allowing the vehicles to contact with other equipped vehicles in their vicinity, which is referred to as Inter-Vehicle Communication (IVC). IVC has two key advantages: low latency due to direct communication among vehicles and broader coverage beyond areas where roadside equipments have been deployed.

The specific characteristics of VANETs allow the development of the following two most relevant category applications [1]:

1. Comfort application: This category tries to improve comfort and traffic efficiency and/or optimize the route from a source to its destination. Traffic, weather, gas station or restaurant location and price information system, and interactive communication such as the Internet access or music download are some examples of this application.

2. Safety application: The purpose of this category is to increase the safety of driver and passengers by exchanging safety relevant information. Examples of the applications in this category are emergency warning system, lane-changing assistant, intersection coordination, traffic sign/signal violation warning, and road-condition warning.

Although much effort is needed in order to make these applications come reality, methods to disseminate various messages seem to be the most important challenge. Moreover, the huge social and economical cost related to road accidents makes research of proactive safety services a task of primary importance in the ITS. A fundamental application for providing this safety service is the fast and reliable propagation of alarm message or warning message to upcoming vehicles in case of hazardous driving situations such as accident and dangerous road surface conditions.

This paper proposes some methods that can reduce the broadcasting time required in the alarm message or warning message propagation by utilizing multiple channels available in e.g. the IEEE 802.11 standard as well as the GPS system. The rest of this paper is organized as follows: characteristics and definition of the alarm message broadcasting are discussed in section 2. Section 3 describes the existing broadcast protocols as the related works. Characteristics of VANETs and the assumptions for this research are given in section 4. Two proposed methods for the alarm message broadcasting and their evaluation are discussed in section 5 and section 6, respectively. Finally we conclude this paper with some observations on further researches.

2. Alarm Message Broadcasting

Basically, blocking line-of-sight by the leading vehicles is one of the main factors of an accident. In case there is a collision accident on the road, if the drivers of the vehicles that are moving toward the accident place cannot make a decision on the suitable actions in time, it can lead to a chain collision or a secondary accident. However, it is possible to decrease the risk of such an accident by providing the necessary information about the accident that just happened to those vehicles and their drivers. The alarm message broadcasting application can be applied to the situation of such an accident as shown in Figure 1.

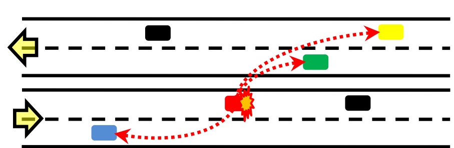

Figure 1: Alarm message broadcasting application

According to Figure 1, when the vehicle located in the middle of the figure has an accident and identifies itself as crashed by using some sensors that detect events like airbag ignition, this vehicle will start to broadcast the information about its accident to nearby vehicles. It will be possible for the drivers of other vehicles to take suitable actions to avoid the secondary accident by using this information. However, in order to guarantee safety, the following two factors have to be considered.

- Maximum allowed speed of the vehicle is about 100 km/hr. (according to the country regulation)
- Human reaction time is 0.3 second, but 0.1 second will be used in acquisition of the information for various sensors and 0.1 second for processing the information. Therefore, at most only 0.1 second is left for vehicle-to-vehicle communication.

Based on these two factors, this alarm information is judged to have a very short useful lifetime. Thus, the information about the accident should be destined with low delay and high reliability.

3. Related Works

Among many broadcast protocols that have been proposed, "Flooding" seems to be the simplest. However, this protocol has some problems such as high collision or contention probability and high data redundancy because each node receiving the message has an obligation to immediately rebroadcast the message to all of its neighbors. This can result in inefficiency in terms of radio resource usage, promptness of the message delivery and reliability, which has been referred to as "Broadcast Storm Problem" [1]. To resolve these problems, several broadcast protocols have been proposed as follows:

Probability Based Method [2, 3]: In the probability based method, each node decides to rebroadcast the message with some probability in order to decrease data redundancy and collision. Although the required broadcasting time is short, it still cannot solve the entire redundancy problem. Moreover, in the congested network, its delivery ratio is rather low.

Area Based Method: In this method, each node rebroadcasts the message by considering the coverage area of the transmission range. In the *Distance Based Scheme* [1, 4], when a node receives the message, the node compares the distance between itself and each of its neighbor nodes that have previously rebroadcasted the same message and the node will not rebroadcast the message if the rebroadcasting is judged redundant based on the comparison results. *Location Based Scheme* [5, 6, 7, 8] uses more precise estimation of the coverage area of the transmission range by making use of the means to determine its own location, e.g. GPS. Although these methods are able to reduce most of the redundant rebroadcasting, they do not take into account a tight time delay constraint which is one of the main important factors in the alarm message broadcasting.

Cluster Based Method [9]: In this method, the related nodes are structured into some clusters and the task for rebroadcasting the message is assigned to only the cluster head node of each cluster. Although this method can work efficiently, the cost to create and maintain the cluster structure is rather high.

Topology Based Method: *Topology based methods* are based on complete knowledge of the network topology which is obtained by exchanging control messages. However, to obtain this kind of knowledge induces large load of traffic in the network, which is not appropriate in the VANETs.

Although the above broadcast protocols are the candidates for the alarm message broadcasting application, they mainly consider on solving the Broadcast Strom Problem. In addition, these protocols use only a single frequency channel and make no use of the rest spectrum that are actually available e.g. in the IEEE 802.11 standard.

According to the objective of safety application, target about the delay of alarm message broadcasting is quite strict as mentioned in section 2. Thus, the approaches with effectively shortened forwarding latency, such as cut-through forwarding method, are required. The cut-through forwarding method has been used in the packet switch technology to allow frame (or packet) forwarding before the whole frame is received [13]. However, the cut-through forwarding method has not been considered for wireless networks until recently because, in general, forwarding latency was not the primary concern for the traffic in the wireless networks. However, this is not the case for safety application. One of the broadcast protocols that utilize the method like cut-through forwarding has been proposed in [12]. In this broadcasting protocol, each node that received the message has an obligation to rebroadcast the message. Thus, the Multiple Access Interference (MAI) increases in accordance with increase in the number of simultaneously rebroadcasting nodes. Moreover, the wide bandwidth is required for the proposed CDMA, although the bandwidth is generally limited in wireless technology.

To achieve the targets of safety application, we propose two new alarm message broadcasting methods that utilize multiple channels available in IEEE 802.11 standard as well as GPS function. Moreover, high priority to rebroadcast the message is given to some specific node to avoid the interference problem and the multiple channels are utilized effectively in the proposed methods.

4. The VANETs Characteristics and Assumptions

This paper focuses on the alarm message broadcasting in the highway scenario where there are a number of vehicles moving towards both directions of the highway with possibly multiple lanes. In this scenario, the alarm message will be destined to many or all of the vehicles located away from the accident vehicle (source node) in less than some predetermined coverage distance. In other words, the position information will be used as an attribute to limit the broadcasting process. The highway is assumed to be rectilinear and the destined radio wave is assumed to be tolerant to the local variations in environment along the highway e.g. buildings or obstacles on the road.

All the vehicles are assumed to be equipped with sensing, calculation, communication capabilities and Global Positioning System function (GPS) so that each of the vehicles can sense an accident, gather information about the accident, destine the alarm message to the nearby vehicles, and determine its own position relatively to the other vehicles. Moreover, each vehicle is equipped with at least two half-duplex transceivers based on e.g. IEEE 802.11 standard and a dedicated channel is assigned to each transceiver. With this assignment, the vehicle can transmit a message on one channel and listen to a different message on the other channel at the same time.

5. Proposed Methods for the Alarm Message Broadcasting

In this section, the targets to be achieved are clearly presented and the basic idea of the two proposed methods for the alarm message broadcasting application is described. These two proposed methods are different from each other in timing when the vehicles can start to rebroadcast the alarm message.

5.1. Targets to be achieved

Efficiency of the alarm message broadcasting methods can be measured in general by whether the following targets can be achieved or not.

- According to the aforementioned human reaction time, the time required for all the vehicles located in the predetermined coverage distance of the source vehicle to receive the alarm message completely is shorter than 0.1 second.

- The alarm message should be broadcasted in a multi-hop manner and the number of the vehicles that newly receive the alarm message in each hop should be as large as possible.
- The broadcasting method should be able to reduce the collision of the alarm messages rebroadcasted in each hop.

5.2. Proposed Methods

5.2.1. Proposed Method 1

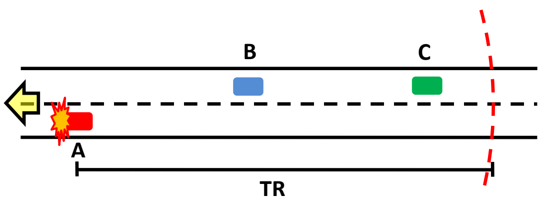

Figure 2: Alarm message broadcasting scenario

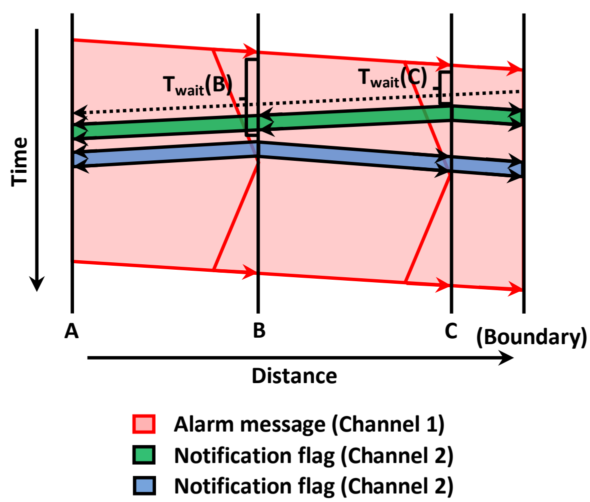

Figure 3: Basic idea of the proposed method 1

Basic Idea

It is assumed that each vehicle is equipped with two transceivers and a dedicated channel is assigned to each transceiver e.g. channel 1 is assigned to transceiver 1 and channel 2 is assigned to transceiver 2 as described in section 4. According to the targets that have to be achieved as described in section 5.1, the basic idea for the proposed method 1 is to give high priority to the furthest vehicle in the transmission range from the source vehicle to rebroadcast the alarm message after receiving it completely. This priority control leads to the avoidance of collision of rebroadcasted alarm messages by the vehicles in the transmission range of the source vehicle by suppressing the rebroadcasting of vehicles with low priority and by making only the vehicle with high priority to rebroadcast the message.

The scenario in Figure 2 will be used to further describe and illustrate the basic idea of the proposed method. In Figure 2, vehicle *A* is assumed to have just had an accident, and vehicles *B* and *C* are assumed to be in the transmission range of the transceiver equipped on *A*. After *A* recognizes an accident event based on the information received from various sensors, *A* acts as the source vehicle and starts to broadcast the alarm message on channel 1 to notify nearby vehicles including *B* and *C* about the accident according to the time sequence shown in Figure 3.

After recognizing that the received message is the alarm message, *B* and *C* calculate their own waiting times $T_{wait}(B)$ and $T_{wait}(C)$, respectively. The waiting time is used by each vehicle to make decision on whether it should responsible for rebroadcasting the alarm message to next hop or not. Although the details of waiting time calculation are described later in subsection 5.2.3, the waiting time is larger for vehicles that are closer to the source vehicle. When the waiting time of a vehicle expires and it did not receive any notification flags from any other following vehicles, it starts to broadcast its own notification flag on channel 2 to notify the other vehicles that it will be responsible for rebroadcasting the alarm message in the following hop. On the other hand, if a vehicle receives a notification flag, then the vehicle decides not to rebroadcast the message, since the vehicle that has transmitted the notification flag should be responsible for the rebroadcasting of the message. In the following hop, the above rebroadcasting vehicle becomes a source vehicle and the same processing for rebroadcasting is performed. This rebroadcasting process is repeated in some more hops, resulting in the dissemination of the alarm message to cover all the relevant vehicles in the predetermined coverage distance from the original source vehicle *A*.

5.2.2. Proposed Method 2

Basic Idea

By reducing the probability of collision in the alarm message broadcasting, proposed method 1 can shorten the broadcasting time, which is defined as the cumulative time required for completing multi-hop broadcasting process of alarm message to cover all the vehicles in the predetermined coverage distance from the source vehicle. This subsection proposes a new method to further shorten the broadcasting time. The proposed method is characterized by the overlap operation of alarm message transmission under the assumption that each vehicle is equipped with at least two transceivers and that different channels are assigned to the transceivers in the individual hops to avoid the collision in broadcasting. For overlap broadcasting for more than 2 hops, at least 3 different channels are required for efficient transmission without interference.

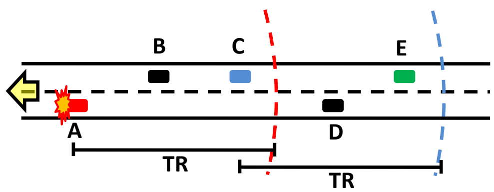

Figure 4: Alarm message broadcasting scenario

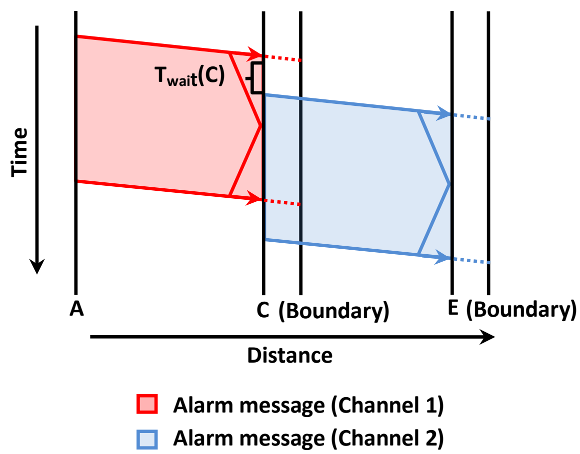

Figure 5: Basic idea of the proposed method with overlap operation

The scenario in Figure 4 will be used to further describe and illustrate the basic idea of the proposed method 2. In Figure 4, vehicle *A* is assumed to have just had an accident, and vehicles *B*, *C* and *D*, *E* are assumed to be in the transmission range of a transceiver equipped on *A* and that of a transceiver equipped on *C* respectively. As described in the proposed method 1, after *A* recognizes an accident event based on the information received from various sensors, *A* will start to broadcast an alarm message. After recognizing that the received message is the alarm message, *B* and *C* calculate their own waiting times $T_{wait}(B)$ and $T_{wait}(C)$, respectively. Different from the proposed method 1, notification flags are not used and the alarm message itself is instead rebroadcasted while the alarm message is under reception. In Figure 5, the furthest vehicle *C* will have priority to rebroadcast the alarm message and start to rebroadcast the alarm message just after the expiration of its waiting time by utilizing a channel which differs from the one used by the source vehicle *A* in order to avoid the interference of the messages and to reduce the broadcasting time.

Thus, vehicle *C* becomes a source vehicle in the next hop to broadcast the alarm message and then in almost the same manner, only vehicle *E* will have high priority to rebroadcast the message. Such rebroadcasting will be repeated to cover all the vehicles in the predetermined coverage distance from the original source node *A*.

5.2.3. Waiting Time Calculation

For the proposed method 1, the waiting time calculation is based on the basic idea that the notification flag sent by the furthest vehicle or the vehicle, which should be responsible for rebroadcasting the alarm message, should arrive at the vehicles located closer to the source vehicle before they completely receive the alarm message from the source vehicle. This basic idea is elaborated as follows.

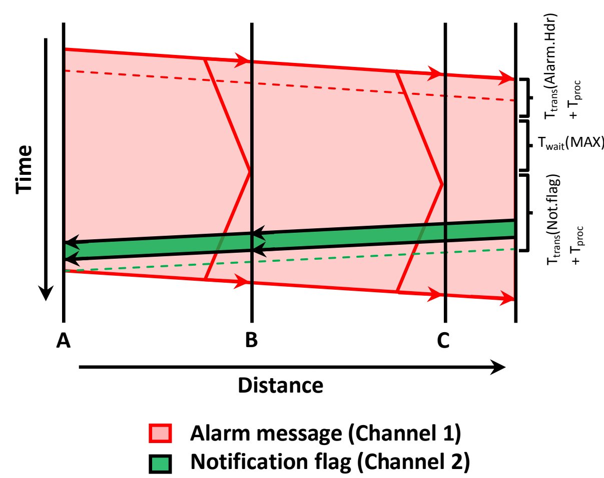

Figure 6: Basic idea of waiting time calculation

In Figure 6, it is assumed that there is a vehicle located at the boundary of the transmission range of *A* and this assumed vehicle starts to broadcast the notification flag on channel 2 after recognizes that the message it has started to receive is the alarm message as mentioned in the Basic Idea subsection of the proposed method 1. The notification flag will be received by all the vehicles between the assumed vehicle and the source vehicle. However, all these intermediate vehicles will rebroadcast the alarm message on the instant they finish receiving the message completely and this almost simultaneous multi-broadcasting will lead to high collision. In order to avoid such collision, the notification flag is expected to be received by these intermediate vehicles before their complete reception of the alarm message. Thus waiting time should be defined so that the notification flag should arrive at *A* before the completion of the sending of the alarm message by *A*. Furthermore, in the designing of the waiting time, the time required for the transmission, propagation and processing of notification flag and alarm message should be taken into account and the waiting time should become larger for an intermediate vehicle closer to the source vehicle.

This basic idea on the waiting time is also applied to the proposed method 2. However, the header of the alarm message itself is used for the same purpose as that of the notification flag in proposed method 1.

In general, the waiting time for vehicle *X* located D_{SX} away from the source vehicle can be represented by the following equation:

$$T_{wait}(X) = \frac{(TR - D_{SX})}{TR} \times T_{wait}(MAX) \qquad \textbf{(1)}$$

$$T_{wait}(MAX) = T_{trans}(Alarm) - \left[T_{trans}(Alarm.Hdr) + T_{proc} + T_{trans}(Notf.flag)^{*1} + (2x\frac{TR}{V_{prop}}) \right] \qquad \textbf{(2)}$$

where D_{SX} = distance between vehicle X and the source vehicle S (m)
TR = transmission range (m)
V_{prop} = radio wave propagation speed (m/s)
T_{proc} = processing time required for recognizing and sending the message (s)
$T_{trans}(M)$= transmission time of message *M* (s)

*1: for the waiting time calculation in the proposed method 2, T_{trans}(Notf.flag) will be replaced with T_{trans}(Alarm.Hdr)

By utilizing equation (1) and (2), the further the vehicle is located from the source vehicle, the smaller its waiting becomes and the earlier it has a chance to access the channel to send its message. Even though it is possible to calculate the waiting time by other methods, the trade-off between the broadcasting time and the number of rebroadcasting vehicles has to be taken into account. This trade-off is discussed in section 6.

5.3. Frame Format

Alarm message/Notification flag Format

Although a message can be forwarded at various layers in general, message forwarding at a lower layer achieves shorter forwarding delay than that at a higher layer. We propose therefore that the alarm message is forwarded by the MAC protocol in the link layer without using the functions in network and transport layers.

Type	Position X	Position Y	Position Z	Data
Alarm/Notf	X	Y	Z	Alarm Info.
8 bits	32 bits	32 bits	32 bits	1412 bytes

- *Type:* Type of the message (Alarm message/ Notification flag / Others)
- *Position X,Y,Z:* Position of the source vehicle represented by Floating Point 32 bits
- *Data:* Various information about the accident

Figure 7: Alarm message data format

The frame format by the proposed methods 1 and 2 is shown in Figure 7 and is summarized as follows.

- Message header size: 30 bytes (fixed)
- Notification flag frame size: 43 bytes
- Alarm message frame size: 1,425 bytes

Theoretically, the maximum frame size that is allowed through the wireless link is equal to 2,346 bytes according to the IEEE 802.11 standard specifications. Because the alarm message frame size assumed in this paper is less than this possible maximum frame size, each of the alarm message and the Notification flag can be sent by using only single frame.

Alarm Message Data Field

The data field of the alarm message mentioned above contains such information as TTL (Time to Live) which is used to limit the maximum distance or the number of hops for the rebroadcasting the alarm message. Apart from the TTL information, the data field will contain the accident information itself which could be obtained from various kinds of sensors equipped on the vehicle. Some examples of the information that can be received from the sensors in addition to the position of the accident are as follows:

- Accident time
- Characteristic of the vehicle at the accident time
- Road conditions
- Safety distance from the accident place
- Help request (ambulance, police, etc.)
- Pictures around the accident place

If it is not possible to send all of the information in one frame, only the primary information that is essential for warning about the accident is broadcasted in the first frame and other supplementary information is broadcast in the following frame(s).

6. Evaluation results

Average broadcasting time for both proposed methods and a conventional method of pure flooding is comparatively evaluated under NS-2 simulation environment. Schematic functional diagram of each vehicle or mobile node of the proposed methods is shown in Figure 8, where the function of the node is extended in NS-2 to support multiple interfaces and multiple channels. As shown in the figure, each node has as many chains of functional entities as its network interfaces. As mentioned in the proposed method subsections, each vehicle must be equipped with at least 2 interfaces. For the proposed method 1, one interface assigned to one channel is used for sending an alarm message while the other interface assigned to the other channel is for sending a notification flag. In order to enable cut-through like forwarding in the proposed method 2, one interface is assigned with one channel while the other interfaces are assigned with different channels.

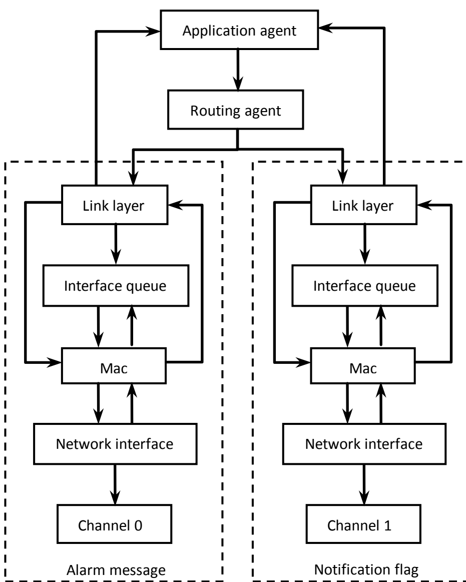

Figure 8: Schematic functional diagram of a mobile node for the proposed method in NS-2 environment

Figure 9 depicts the simulation scenario of a straight highway with one lane where the distance between any two consecutive vehicles is randomly chosen from the values between 20 m and 40 m, which is the result of the consideration of the usual multiple-lane in highways. In this scenario, the alarm message will be rebroadcasted in the multi-hop manner until it becomes possible to cover the predetermined coverage distance from the source vehicle. In the simulation, the time required for a vehicle which is located furthest from the source vehicle within the coverage distance to receive the alarm message completely is evaluated for various transmission range values. The simulation parameters and their values are shown in Table 1.

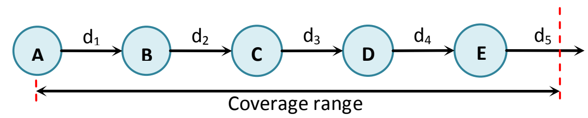

Figure 9: Simulation topology

Table 1: Simulation parameters in NS-2 environment

Simulation parameters	Value
Data speed	1 Mbs
Radio propagation speed	3 x 10^8 m/s
Propagation model	Two-ray ground
Antenna type	Omni antenna
Alarm message size	1425 bytes
Notification flag size	43 bytes
Transmission range	250 m
Speed of vehicle	20-27 m/s
No. of channels	1 channel (Flooding method), 2 channels (Proposed method 1), 3 channels (Proposed method 2)
Coverage distance	1000 m, 3000 m
No. of repetitions for simulation	100 times

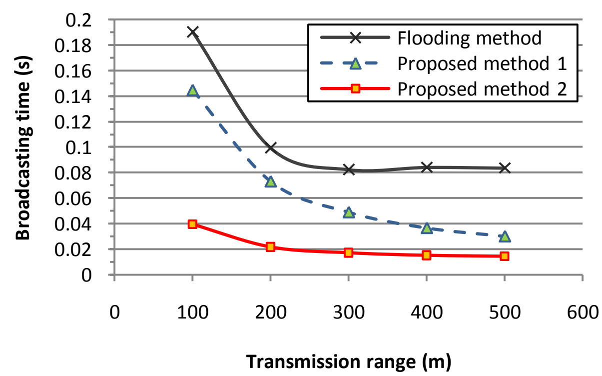

Figure 10: Average broadcasting time for coverage distance 1000 m

As shown in Figure 10, by reducing the possibility of the collision in the alarm message rebroadcasting and giving high priority to the furthest vehicle in the transmission range from the source vehicle to rebroadcast the alarm message, both of the proposed methods can achieve the broadcasting time shorter than the pure flooding method.

Due to the decrease in the number of hops in the alarm message rebroadcasting to cover the coverage distance, the average broadcasting time of the proposed methods decreases as the transmission range increases. The proposed method 1 can achieve shorter than 0.1 second broadcasting time for the transmission range of over 200 m. However, the proposed method 2 can achieve shorter than 0.1 second broadcasting time for every transmission range in the evaluation. The average broadcasting time of the proposed methods for the coverage distance 3000 m is about 3 times longer than the case where the coverage distance is 1000 m for various transmission ranges, though they are not illustrated graphically in this paper.

In addition to the transmission range, size of the alarm message and the number of interfaces or channels that can be utilized have a strong influence on the average broadcasting time of the proposed methods. However, mobility speed, which is one of the main characteristics of VANETs, does not have a significant influence on the efficiency of the proposed methods for the coverage distance used in the above evaluation. The influence of the alarm message size and the mobility is shown in Figure 11 and 12, respectively.

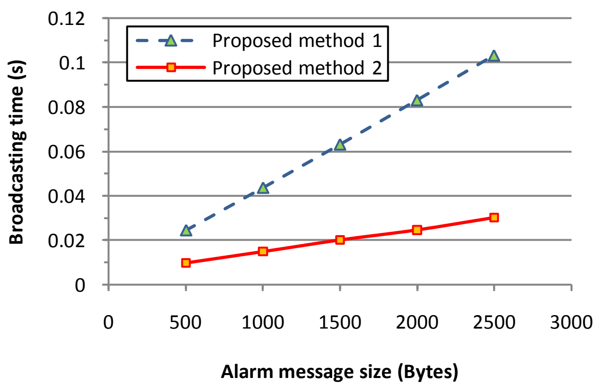

Figure 11: Influence of the alarm message size on the average broadcasting time for coverage distance 1000 m

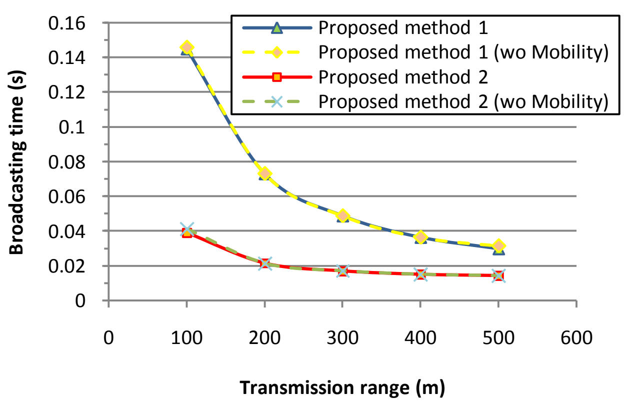

Figure 12: Influence of mobility on the average broadcasting time for coverage distance 1000 m

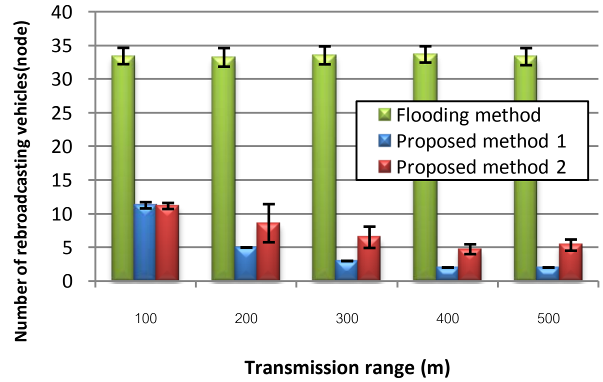

Figure 13: Number of rebroadcasting vehicles and its standard deviation for coverage distance 1000 m

Figure 13 illustrates the total number of vehicles which are located in the coverage distance 1000 m and rebroadcasted the alarm message. By giving priority control in the alarm message rebroadcasting, the number of rebroadcasting vehicles of the proposed methods is significantly smaller than that of the pure flooding method which obliges every vehicle to rebroadcast the alarm message.

In the proposed method 1, the notification flag is utilized and rebroadcasting of the alarm message is started after its complete reception from the source vehicle. As mentioned in section 5, the vehicle that is located furthest from the source vehicle within its transmission range will start to broadcast the notification flag and becomes responsible for rebroadcasting the alarm message. When leading vehicle receives this notification flag before the complete reception of the alarm message from the source vehicle, the vehicle will not rebroadcast the alarm message. In other words, the duration of time allowed for making a decision on whether to rebroadcast the alarm message is equal to the transmission time of the alarm message.

In the proposed method 2, the header of alarm message is used to notify the leading vehicles of no need to rebroadcast the alarm message. Thus, the time allowed for a vehicle to make a decision on whether to rebroadcast the alarm message is equal to the difference between the waiting time of its own and that of the alarm message rebroadcasting vehicle. In other words, if the time required for the header of the alarm message to be sent from the rebroadcasting vehicle to one leading vehicle is larger than the difference between the waiting time of that leading vehicle and that of the rebroadcasting vehicle, the header of the alarm message will arrive at the leading vehicle after the expiration of the waiting time of that leading vehicle. Thus, that leading vehicle will know that there is a further vehicle which should be responsible for rebroadcasting the alarm message after the leading vehicle started to rebroadcast the alarm message.

Because the proposed method 1 allows the leading node more time for making a decision on rebroadcasting the alarm message than the proposed method 2, the proposed method 1 can achieve smaller number of rebroadcasting vehicles than the proposed method 2.

Moreover, as mentioned in Waiting Time Calculation subsection, the approach used in waiting time calculation also has an influence on the trade-off between broadcasting time and the number of rebroadcasting vehicles. In other words, there is the possibility that the longer becomes the maximum waiting time used in the waiting time calculation, the larger becomes the difference of the waiting time between two consecutive vehicles and the longer becomes the duration of time allowed for the nodes to determine whether to rebroadcast the alarm message. Consequently, the possibility that the leading vehicles will receive the notification flag in the proposed method 1 and the header of the alarm message in the proposed method 2 from their following vehicle, which is responsible for rebroadcasting the alarm message, before the expiration of their waiting time and do not rebroadcast the alarm message will increase, resulting in smaller number of rebroadcasting vehicles. However, the broadcasting time increases as the waiting time increases. This result will be reverse for the situation with the shorter waiting time.

7. Applicability of Proposed Methods to Road with Curve

Until the previous section, the proposed methods have been studied only in the straight highway scenario. If the proposed methods are applied to a curve scenario, there is some possibility that some vehicles closer to the source vehicle cannot receive the alarm message while the further vehicles can receive the alarm message. Such possibility depends on the shape of the curve. As shown in Figure 14, the proposed methods efficiently work even for a curve with $\theta \geq 90°$, where θ is an angle parameter of the curve and is defined in the figure.

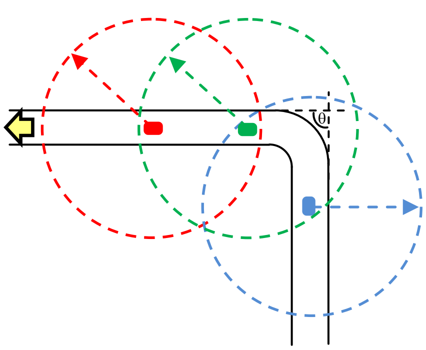

Figure 14: Alarm message broadcasting scenario when $\theta \geq 90°$

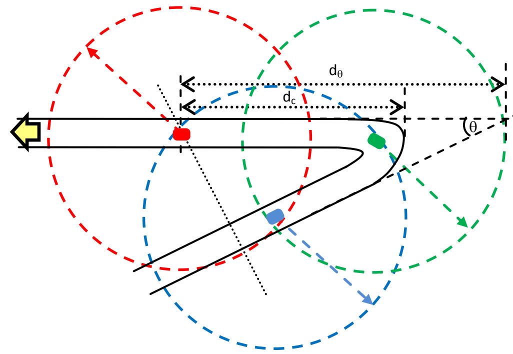

Figure 15: Alarm message broadcasting scenario when $\theta < 90°$

For the case with $\theta < 90°$, if we assume that the vehicles have the geometric information of the curve e.g. d_c, d_θ and θ as shown in Figure 15, the proposed methods can still efficiently work under the following conditions:

- $TR \leq d_c \leq d_\theta$
- $\theta \leq \sin^{-1}(TR/ d_\theta)$

Figure 15 depicts an example case where the above mentioned conditions are completely satisfied. The extension of the proposed method to cover cases where the conditions are not completely satisfied is for further researches.

8. Conclusion and Further Researches

In this paper, we proposed two broadcasting methods for the fast alarm message broadcasting in VANETs. The proposed methods utilize multiple radio channels simultaneously by equipping each vehicle with multiple transceivers as well as the position information provided by a GPS system in order to reduce the broadcasting time. By reducing the broadcasting time of the alarm message, drivers of the vehicles moving toward the accident place will have more time to make a decision on the suitable action, resulting in more safety alarm message broadcasting application. Moreover, the proposed methods are able to solve the Broadcast Storm Problem as well. The proposed methods are characterized by the fact that the high priority to rebroadcast the alarm message is given to the furthest vehicle within the transmission range.

Depending on the conditions of the road shape scenarios, there is some possibility that some vehicles will not receive the alarm message even when they can receive the message by theoretically ideal rebroadcasting. Thus, our future works will focus on the approaches to cope with such a problem.

References

[1] Y. Tseng, S. Ni, Y. Chen, J. Sheu, The broadcast storm problem in a mobile ad hoc network, Wireless Networks, v.8 n.2/3, p.153-167, March-May 2002

[2] B. Williams, T. Camp, "Comparison of Broadcasting Techniques for Mobile Ad Hoc Networks", Proceedings of the 3rd ACM international symposium on Mobile ad hoc networking & computing, p.194-205, 2002

[3] H. Alshaer, E. Horlait, An optimized adaptive broadcast scheme for inter-vehicle communication, Vehicular Technology Conference, 2005. VTC 2005-Spring. 2005 IEEE 61st

[4] T. Osafune, L. Lin, M. Lenardi, "Multi-Hop Vehicular Broadcast (MHVB)", 2006 6th International Conference on ITS Telecommunications Proceedings

[5] L. Briesemeister and G. Hommel, "Role-Based Multicast in Highly Mobile but Sparsely Connected Ad Hoc Networks", Mobile and Ad Hoc Networking and Computing, 2000. MobiHOC. 2000 First Annual Workshop on, 11 Aug. 2000 Page(s):45 – 50.

[6] M. Sun, W. Feng, T. Lai, K. Yamada, H. Okada, K. Fujimura, "GPS-based message broadcasting for inter-vehicle communication", Parallel Processing, 2000. Proceedings. 2000 International Conference on Volume , Issue , 2000 Page(s):279 – 286

[7] E. Fasolo, R. Furiato, A. Zanella, "Smart Broadcast Algorithm for Inter-vehicular Communications", IWS 2005/WPMC 2005, Sep. 2005.

[8] E. Fasolo, A. Zanella, M. Zorzi, "An Effective Broadcast Scheme for Alert Message Propagation in Vehicular Ad hoc Networks", 2006. ICC '06. IEEE International Conference on Communications

[9] T. D.C. Little, A. Agrawal, "An Information Propagation Scheme for VANETS", Proceeding of the 8th International IEEE Conference on Intelligent Transportation Systems, September 13-16, 2005.

[10] J. P. Sign, N. Bombos, B. Srinivasan, D. Clawin, "Wireless LAN Performance Under Varied Stress Condition in Vehicular Traffic Scenarios", Vehicular Technology Conference, 2002. Proceedings. IEEE 56th VTC 2002-Fall. 2002

[11] C. Cheng, P. Hsaio, H.T. Kung, D. Vlah, "Parallel Use of Multiple Channels in Multi-hop 802.11 Wireless Networks, Military Communications Conference, 2006. MILCOM 2006

[12] O. Shagdar, M. N. Shirazi, S. Tang, R. Suzuki, S. Obana, "Improving Reliability of Cut-Through Packet Forwarding in CDMA Vehicular Network", IEICE Technical Report, NS2007-86 (2007-10)

[13] Intel, "Switches − What Are Forwarding Modes and How Do They Work?", http://support.intel.com/support/express/switches/sb/cs-014410.htm

[14] "The Network Simulator - ns-2", http://www.isi.edu/nsnam/ns/

[15] F. J. Ros, P. M. Ruiz, "Implementing a New Manet Unicast Routing Protocol in NS2", 2004

[16] R. A. Calvo, J. P. Campo, "Adding Multiple Interface Support in NS-2, 2007

[17] T. Kim, D.J. Lovell, "Observation of real driving behavior in car-following: preliminary results", Vehicular Technology Conference, 2005. VTC-2005.