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Efficient Alarm Messaging by Multi-Channel Cut-Through Rebroadcasting based on Inter-Vehicle Communication

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***Abstract*—At present, 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 the line-of-sight of the drivers by the extensive use of on-board devices in order to improve the safety and efficiency of road traffic. However, due to mobility constraints and driver behaviors in VANETs, the broadcasting approaches used in Mobile Ad Hoc Networks (MANETs) cannot be properly applied to the applications in VANETs. Moreover, the conventional broadcasting methods for broadcasting an alarm message have a defect of long time required for the complete dissemination, which leads to the degradation in the safety of road traffic in case of emergency. This paper proposes a new broadcasting method called Cut-Through Rebroadcasting (CTR) for alarm message dissemination scenarios based on the minimization of the number of rebroadcasting vehicles and the overlap rebroadcasting by making use of multiple-channels.**

***Index Terms*—alarm message, broadcasting method, multiple channels, vehicular ad hoc network**

I. Introduction

There has been increasing interest in the application of advanced information technology to transportation systems for providing improved comfort and additional safety in driving. Existing Intelligent Transport System (ITS) deployments, e.g. Advanced Cruise-Assist Highway System (AHS) [1], mainly rely on networks in the roadside infrastructure or Road-Vehicle Communication (RVC). 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 infrastructure equipments have been deployed.

The vehicles with such IVC capability form ad hoc networks called Vehicular Ad Hoc Networks (VANETs). Their specific characteristics allow the development of *Comfort Application* and *Safety Application* [2]. Although much effort is needed in order to make these applications reality, methods to disseminate various messages seem to be one of the most important challenges. In addition, 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 an alarm or warning message to the upcoming vehicles in case of hazardous driving situations such as accidents and dangerous road surface conditions. However, the existing broadcasting methods have some serious defects such as long delay for the complete propagation and high cost due to the use of wide frequency band. Because of these serious problems, they have not yet been actually put into wide commercial use.

In order to solve such problems, this paper proposes a method that can reduce the broadcasting time required for the alarm or warning message propagation by utilizing multiple channels available e.g. in IEEE 802.11 standard as well as the Global Positioning System (GPS). This proposed method is called Cut-Through Rebroadcasting (CTR).

II. Alarm Message Broadcasting

According to Fig. 1, when the vehicle located in the middle has an accident and recognizes itself as crashed by using some sensors that detect events like airbag ignition, this vehicle will start to broadcast an alarm message to propagate the information about its accident to nearby vehicles as shown by arrows. 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). Consequently, the vehicle has very short period of time for communication with other vehicles encountered on the road.
- Human reaction time is 0.3 s, but 0.1 s will be used for the acquisition of the information by various sensors and 0.1 s for processing the information. Therefore, at most only 0.1 s is left for vehicle-to-vehicle communication [1]. Furthermore, if the acquiring and processing the information cannot be achieved in 0.2 s, the vehicle to vehicle communication has to be done in less than 0.1 s.

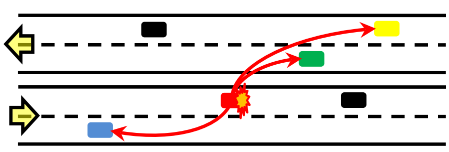

Fig. 1. Alarm message broadcasting application

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

III. Related Works

Among many broadcasting methods that have been proposed, *Flooding* seems to be the simplest. However, this method has some problems such as high collision or contention probability and high data redundancy because every vehicle 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* [2]. Consequently, a lot of broadcasting methods have been proposed in order to solve this problem and they can be taken as candidates for the alarm message broadcasting application. However, they have in practice serious problems from the viewpoint of the characteristics of VANETs as follows:

Probability Based Method [3], [4]***:*** In the probability based method, each vehicle decides to rebroadcast the message with some probability in order to decrease data redundancy and collision. Although the required average broadcasting time is rather short, this method still cannot entirely solve the redundancy problem. Moreover, its delivery ratio is generally rather low depending on the probability, which leads to the serious problem of low reliability.

Area Based Method: In this method, each vehicle decides to rebroadcast the message by considering the additional coverage area of the transmission range achieved by the rebroadcasting. In the *Distance Based Scheme* [2], [5], when a vehicle receives the message, the vehicle will not rebroadcast the message if the distance between itself and its nearest neighbor vehicle which has previously rebroadcasted the same message is smaller than a predetermined threshold because the rebroadcasting is judged redundant. The *Location Based Schemes* [5], [6], [7], [8], [9], [10] make more precise estimation of the additional coverage area by making use of the means to determine its own location, e.g. GPS.

An *Area Based Method* named *Optimized Dissemination of Alarm Message (ODAM)* [10] assigns the duty of message rebroadcasting to only furthest neighbor from the source vehicle in order to ensure the largest additional coverage area which has not yet been covered by the source vehicle. The intermediate vehicles that receive the message should not rebroadcast the message immediately. Instead, these vehicles must wait for some waiting time, whose duration length is inversely proportional to the distance between itself and the source vehicle. At the expiration of the waiting time, if a vehicle has not received the same message coming from another vehicle, it rebroadcasts the message. Although this method is considered efficient in terms of overhead cost and redundancy, it does not take into account a tight time delay constraint of the alarm message broadcasting application and thus its required time for the complete propagation of the message is rather long.

Cluster Based Method [11]***:*** In this method, all the related vehicles are structured into some clusters and the task for rebroadcasting the message is assigned to only the cluster head vehicle of each cluster. Although this method can work efficiently, the cost to create and maintain the cluster structure is rather high because of high speed move of the vehicles, which leads to the large traffic overload and long delay of the message propagation in general.

Topology Based Method [12], [13]***:*** *Topology based methods* are based on the complete knowledge of the network topology which is obtained by exchanging the control messages beforehand. Although this method is efficient in terms of redundancy and collision reduction, this method is not considered feasible in the VANETs because the high control traffic load is required just like cluster based method.

Cut-through Based Method [17]***:*** According to the strict delay constraint of safety application, the approaches with effectively shortened forwarding latency e.g. 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 frame is entirely received [16]. Unfortunately, the cut-through forwarding method has not been studied 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 the safety application. One of the broadcasting methods that utilize cut-through forwarding has been proposed in [17]. In this broadcasting method, each vehicle that received the message has an obligation to rebroadcast the message. Thus, the Multiple Access Interference (MAI) increases in accordance with the number of simultaneously rebroadcasting vehicles. Moreover, the wide bandwidth is required for the proposed Code Division Multiple Access (CDMA).

IV. Cut-Through Rebroadcasting for Alarm Message

It should be noted that all the existing conventional broadcasting methods except the cut-through based method use only a single frequency channel and make no use of the rest channels that are actually available e.g. in IEEE 802.11 standard. However, in order to achieve the targets of safety application, we propose CTR method that utilizes multiple channels available e.g. in IEEE 802.11 standard as well as GPS function. In CTR, high priority to rebroadcast the message is given to some specific vehicles to avoid the interference problem and the multiple channels are utilized effectively to achieve overlap broadcasting.

A. The Characteristics and Assumptions for VANETs

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 vehicle) and in less than some predetermined coverage distance. In other words, the position information will be used as an attribute to limit the broadcasting process. It is assumed that the highway is rectilinear and that there are no obstacles for the radio wave propagation along the highway e.g. buildings on the road.

All the vehicles are assumed to be equipped with sensing, calculation, communication capabilities and GPS so that each vehicle can sense an accident, gather information about the accident, transmit 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 and receive a different message on the other channel at the same time. Furthermore, all the antennas are assumed non-directional.

B. Targets to be Achieved

Efficiency of the alarm message broadcasting method 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 to receive the alarm message completely is shorter than 0.1 s.
- Since the alarm message is broadcasted in a multi-hop manner, the number of vehicles that newly receive the alarm message in each hop should be as large as possible and thus the number of rebroadcasting vehicles should be smallest.

C. Cut-Through Rebroadcasting

The basic idea is to give high priority to the furthest vehicle in the transmission range from the source vehicle to rebroadcast the alarm message after recognizing it from its header. 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 rebroadcast the message. Moreover, this method is characterized by utilizing cut-through-like forwarding approach or the overlap operation of alarm message transmission by some vehicles under the assumption that each vehicle is equipped with at least two transceivers and 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.

The scenario in Fig. 2 will be used to further describe and illustrate the basic idea of CTR. In Fig. 2, *A* is assumed to have just had an accident, and *B*, *C* and *D*, *E* are assumed to be in the transmission range of the transceivers equipped on *A* and in that of the transceivers equipped on *C* respectively. After *A* recognizes an accident event based on the information received from various sensors, *A* acts as the source vehicle and starts to broadcast an alarm message to notify nearby vehicles including *B* and *C* of the accident. 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 be responsible for rebroadcasting the alarm message in the next hop or not. It should be remarked that the waiting time is longer for vehicles that are closer to the source vehicle. The details of waiting time calculation will be described later. When a waiting time of a vehicle expires and it has not received any alarm message from any other following vehicles, it starts to rebroadcast the alarm message in the following hop. On the other hand, if a vehicle has received an alarm message from

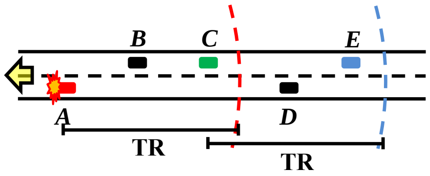

Fig. 2. Alarm message broadcasting scenario

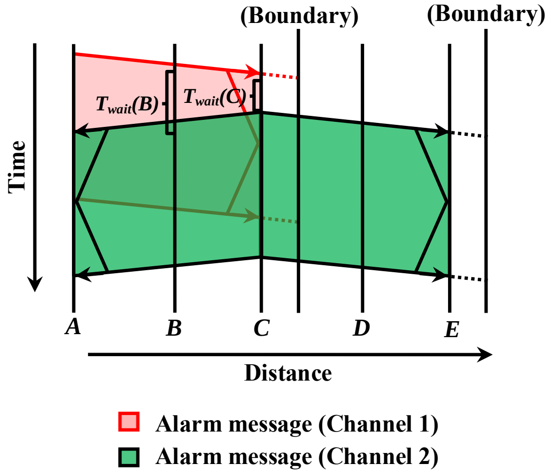

Fig. 3. Basic idea of Cut-Through Rebroadcasting

any other following vehicles before the expiration of its waiting time, then it decides not to rebroadcast the alarm message. In Fig. 3, 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.

Then, *C* becomes a source vehicle in the next hop to rebroadcast the alarm message and then in almost the same manner, only *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 vehicle *A*.

D. Waiting Time Calculation

The waiting time calculation is based on the basic idea that the header of the alarm message sent by the furthest vehicle, which should be responsible for rebroadcasting the alarm message, should arrive at the vehicles located closer to the source vehicle before the waiting time expiry of these vehicles. This basic idea can be elaborated as follows.

In Fig. 4, after an intermediate vehicle, which is located in the transmission range of *A*, recognizes that the message it has started to receive is the alarm message broadcasted by *A* from its header, the vehicle should wait for some time to be notified whether there is a further vehicle which will responsible for rebroadcasting the alarm message or not instead of immediate rebroadcasting. This notification is achieved by the recognition of the header of the alarm message rebroadcasted by the further vehicle if any. By this approach, it becomes possible to avoid the collision of the alarm message broadcasting and achieve the largest additional coverage distance. An imaginary vehicle is assumed at the boundary of the transmission range of *A*, and this vehicle is assumed to start to rebroadcast the alarm

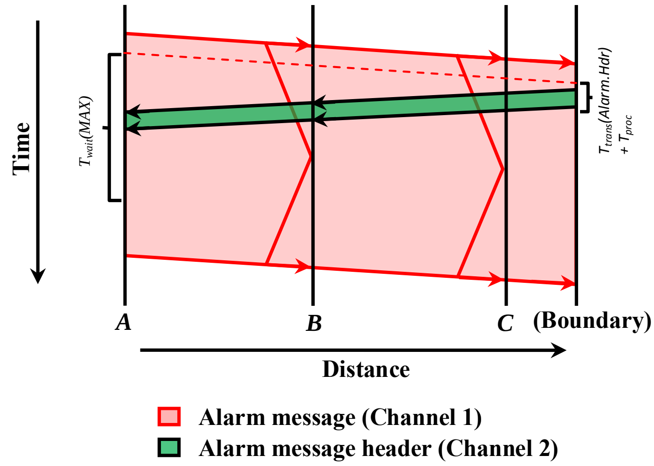

Fig. 4. Basic idea of waiting time calculation

message just after recognizing the alarm message. Thus, the waiting time of intermediate vehicles should be defined so that they wait long enough to receive the alarm message header rebroadcasted by this assumed vehicle. Furthermore, in the designing of the waiting time, the time required for the transmission, propagation and processing of header of the alarm message should be taken into account and the waiting time should become longer for an intermediate vehicle closer to the source vehicle.

In general, the waiting time for vehicle *X* located D_{SX} away from the source vehicle *S* can be represented by the following equations with a parameter Delta (Δ):

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

$$T_{wait}(MAX) = \left[T_{trans}(Alarm.Hdr) + T_{proc} + (2 \times \frac{TR}{V_{prop}}) \right] \times (1 + \Delta) \qquad (2)$$

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

By utilizing (1) and (2), the further the vehicle is located from the source vehicle, the shorter its waiting time 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 V.

After various experiments, 0.0 is basically chosen as the value of Delta based on the consideration about the broadcasting time required to cover the coverage distance. Some discussion on this choice is given in Section V.

E. Frame Format

Although a message can be forwarded in various layers in general, message forwarding in a lower layer achieves shorter forwarding delay than that in 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/Others	X	Y	Z	Alarm Info.
8 bits	32 bits	32 bits	32 bits	1,382 bytes

- *Type* (1 byte)*:* Type of the message (alarm message/ others)
- *Position X,Y,Z* (4 bytes x 3 = 12 bytes)*:* Position of the source vehicle represented by floating point 32 bits
- *Data* (1,382 bytes)*:* Various information about the accident

Fig. 5. Frame format of the alarm message

The frame format used in CTR is as shown in Fig. 5 and is summarized as follows.

- Frame header size: 30 bytes (fixed)
- Alarm message header size: 13 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 messages can be sent by using only single frame.

The data field of the alarm message mentioned in Fig. 5 contains such information as Time to Live (TTL) which is used to limit the maximum number of hops for 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
- Characteristics of the vehicle at the accident time
- Road conditions
- Safety distance from the accident place
- Help request (ambulance, police, etc.)
- Pictures or movies 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 broadcasted in the following frame(s).

V. Evaluation Results

A. Evaluation Scenario

In order to demonstrate the efficiency of CTR, the average broadcasting time and the number of rebroadcasting vehicles of CTR, ODAM, and the pure flooding method are comparatively evaluated under NS-2 simulation environment. ODAM is selected for this comparison because it is considered most efficient for the alarm message broadcasting application among the conventional broadcasting methods as described in section 0.

Fig. 6 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 two predetermined distances. 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 addition, as mentioned in section IV, each vehicle must be equipped with at least 2 transceivers assigned with different channels. In the simulation, the time required for a vehicle which is located

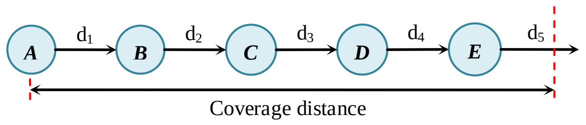

Fig. 6. Simulation topology

TABLE I. SIMULATION PARAMETERS AND THEIR VALUES IN NS-2 ENVIRONMENT

Simulation parameters	Value
Data speed	1 Mbps
Radio propagation speed	3 x 10^8 m/s
MAC layer	CSMA/CA
Propagation model	Two-ray ground
Antenna type	Omni antenna
Processing time required for sending from application layer to MAC layer	0.075 ms
Processing time required for sending from MAC layer to application layer	0.025 ms
DCF Interframe Space (DIFS)	0.050 ms
Contention window	31 (default)
Slot time	0.020 ms
Alarm message size	500-2500 bytes (default 1425 bytes)
Alarm message header size	43 bytes
Transmission range	100-500 m (default 250 m)
Distance between two consecutive vehicles	20-40 m, 40-60 m, 60-80 m (default 20-40 m)
Speed of vehicle	20-27 m/s
Delta (Δ)	-1.0-15.0 (default 0.0)
No. of channels	1 channel (Flooding, ODAM), 2, 3 channels (CTR) (default 3 channels)
Coverage distance	1000 m, 3000 m (default 1000 m)
Number of lanes	1-5 lanes (default 1 lane)
Lane width	3.5 m
No. of repetitions for simulation	100 times

furthest from the source vehicle within the coverage distance to completely receive the alarm message is evaluated as the broadcasting time for various transmission range values. The simulation parameters and their values are shown in Table I.

B. Average Broadcasting Time

Fig. 7 shows the average broadcasting time of the above mentioned three methods for the case where the coverage distance is 1000 m and the distance between two consecutive vehicles is randomly chosen from the values between 20-40 m. Error bars in Fig. 7 and the following figures show the 95% confidence interval of the results concerned. It is understood that CTR can achieve the broadcasting time shorter than the pure flooding method, by reducing the possibility of the collision in the alarm message rebroadcasting and giving high priority to rebroadcast the alarm message to the furthest vehicle in the transmission range from the source vehicle. Fig. 8 illustrates the distribution of the broadcasting time of CTR.

Compared with ODAM, CTR can achieve significantly shorter average broadcasting time by allowing the overlap in the alarm message broadcasting and rebroadcasting just after the expiration of the waiting time, while a vehicle in ODAM has to completely receive the alarm message and wait for the expiration of waiting time before they can make a decision on whether to rebroadcast the alarm message.

Because CTR starts to rebroadcast the alarm message after the expiration of waiting time, the average broadcasting time mainly consists of the transmission time of the alarm message header, its processing time, waiting time in each hop and the transmission time of the alarm message in the last hop, which are about 0.76 ms, less than 0.77 ms, less than 1.53 ms and 11.8 ms, respectively. The components of the average broadcasting time of CTR, flooding and ODAM in Fig. 7 are illustrated in Fig. 9 and Fig. 10.

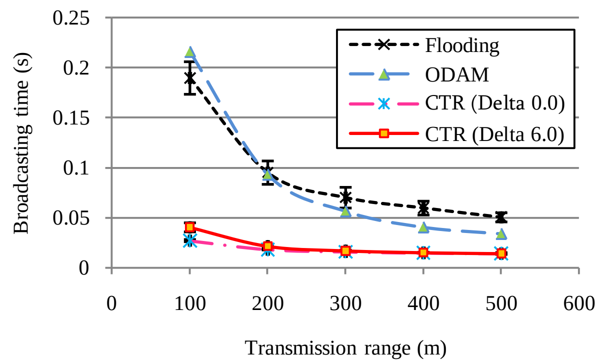

Fig. 7. Average broadcasting time required to cover the coverage distance

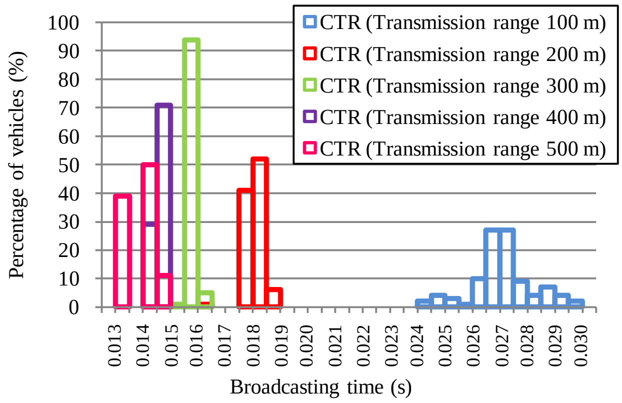

Fig. 8. Distribution of the broadcasting time

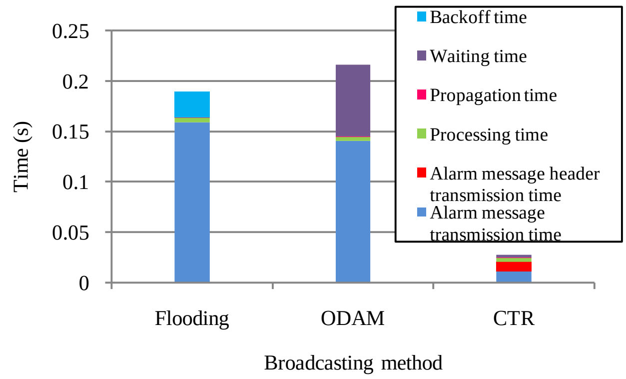

Fig. 9. Components of the average broadcasting time of the broadcasting methods for the case where the transmission range is 100 m

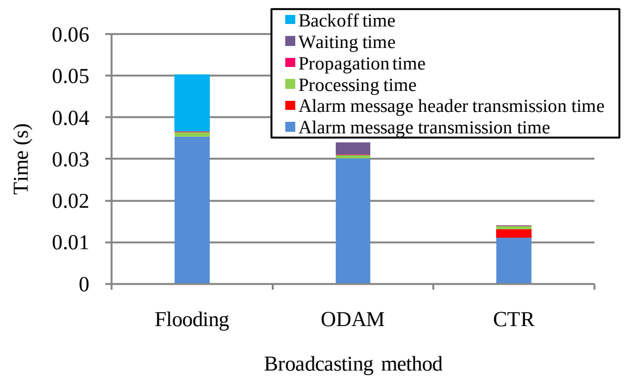

Fig. 10. Components of the average broadcasting time of the broadcasting methods for the case where the transmission range is 500 m

According to Fig. 7, CTR can achieve much shorter than 0.1 s average broadcasting time for every transmission range in the evaluation. The average broadcasting time of CTR decreases as the transmission range increases due to the decrease in the number of hops in the alarm message rebroadcasting to cover the coverage distance. Additionally, the average broadcasting time of CTR decreases as the value of Delta decreases due to the decrease in the value of $T_{wait}(MAX)$ used in the waiting time calculation.

In addition to the transmission range, other parameters which might have an influence on the average broadcasting time are evaluated as follows:

Distance between any two consecutive vehicles: Fig. 11 illustrates the influence of the distance between two consecutive vehicles on the average broadcasting time of CTR. As the distance between any two consecutive vehicles

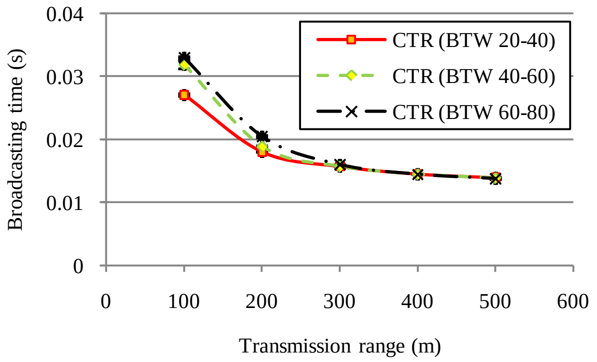

Fig. 11. Influence of the distance between any two consecutive vehicles on the average broadcasting time

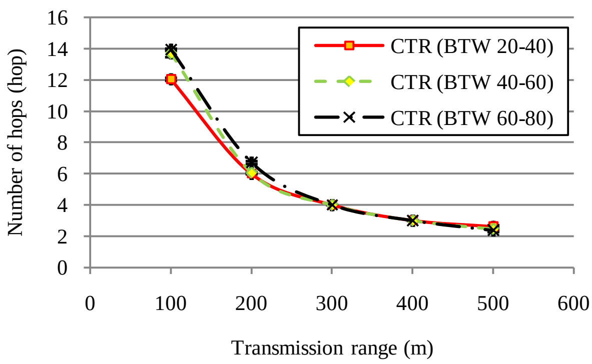

Fig. 12. Influence of the distance between any two consecutive vehicles on the average number of hops

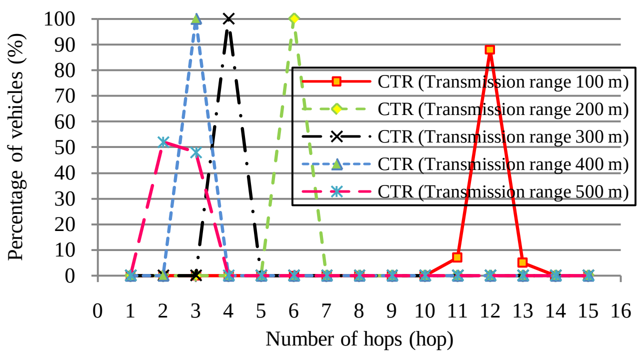

Fig. 13. Distribution of the number of hops for the case where the distance between two consecutive vehicles is 20-40 m

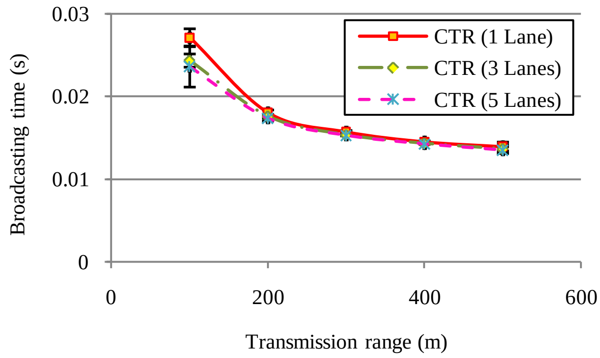

Fig. 14. Influence of the number of lanes on the average broadcasting time

increases, the possibility that there is a vehicle located close to the boundary of the source vehicle's transmission range will decrease. Consequently, the number of hops required to cover the coverage distance will increase as shown in Fig. 12, resulting in the increase in the average broadcasting time of CTR. The distribution of the number of hops of the CTR can be illustrated as in Fig. 13.

However, it can be noticed that the average broadcasting time of CTR is almost the same even when the distance between two consecutive vehicles is changed from 20-40 m to 40-60 m or 60-80 m as far as the average number of hops required to cover the coverage distance is the same. The reason for this is due to the fact that the propagation speed is extremely fast and that the propagation time of a message between two consecutive vehicles is about 0.1 µs for the case where the distance between two consecutive vehicles is 30 m, which is negligibly small in comparison with other required time such as the transmission or procession time of the message, which are about 11.8 ms and less than 0.77 ms, respectively.

Number of lanes: According to Fig. 14, which illustrates the influence of the number of lanes on the average broadcasting time of CTR, the average broadcasting time decreases as the number of lanes increases. This is due to the increase in the possibility that there is a vehicle located close to the boundary of the source vehicle's transmission range. Consequently, the average broadcasting time mainly decreases in accordance with the decrease in the number of hops required to cover the coverage distance. Apart from the decrease in the number of hops, the decrease in the average broadcasting time is also due to the decrease in the waiting time which is normally less than 1.53 ms in each hop to the value close to 0.

Coverage distance: According to Fig. 15, the average broadcasting time of CTR increases in accordance with the increase in the coverage distance. The main reason is due to the increases in the number of hops required to cover the coverage distance.

Alarm message size: Fig. 16 depicts the influence of the alarm message on the average broadcasting time of CTR. As the alarm message size increases, the average broadcasting time increases in accordance with the increase in the average alarm message header transmission time in each hop.

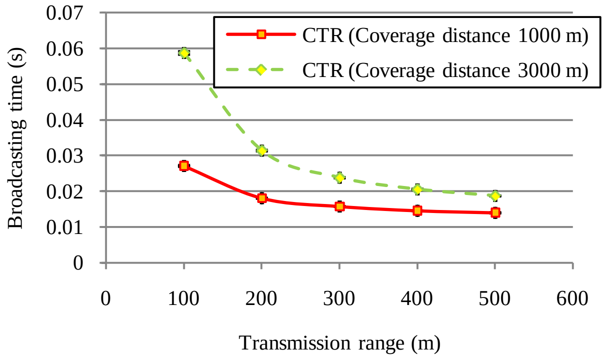

Fig. 15. Influence of the coverage distance on the average broadcasting time

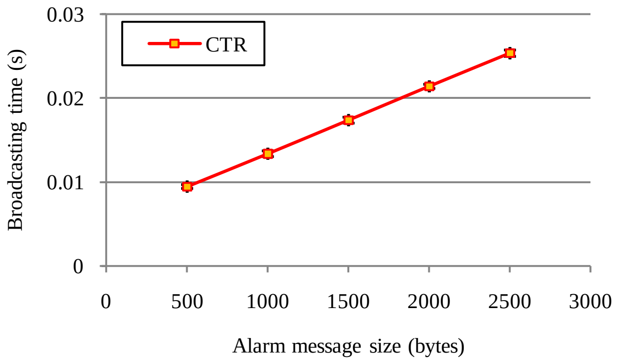

Fig. 16. Influence of the alarm message size on the average broadcasting time

Mobility of the vehicles: Although the mobility of the vehicles is one of the main characteristics of VANETs, it does not have a significant influence on the efficiency of CTR as shown in Fig. 17. The time required for broadcasting the alarm message until it becomes possible to cover the coverage distance in the evaluation is rather short. In this period of time, the distance of the move of each vehicle is rather small. Because the propagation speed is extremely fast and the propagation time of a message between two consecutive vehicles is negligibly small, the influence of the mobility of the vehicles on the average broadcasting time is not significant in comparison with other required time.

Value of Delta: Fig. 18 and Fig. 19 illustrate the influence of the value of Delta on the average broadcasting time. According to (2), $T_{wait}(MAX)$ increases as the value of Delta increases, resulting in the increase in the waiting time in each hop and the average broadcasting time. It should be noticed that, for the negative value of Delta, the average broadcasting time does not significantly change when compared with the case of positive value of Delta. Based upon such study on Delta, 0.0 is set for the basic value of Delta. However, some evaluation results are shown for the case where the value is not 0.0 for comparison purpose.

Number of channels: Fig. 20 illustrates the influence of the number of channels on the average broadcasting time. By utilizing only two channels in the alarm message rebroadcasting, the probability of the collision of the alarm message broadcasting could be significantly higher than the case where three channels are utilized. Thus, in order to avoid such collision, this paper proposed that at least three channels should be utilized in the alarm message rebroadcasting.

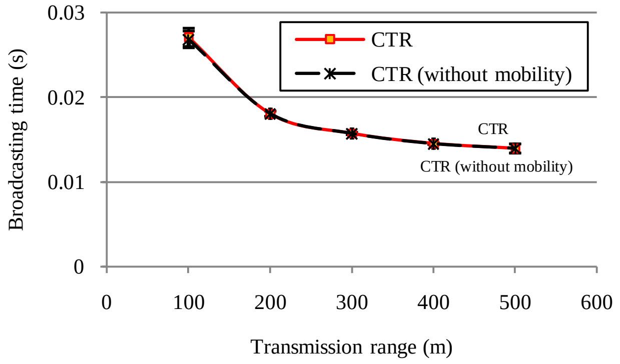

Fig. 17. Influence of mobility on the average broadcasting time

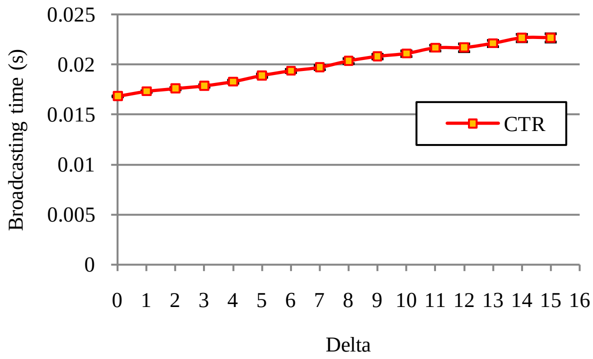

Fig. 18. Influence of the value of Delta on the average broadcasting time for the positive value of Delta

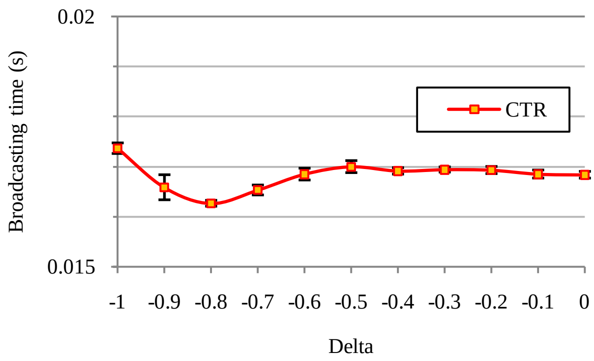

Fig. 19. Influence of the value of Delta on the average broadcasting time for the negative value of Delta

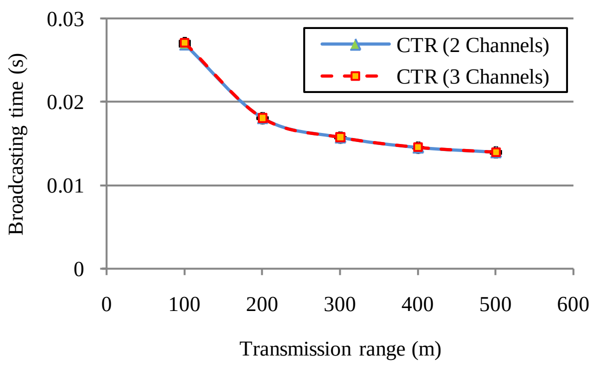

Fig. 20. Influence of the number of channels on the average broadcasting time

However, it should be noted that, for the rebroadcasting vehicles, since most of the alarm message has been forwarded when the collision occurs, the collided alarm message, which is generally discarded upon its complete reception, could not be discarded. Thus utilizing only two channels in the alarm message rebroadcasting is able to achieve the same average broadcasting time as utilizing three channels. More study is considered useful to further clarify the impact of the number of channels on the broadcasting time in detail.

C. *Number of Rebroadcasting Vehicles*

Fig. 21 illustrates the total number of vehicles which were located in the coverage distance 1000 m and rebroadcasted the alarm message by the above mentioned three methods and also the theoretically minimum value of the number of rebroadcasting vehicles for reference. The distribution of the number of rebroadcasting vehicles of CTR is shown in Fig. 22. By giving priority control in the alarm message rebroadcasting, the number of rebroadcasting vehicles of CTR is significantly smaller than those of ODAM and the pure flooding method which obliges every vehicle to rebroadcast the alarm message. The reason why the number of rebroadcasting vehicles by CTR where Delta is 6.0 is a little larger than the theoretically minimum value and is smaller than the case where Delta is 0.0 is as follows.

According to $T_{wait}(MAX)$ in (2), because propagation time of a message between two consecutive vehicles is negligibly small in comparison with other required time, $T_{wait}(MAX)$ can be considered as a constant value. With the same average distance between two consecutive vehicles, the difference between the waiting times of any two consecutive vehicles, which can be calculated by (1), decreases as the transmission range increases. In addition, $T_{wait}(MAX)$ decreases as the value of Delta decreases, resulting in decrease in the difference between the waiting time of any two consecutive vehicles as well. Thus, the possibility that the leading vehicles will not receive the header of the alarm message from the rebroadcasting vehicle before the expiration of their waiting time and start to rebroadcast the alarm message will increase, resulting in larger number of rebroadcasting vehicles.

Although it is possible to increase the value of $T_{wait}(MAX)$, the average broadcasting time increases accordingly. Thus, the trade-off between the average broadcasting time and the number of rebroadcasting vehicles has to be considered in the waiting time calculation.

It should be noted that CTR may be improved for reducing the number of rebroadcasting vehicles by the cancellation of rebroadcasting the alarm message after the reception of the header of the alarm message if the rebroadcasting has not yet actually started and has been suspended by the operation like CSMA/CA. However, the issues about layer violation have to be considered. According to Fig. 23, by allowing the cancellation of rebroadcasting the alarm message suspended by the operation like CSMA/CA in the MAC layer, CTR can achieve the optimum number of rebroadcasting vehicles and the minimum number of hops required to cover the whole coverage distance.

In addition to the transmission range, other parameters which might have an influence on the average number of rebroadcasting vehicles are evaluated as follows:

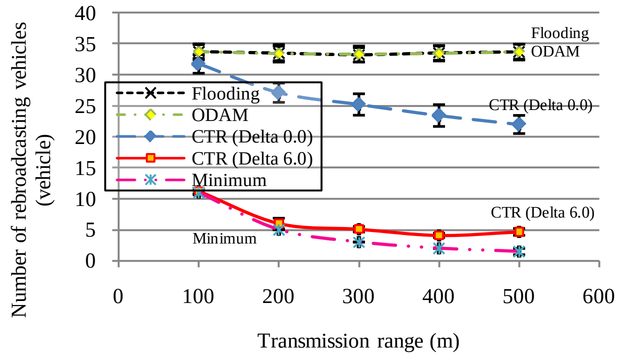

Fig. 21. Average number of rebroadcasting vehicles required to cover the coverage distance

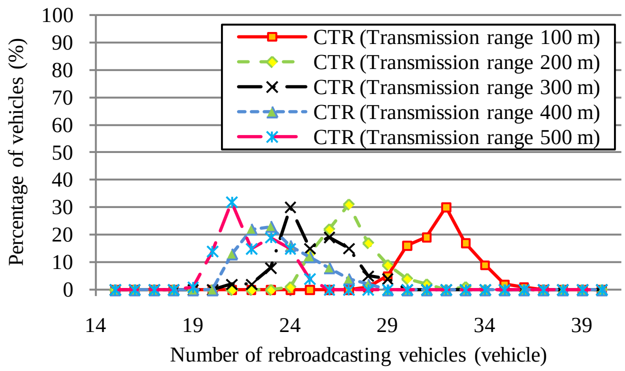

Fig. 22. Distribution of the number of rebroadcasting vehicles

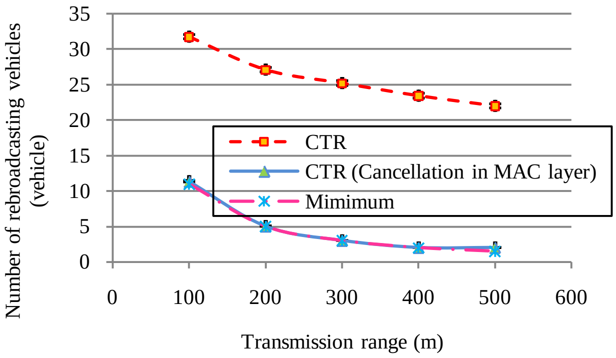

Fig. 23. Improvement of CTR by the cancellation of rebroadcasting the alarm message suspended by the operation like CSMA/CA

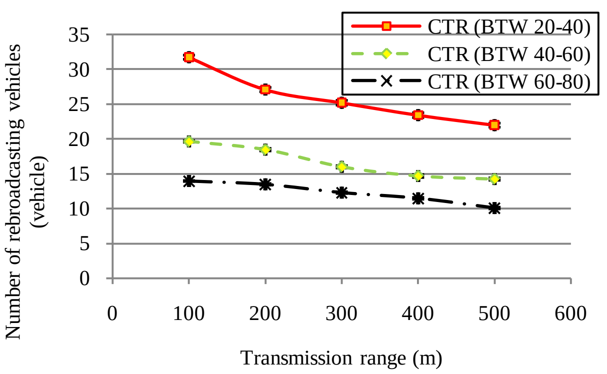

Fig. 24. Influence of the distance between any two consecutive vehicles on the average number of rebroadcasting vehicles

Distance between any two consecutive vehicles: According to Fig. 24, the number of rebroadcasting vehicles is changed in accordance with to the number of hops shown in Fig. 12 when the distance between any two consecutive vehicles is changed from 20-40 m to 40-60 m or 60-80 m. In addition to the number of hops, the number of rebroadcasting vehicles is also influenced by the density of the vehicle in each hop and the number decreases in accordance with the increase in the distance between any two consecutive vehicles.

Number of lanes: The increase in the number of rebroadcasting vehicles in accordance with the increase in the number of lanes is influenced by the increase in the density of the vehicle in each hop. Moreover, for the case where the number of lanes is larger than one, the decrease in the distance between any two consecutive vehicles also has an influence on the number of rebroadcasting vehicles. The influence of the number of lanes on the number of rebroadcasting vehicles is shown in Fig. 25.

Coverage distance: As shown in Fig. 26, the number of rebroadcasting vehicles increases as the coverage distance increases. This is due to the increase in the number of hops required to cover the coverage distance.

Value of Delta: According to Fig. 27 and Fig. 28, the number of rebroadcasting vehicles increases as the value of Delta decreases. According to $T_{wait}(MAX)$ in (2), because propagation time of a message between two consecutive vehicles is negligibly small in comparison with other required time, $T_{wait}(MAX)$ can be considered as a constant value. With the same average distance between two consecutive vehicles, the difference between the waiting times of any two consecutive vehicles, which can be calculated by (1), decreases as the transmission range increases. In addition, $T_{wait}(MAX)$ decreases as the value of Delta decreases, resulting in the decrease in the difference between the waiting time of any two consecutive vehicles as well. Thus, the possibility that the leading vehicles will not receive the header of the alarm message from the rebroadcasting vehicle before the expiration of their waiting time and start to rebroadcast the alarm message will increase, resulting in the larger number of rebroadcasting vehicles. It should be noticed that, for the negative value of Delta, the number of rebroadcasting vehicles does not significantly change when compared with the case of positive value of Delta.

According to the influence of the value of Delta on the average broadcasting time and the number of rebroadcasting vehicles, this paper proposes to choose 0.0 as the value of Delta. The reason for this is as follows. Choosing 0.0 as the value of Delta can achieve the shortest broadcasting time when compared with other positive values of Delta. In addition, the broadcasting time when 0.0 is chosen as the value of Delta is not significantly different from other negative values of Delta but the smaller number of rebroadcasting vehicles can be achieved.

For the case where the alarm message data field is larger than the maximum frame size and is supposed to be sent in multiple consecutive frames, choosing 0.0 as the value of Delta can lead to the increase in the broadcasting time required to receive all the frames of the alarm message. This is due to the fact that there is a possibility that the alarm message rebroadcasting of some vehicles is suspended by the

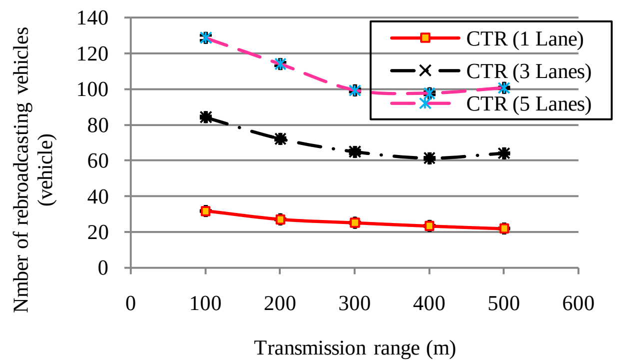

Fig. 25. Influence of the average number of lanes on the average number of rebroadcasting vehicles

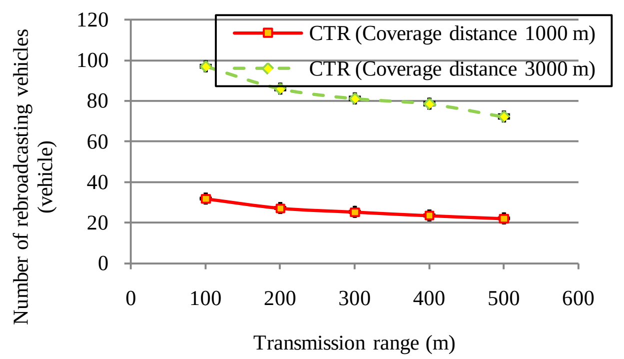

Fig. 26. Influence of the coverage distance on the average number of rebroadcasting vehicles

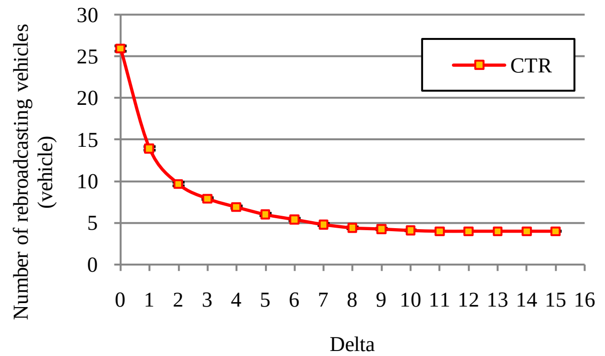

Fig. 27. Influence of the value of Delta on the averge number of rebroadcasting vehicles for the positive value of Delta

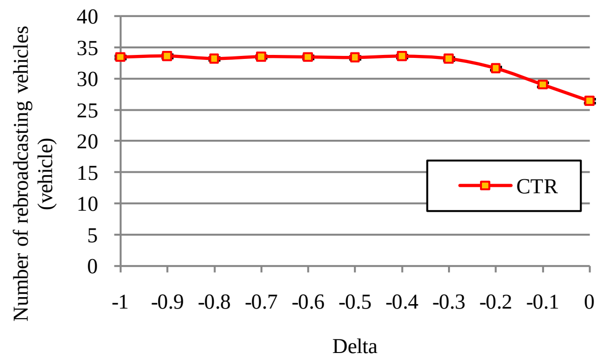

Fig. 28. Influence of the value of Delta on the average number of rebroadcasting vehicles for the negative value of Delta

operation like CSMA/CA while the first frame of the alarm message is sent by the furthest vehicle. Thus, after the furthest vehicle finished sending the first frame and before this vehicle starts to send the second frame, these vehicles probably start to rebroadcast the alarm message. Consequently, the second frame of the alarm message which should be sent by the furthest vehicle will be suspended by the operation like CSMA/CA.

However, this problem can be handled by either increasing the value of Delta which can result in smaller number of rebroadcasting vehicles or the cancellation of alarm message rebroadcasting after the reception of the alarm message header if the rebroadcasting has not yet actually started and has been suspended by the operation like CSMA/CA.

VI. Conclusion and Further Researches

By reducing the broadcasting time of the alarm message, the 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.

This paper has proposed a new broadcasting method in order to achieve such reduction in the broadcasting time by making use of multiple channels and GPS capability. This method is named Cut-Through Rebroadcasting (CTR). CTR can be characterized by the fact that the high priority to rebroadcast the alarm message is given to only the furthest vehicle within the transmission range. CTR can greatly reduce the broadcasting time mainly because of this priority control and the overlap rebroadcasting of the alarm messages by two or three vehicles. The resultant broadcasting time is well below the upper limit of 0.1 s even when the coverage distance is e.g. 3000 m. Moreover, CTR is able to solve the *Broadcast Storm Problem* as well. In addition, CTR may be improved for reducing the number of rebroadcasting vehicles by the cancellation of rebroadcasting the alarm message after the reception of the header of the alarm message if the rebroadcasting has not yet actually started and has been suspended by the operation like CSMA/CA in case of collision. However, more study is required to confirm and evaluate this improvement in detail. Future study is also considered important to minimize the waiting time of vehicles in order to further decrease the broadcasting time.

This paper has an assumption of rectilinear road. If the road is not rectilinear and has a shape of e.g. curve, then some vehicles in the coverage distance may not be able to receive the alarm message according to so far proposed efficient broadcasting method. Thus, our future researches will focus on the approaches to cope with such a problem.

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