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Multiple Channel Rebroadcasting of Alarm Message for Vehicular Ad Hoc Networks (VANETs)

車々間通信用アドホックネットワークにおいて複数チャンネルを用いた緊急メッセージの伝達手法

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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, characteristics of VANETs are quite different from those of general Mobile Ad Hoc Networks (MANETs). Accordingly, the broadcasting methods used in MANETs cannot be properly applied to the applications in VANETs. Moreover, the conventional 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. In order to solve this problem, this paper focuses on broadcasting methods to provide efficient dissemination of an alarm message in the aspect of broadcasting time and proposes new broadcasting methods for alarm message dissemination scenarios. The proposed methods are based on the minimization of the number of rebroadcasting vehicles and the overlap rebroadcasting by making use of multiple-channels and assigning the highest priority to rebroadcast the alarm message to the furthest vehicle located away from the source vehicle. This thesis describes the basic principles and detail algorithms of the proposed methods, demonstrates their efficiency with their evaluation results and discusses the related works and some directions of the further researches.

Keywords—alarm message, broadcasting method, multiple channels, vehicular ad hoc network, VANET

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Chapter 1

INTRODUCTION

As illustrates in Fig. 1, 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 mainly rely on networks in the roadside infrastructure or Road-Vehicle Communication (RVC) as shown in Fig. 2. In Japan, one example of this system is Advanced Cruise-Assist Highway System, referred to as AHS [1]. 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 as illustrates in Fig. 3. After detecting the obstacles, these sensors will notify the vehicles in their transmission range of the obstacles, where the vehicles are equipped with Vehicle Information and Communication System (VICS), one kind of navigation systems widely used in Japan. 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.

Fig. 1. Application of advanced information technology to transportation systems

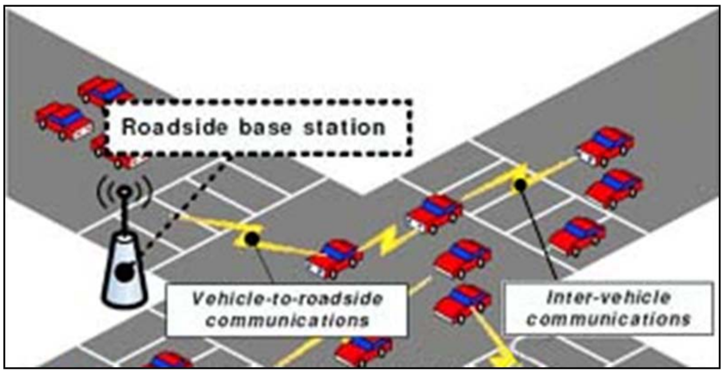


Fig. 2. Intelligent Transport System (ITS)

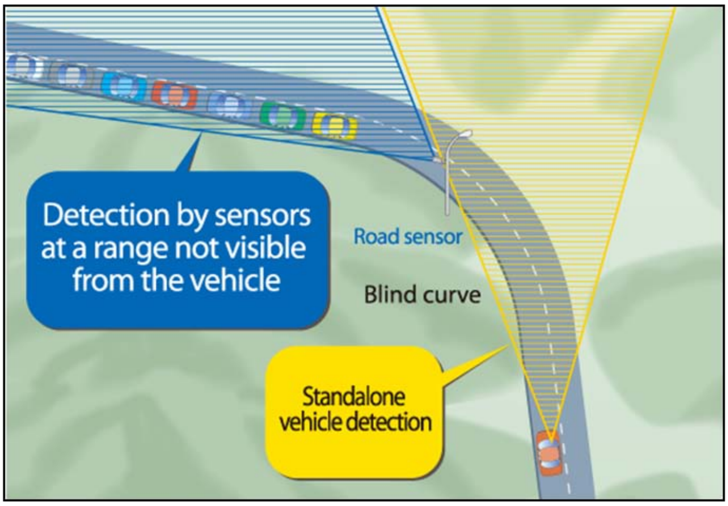


Fig. 3. Advanced Cruise-Assist Highway System (AHS)

The vehicles with such IVC capability form the ad hoc networks called Vehicular Ad Hoc Networks (VANETs). Their specific characteristics allow the development of the following two category applications [2]:

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

b) ***Safety application:*** The purpose of this category is to enhance the safety of drivers and passengers by exchanging safety related information. Some examples 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 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 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 accident 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 thesis proposes some methods that can reduce the broadcasting time required for the alarm or warning message propagation in some predetermined distance by utilizing multiple channels available e.g. in IEEE 802.11 standards as well as the Global Positioning System (GPS) system.

The rest of this thesis is organized as follows: The characteristics of VANETs, the common attributes to many or all broadcasting methods, the fundamental problems of broadcasting and the exiting standards in vehicular environment are described in Chapter 2 . The characteristics and definition of the alarm message broadcasting are discussed in Chapter 3 . Chapter 4 describes the existing broadcasting methods as the related works and clarifies their problems. Targets and the assumptions for this research are given in Chapter 5 . Two methods for the alarm message broadcasting are proposed also in Chapter 5 . Their evaluation results are discussed in Chapter 6 . Chapter 7 discusses about the basic idea of the extension of the proposed methods for the curve scenario and some considerations. Finally we conclude this paper with some observations on further researches in Chapter 8 .

Chapter 2

PRELIMINARIES

2.1. Characteristics of VANETS

Because VANETs are a subclass of MANETs, VANETs inherit important characteristic from MANETs, which means that VANETs have no infrastructure. However, VANETs behave fundamentally different from MANETs. Constraint on mobility, driver's behavior, and high speed of the vehicle create unique characteristics which have influence on the applications in IVC networks. The major differences are as follows [3]:

a) Rapid changes in VANETs topology are difficult to manage. Due to high relative speed between the vehicles, network's topology changes very fast.

b) The IVC network is subject to frequent fragmentation, even at high rate of IVC deployment. Moreover, VENET's connectivity depends on the scenario.

c) The IVC network has a small effective network diameter. Rapid changes of link's connectivity cause many paths to disconnect before they can be utilized.

d) There is no significant power constraint, unlike other types of MANETs which rely on battery life.

e) VANETs are generally of potentially large-scale: the scale of the VANETs could be quite large in the center of the cities or highways at the entrance of the cities.

f) Density of VANETs is variable: density of the network depends on density of the vehicles which highly change. The network's density could be dense in the traffic jam situation and could be sparse in the suburban traffics.

g) The topology of the network could be affected by the driver's behavior due to driver's reaction to the messages. In other words, the contents of the message have an influence on network topology.

2.2. Broadcast Storm Problem

When talking about broadcasting, a simple and straight-forward approach to perform broadcast is by flooding. In this approach, the vehicle receiving a broadcast message for the first time has an obligation to rebroadcast the message. In a CSMA/CA environment, disadvantages of flooding approach are as follows [4]:

a) Redundant rebroadcasts: When a host decides to rebroadcast a broadcast message to its neighbors, the message might have been already received by many of those neighbors.

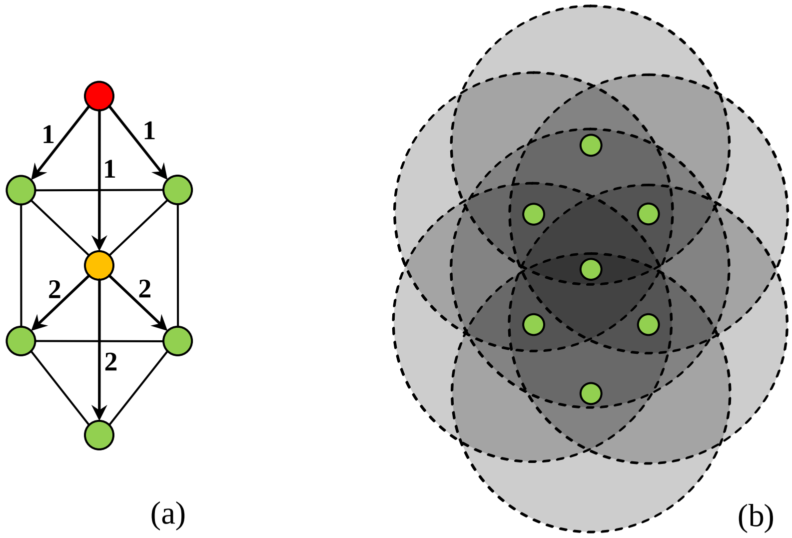


Fig. 4. (a) The optimal broadcasting schedules. Connectivity between any two vehicles is represented by links. Red node is the source vehicle, and orange node is the rebroadcasting vehicle.
(b) The signal overlapping problem related to the scenario in (a)

Fig. 4(a) demonstrates how much redundancy could be generated. In this scenario, only two transmissions by the red and orange vehicles are sufficient to complete a broadcast as opposed to seven transmissions caused by flooding. The main reason for the redundancy is the fact that the radio signals from different antennas may overlap with each other as presented in Fig. 4(b). The gray levels in the figure indicate the levels of signal overlapping. In the worst case, an area can be overlapped seven times.

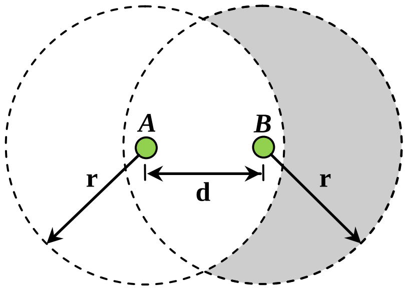


Fig. 5. Additional area that can benefit from a rebroadcast, when *A* broadcasts the message and *B* decides to rebroadcast the message

Let S_A and S_B denote the circle areas covered by *A*'s and *B*'s transmissions, respectively. The additional area that can benefit from *B*'s rebroadcast is represented by the gray region, denoted as $S_{B\text{-}A}$. Let *r* be the radii of S_A and S_B, and *d* be the distance between *A* and *B*, as shown in Fig. 5. $|S_{B\text{-}A}| = |S_B| - |S_{A\cap B}| = \pi r^2 - \text{INTC}(d)$, where INTC(d) is the intersection of the two circles centered at two points distanced by *d*.

$$\text{INTC}(d) = 4\int_{d/2}^{r} \sqrt{r^2 - x^2}\, dx \tag{1}$$

When $d = r$, the coverage area $|S_{B\text{-}A}|$ is the largest, which equals:

$$\pi r^2 - \text{INTC(d)} = r^2\left(\frac{\pi}{3}+\frac{\sqrt{3}}{2}\right) \approx 0.61\pi r^2 \quad (2)$$

This means that rebroadcast can provide only 0-61% additional coverage over the area already covered by previous broadcasting. So the efficient broadcast protocol should have the additional coverage area close to 61% as much as possible.

b) Contention: After the source vehicle broadcasts the message, if many of its neighbors decide to rebroadcast the message, these transmissions may severely contend with each others. According to Fig. 6, assuming the case of number of vehicles (n) = 3, let B and C be the two receiving vehicles and they are randomly located within A's transmission range. C will contend with B in case where C is located in $S_{A\cap B}$ area. Undoubtedly, the contention is higher as n increases.

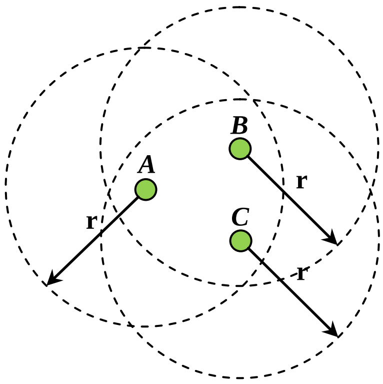


Fig. 6. Contention in message broadcasting

c) Collision: Because of the deficiency of backoff mechanism, the lack of RTS/CTS dialogue, and the absence of Collision Detection (CD), collisions are more likely to occur and cause more damage.

2.3. IEEE 802.11 MAC Specification

Most of broadcasting methods are based on wireless network utilizing IEEE 802.11 Medium Access Control (MAC) with Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA) scheme. In this environment, the communication can be done directly or indirectly. In the latter case, the multi-hop communication is used, where the message generated from the source vehicle is relayed by intermediate vehicles before reaching the destination vehicle. Hidden Node Problem, where a vehicle is not able to ascertain whether its neighbors are busy on receiving message from another neighbor or not, is one of the difficulties in both MANETs and VANETs. In order to overcome this problem in unicasting scheme, Request To Send / Clear To Send / Data / Acknowledgement (RTS/CTS/Data/ACK) have been applied. However, this procedure may not proper to use in broadcasting scheme for VANETs because of difficulty in coordinating and cost in bandwidth. Therefore, the only requirement for the broadcasting vehicles is that they sense the channel before broadcasting but, unfortunately, it does not prevent collisions from hidden nodes. Moreover, in congested network, a significant amount of collisions occur leading to many dropped packets. Because of this reason, the effective broadcasting methods try to limit the probability of collisions by limiting the number of rebroadcast in the network.

2.4. Existing Standard in Vehicular Environment

2.4.1. Dedicated Short Range Communication

Dedicated Short Range Communication (DSRC) is a short to medium range wireless communication exclusively designed for both public safety and private operations in road-to-vehicle communications and vehicle-to-vehicle communications based on a variant of the IEEE 802.11a. It should be noted that DSRC is a general purpose communications link between the vehicle and the roadside [5].

The primary goal of DSRC is to enable public safety applications that can save lives and improve traffic flow e.g. Electronic Tool Collection (ETC), digital map update, Rear-end Collision Avoidance, Extended Emergency Brake Light, etc [6].

In 1999, a spectrum of 75 MHz width at 5.9 GHz was assigned by the U.S. Federal Communication Commission (FCC) to DSRC. According to Fig. 7, the DSRC spectrum is structured into seven 10 MHz wide channels. Channel 178 is the control channel (CCH), which is restricted to safety communications only. The two channels at the ends of each side of the spectrum are reserved for special purposes. The rest are service channels (SCH) available for both safety and non-safety usage. The control channel is to be regularly monitored by all vehicles. In the meantime, a licensed roadside unit could use the control channel to announce its services to approaching vehicles typically non-safety applications and conduct the actual application in one of the service channels. For example, a roadside unit could announce a local digital map update in the control channel and transfer this data to interested vehicles in a service channel.

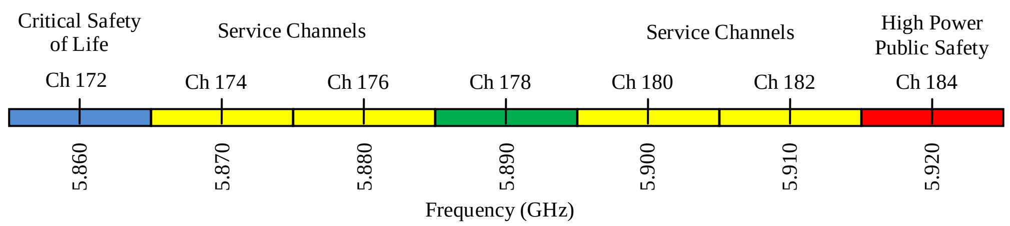


Fig. 7. DSRC spectrum band and channels

Similar to DSRC, the efforts to set spectrum aside for vehicular usage are occurring in other parts of the world. In Europe, it is getting close to allocating 30 MHz of spectrum band in the 5 GHz range for the express of supporting vehicular communications for safety and mobility applications.

In Japan, DSRC with a spectrum of 80 MHz width at 5.8 GHz was already standardized as ARIB STD-T75 and is mainly used in ETC application. Moreover, in order to support multiple applications both IP and non-IP application, Application Sub-Layer (ASL) for DSRC was proposed and standardized as ARIB STD-T88 [8]. Some examples of multiple applications with ASL are information services with IP application, car discrimination system at parking areas and payment at gas station. Recently, the ITS on-board units has also been developed for utilizing DSRC in the services such as smooth passage through all types of gates, regional guides according to location and needs and timely driving support information.

2.4.2. IEEE 802.11p: Wireless Access in Vehicular Environments

In 2004, the effort to standardizing DSRC radio technology is migrated to the IEEE 802.11 standard group as DSRC radio technology is essentially IEEE 802.11a adjusted for low overhead operations in the DSRC spectrum. Within IEEE 802.11, DSRC is known as IEEE 802.11p WAVE, which stands for Wireless Access in Vehicular Environments. It should be noted that IEEE 802.11 is not a standalone standard, but it is intended to amend the overall IEEE 802.11 standard. It should be noticed that the IEEE 802.11p is making progress and moving closer towards acceptance by the general IEEE 802.11 working group. It is projected to pass letter ballot in the first half of 2008 [9] and roughly scheduled to be published in 2009 [10].

At the time of writing, the IEEE 802.11p draft version 5.0 had already gone through its recirculation ballot in the IEEE 802.11 working group. The ballot result reached 85% which is well over the critical approval rate of 75%. Presently, this draft will be moved to the sponsor ballot process [11].

Basically, the IEEE 802.11 standard is meant to:

- Describe the functions and services required by WAVE-conformant stations to operate in a rapidly varying environment and exchange messages without having to join a Basic Service Set (BSS) as in conventional IEEE 802.11.
- Define the WAVE, signaling technique and interface function that are controlled by the IEEE 802.11 MAC.

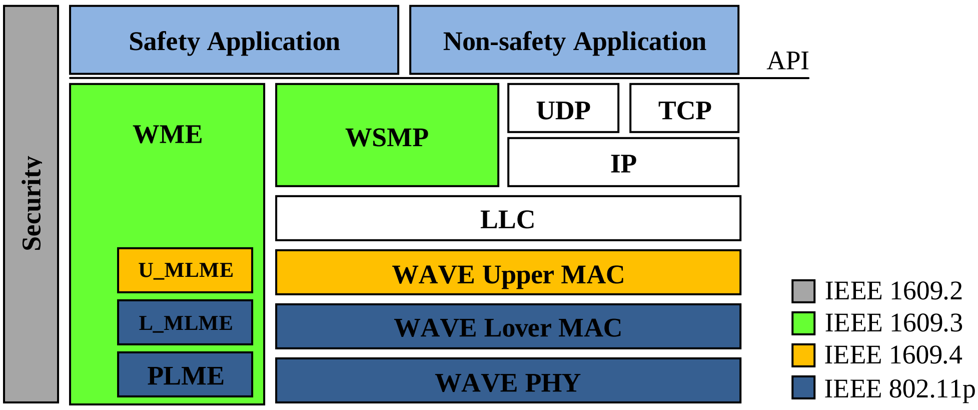


Fig. 8. DSRC standards and communication stack

According to Fig. 8, IEEE 802.11p WAVE is only a part of standards protocols for DSRC based operations. The IEEE 802.11p standard is limited by the scope of IEEE 802.11, which is strictly a MAC and PHY level standard that meant to work within a single logical channel. All knowledge and complexities related to the DSRC channel plan and operational concept are taken care of by the upper layer IEEE 1609 standards.

2.4.2.1. WAVE mode

Because the vehicular safety communications required an instantaneous data exchange capabilities and cannot afford scanning channels for the beacon of a BSS and executing multiple handshakes to establish the communications, IEEE 802.11 MAC operations are too much time-consuming to be applied in IEEE 802.11p.

Thus, it is necessary for all IEEE 802.11p radios to be in the same channel and configured with the same Basic Service Set Identification (BSSID) to enable safety communications.

IEEE 802.11p introduced an amendment for IEEE 802.11 called “WAVE mode”. In the WAVE mode, a station is allowed to transmit and receive data frames with the wildcard BSSID value and without the need to priori belong to a Basic Service Set (BSS). The wildcard BSSID is composed of all “1s” and used by the current IEEE 802.11 for only management frames of subtype probe request. Based on this approach, two vehicles can immediately communicate with each other upon encounter without any additional overhead as long as they operate in the same channel using the wildcard BSSID.

2.4.2.2. WAVE BSS

Because the overhead of traditional BSS connection setup may be too expensive in the vehicular environment, IEEE 802.11p introduces a new BSS type called WAVE BSS (WBSS). WBSS is formed by first transmitting an on demand beacon which is used for advertise a WAVE BSS. Such advertisement contains the needed information for receiver stations’ upper layer mechanisms above the IEEE 802.11 to understand the services offered in the WBSS in order to decide whether to join, as well as the information needed to configure itself into a member of the WBSS. In other words, a station can decide to join and complete the joining process of a WBSS by only receiving a WAVE advertisement with no further interactions.

2.4.2.1. Expanding wildcard BSSID usage

From the safety aspect, the use of wild card BSSID is also supported even for a station belonging to a WBSS. In other words, a station in WBSS is still in WAVE mode, and can still transmit or receive frames with the wildcard BSSID in order to reach all neighboring stations in cases of safety concerns.

Chapter 3

ALARM MESSAGE BROADCASTING

In case there is a collision accident on a road, generally, blocking the line-of-sight by the leading vehicles or bad weather are some factors that prevent the drivers of the vehicles, which are moving toward the accident place, from perceiving the accident in front. If the accident information is not given to the drivers and they cannot make a decision on their suitable actions in time, then it can lead to a chain collision or a secondary accident either with the accident vehicle or a vehicle which brakes suddenly due to the accident. However, it is possible to decrease the risk of such an accident by providing the necessary information about the accident that has just happened to those vehicles and their drivers. The alarm message broadcasting can be applied to the situation of such an accident as shown in Fig. 9.

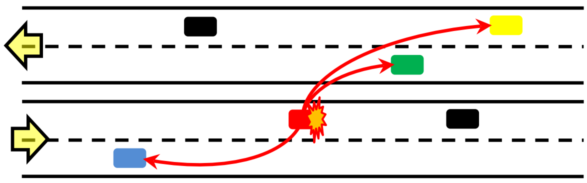


Fig. 9. Alarm message broadcasting application

According to Fig. 9, when the red vehicle located in the middle has an accident and recognizes itself as crashed by using some sensors that detect events like e.g. airbag ignition, level of sound (dB), this vehicle will start to broadcast the 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.

- According to the country regulation, the maximum allowed speed of the vehicle is about 100 km/hr or 27.8 m/s. 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 [1], but 0.1 s will be used for the acquisition of the information by various sensors and 0.1 s for processing the information before sending as the alarm message. Therefore, at most only 0.1 s is left for vehicle-to-vehicle communication. 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.

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.

Chapter 4

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, high 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 [4]. 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:

4.1. Probability Based Method

In the probability based method, each vehicle decides to rebroadcast the message with some probability in order to decrease data redundancy and collision. The probabilistic scheme proposed by Y. Tseng et al. [4] is similar to Simple Flooding except that the vehicles only rebroadcast with some predetermined probability. Normally, in the network, multiple vehicles share similar transmission coverage. Thus, to have some vehicles not rebroadcast the message reduces redundancy in the network. In other words, network resources can be saved without harming delivery effectiveness. This method can be utilized by assigning probability P to a vehicle to rebroadcast the message, on its receiving a broadcast message for the first time. Cleary when P = 1, this method is equivalent to Simple Flooding. In order to response to the contention and collision problems, a small random delay (a number of slots) should be inserted before rebroadcasting the message so that the timing of rebroadcasting can be differentiated.

H. Alshear et al. [13] proposed the method where a vehicle rebroadcasts with average probability $\bar{\theta}$, which is determined dynamically in term of the vehicles' density in the predetermined distance. This method is different from the deterministic rebroadcast method proposed in [4], because this method always assigns the same probability to rebroadcast the message which might cause redundancy in the broadcasting for the case where the rebroadcast probability is high or may produce poor message delivery ratio in a network with low rebroadcast probability. The idea of this method is to reduce the set of forwarding or rebroadcasting vehicles based on an optimal choice for the rebroadcast probability at each vehicle so that the message delivery ratio within the predetermined distances is maintained. In this method, each vehicle determines its own rebroadcast probability depending on its local information within two-hops. The local information is simply obtained from the periodical "Hello" packets. By this approach, the rebroadcast probability is dynamically determined depending on the estimation of local vehicles density around each vehicle. Furthermore, by exchanging the local information between vehicles, this method also has the characteristics of Topology Based Methods, which is described in 4.4. , as well.

Although the required broadcasting time is rather short, this kind of methods 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.

4.2. Area Based Method

Most of the broadcasting methods in VANETs proposed in recent years are based on the assumption that many vehicles do or will soon utilize navigation systems like the Global Positioning System (GPS), and they are actually utilizing this technology. Although today's GPS receivers are accurate to within 100 meters, this is expected to dramatically improve during next several years. Future navigation systems will use differential correction or integrate inertial sensors to enhance the accuracy of positioning down to a few meters or better.

Based on the position information received from GPS, each vehicle decides to rebroadcast the message by considering the additional coverage area of the transmission range achieved by the rebroadcasting.

Assume that a vehicle receiving the broadcast message is located only a few meters away from the source vehicle. If this vehicle is supposed to rebroadcast the message, the additional coverage area covered by the rebroadcasting of this vehicle is rather small. On the opposite way, the larger additional coverage area can be achieved if the vehicle that is supposed to rebroadcast the message is located at the boundary of the source vehicle's transmission range. As shown in Fig. 10, *B* and *C* are located in the transmission range of *A*. Assuming that the transmission range is the same for all vehicles, the area which can be covered by *A* and *C*'s rebroadcasting covers the area that *B* can cover. Thus, it would be waste of wireless bandwidth if *B* rebroadcasts the message.

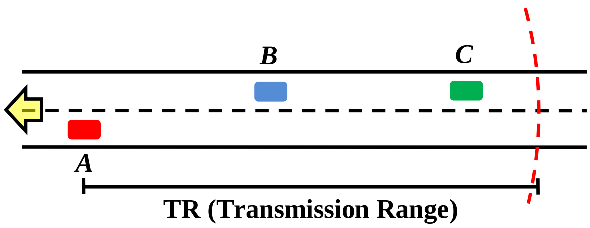


Fig. 10. Redundant message rebroadcasting

The Area Based Method can be roughly categorized into two categories as follows:

4.2.1. Distance Based Scheme [2], [14]

A vehicle utilizing this scheme compares the distance between itself and each neighbor vehicle that has previously rebroadcast the same message before rebroadcasting the message. As described in the previous paragraph of this section, the longer becomes the distance, say *d*, between the source vehicle and rebroadcasting vehicle, the larger additional coverage area will be achieved.

Basically, before a rebroadcast message is actually sent, the vehicle supposed to rebroadcast may have heard the same message several times. Let d_{min} be the distance to nearest node from which the same message is heard. Rebroadcasting will provide additional coverage no more than $\pi r^2 - INTC(d_{min})$ as described in section 2.2. of the Broadcast Storm Problem. d_{min} will be used as the factor to determine whether to rebroadcast the message or not. If d_{min} is smaller than some distance threshold *D*, the vehicle will not rebroadcast the message. The basic idea of the Distance Based Scheme can be represented in Fig. 11.

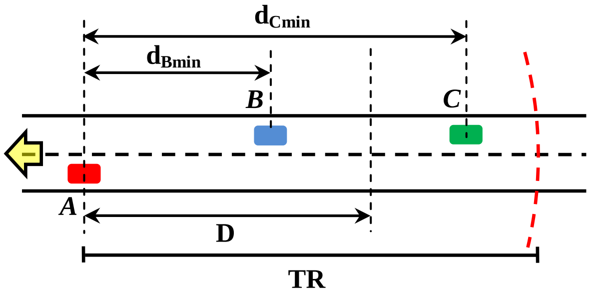


Fig. 11. Message Rebroadcasting utilizing Distance Based Scheme

4.2.2. Location Based Scheme

The Location Based Scheme uses a more precise estimation of expected additional coverage area to determine whether to rebroadcast or not. The Location Based Scheme can be categorized into two categories based on the approach used to determine the delay time in broadcasting: one approach is waiting time and the other approach is contention window.

4.2.2.1. Waiting Time Based Approach [15], [16]

In this approach, the broadcasting methods assume that the message header contains the position of its sender. According to the knowledge of its own position, the vehicle that received the broadcasting message can determine a waiting time or delay time depending on the distance between itself and the source vehicle in such a manner that the waiting time is shorter for the further receiver.

$$WT(d) = -\frac{MaxWT}{Range} * \hat{d} + MaxWT \tag{3}$$

where WT = Waiting Time
d = distance to the sender
MaxWT = Maximum Waiting Time
Range = Transmission Range
$\hat{d}$ = min {d, Range}

The equation (3) proposed in [15] is the example of the functions used by this approach to determine the waiting time. It should be noted that the equations proposed in other papers are slightly different from (3).

The reason why the vehicle should wait rather than rebroadcast the message immediately can be described as follows. Consider the nature of broadcasting of radio waves, that is, when the source vehicle broadcasts the message, multiple vehicles located in its transmission range can receive the same message simultaneously. Then, immediate rebroadcasting by these vehicles would cause burst-like traffic and collision on the transmission channel. Mostly, the Medium Access Control (MAC) in ad hoc network is based on Carrier Sense Multiple Access (CSMA) mechanism. It is well known that CSMA suffers from instability when the capacity of the channel is fully utilized. Thus, this approach tries to avoid peak and collision of traffic by forcing the rebroadcasting vehicle to wait for some waiting time before rebroadcasting the message. Moreover, by using the function of Waiting Time (WT), vehicles located at the boundary of source vehicle’s transmission range take part in broadcasting the message more quickly than other nodes, resulting in larger additional coverage area in rebroadcasting.

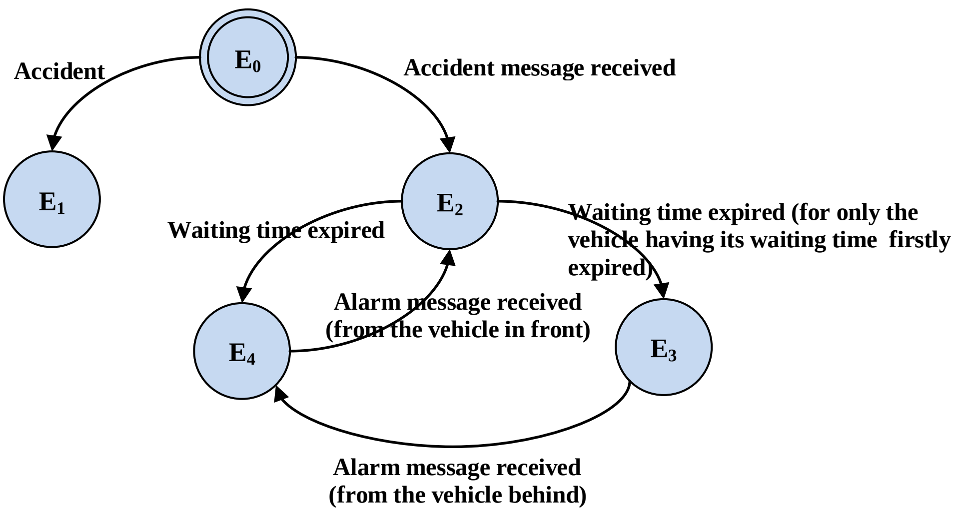


Fig. 12. Finite State Machine representing the behavior of a vehicle in Alarm Message Broadcasting Application

Normally, the behavior of the vehicle utilizing this scheme in Alarm Message Broadcasting Application is represented as a finite state machine in Fig. 12. Initially, all vehicles are in the state E_0. In case that the vehicle has an accident, it moves to state E_1, where it starts to broadcast the message. All the vehicles receiving the message move to state E_2 where they wait according to a waiting time determined by (3). The first vehicle having its waiting time expired moves to state E_3 which means that it becomes the rebroadcasting vehicle. The other vehicles which were in state E_2 move to state E_4 because it is useless for those vehicles to rebroadcast the message when there is a vehicle that can rebroadcast the message with larger additional coverage area. When the rebroadcasting vehicle in E_3 receives a message from another vehicle located behind it, it moves to state E_4. The vehicles which are in state E_4 move to state E_2 in case that they receive the message coming from a rebroadcast node in front of them (situation of overtake).

4.2.2.2. Contention Window Based Approach [16], [17], [18]

This approach assumes that a vehicle generates a broadcasting message that has to be propagated along a strip in a specific direction. Each broadcasting message contains a header field that includes the spatial coordinates of the source vehicle and the message-propagation direction.

Assume that each transmission message can be correctly received with in given coverage area. Such an area is partitioned into non-overlapping sectors. Each sector is associated to a contention window, as represented in Fig. 13. Upon receiving the broadcasting message, the vehicles determine the sector they belong to by comparing their coordinates with those of the source vehicle. Then, the vehicles belonging to each sector independently select a backoff value in the contention window. According to CSMA/CA scheme of IEEE 802.11, backoff counters are decremented by one at each idle slot, till zero to start to rebroadcast the message. Size of the contention window used in the approach is one factor that guarantees that the vehicles in a further sector always rebroadcast before those in other closer sectors.

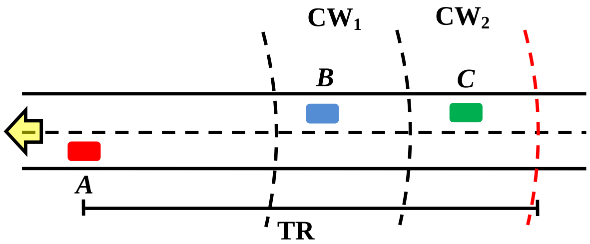


Fig. 13. Message Rebroadcasting utilizing Location Based schemes with Contention Window Based Approaches

An Area Based Method named Optimized Dissemination of Alarm Message (ODAM) [19] assigns the duty of message rebroadcasting to only one vehicle that has been chosen among the neighbors of the source vehicle. This chosen vehicle is called relay. The choice is made in order to ensure the largest additional coverage area which has not yet been covered by the source vehicle. Consequently, the furthest neighbor from the source vehicle will be chosen as the relay. To make the furthest vehicle from the source vehicle become a relay, 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 suitable for the VANETs due to the efficiency 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.

4.3. Cluster Based Method

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.

T. D.C. Little et al. [20] proposed a broadcasting scheme based on interconnected blocks of vehicles, referred as cluster. Normally, in the highway scenario, this kind of node arrangement can be used to represent usual highway behavior of vehicles where vehicles tend to travel in blocks with gaps occurring between consecutive blocks.

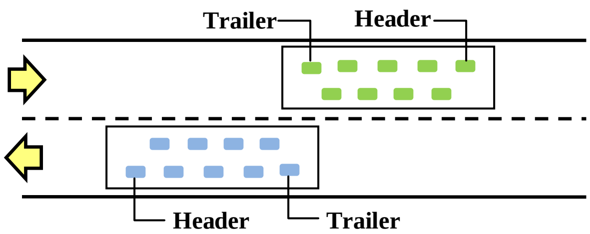


Fig. 14. Example illustrating clusters traveling along a highway with the vehicles assuming the role of header and trailer

As shown in Fig. 14, each cluster has a header and trailer, which are located at the front and rear of each cluster, and are responsible for communication with other clusters while other vehicles are described as intermediate vehicles. By this way, this method can limit the congestion caused by a large number of participating vehicles. Within the cluster, messages are shared with all vehicles to both facilitate header/trailer replacement and general awareness of disseminated messages. The intermediate vehicles retain the passive role of receiving messages and acknowledgements from other blocks and forwarding them to the header or trailer sharing the information within the cluster. The messages originated from the intermediate vehicles are immediately sent to header or trailer.

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.

4.4. Topology Based Method [21], [22]

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.

4.5. Cut-through Based Method [26]

According to the objective of safety application, target about the delay of alarm message broadcasting is quite strict. However, all the broadcasting methods mentioned above, including ODAM, mainly consider solving the Broadcast Storm Problem and they have a defect of rather long delay for the propagation of the alarm message. Thus, some other 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 frame is entirely received [25]. 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 [26]. 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), although the bandwidth is generally limited in wireless technology.

Table I illustrates the advantage and disadvantage points of the broadcasting methods mentioned above.

TABLE I. COMPARISON OF BROADCASTING METHODS

Broadcasting Schemes	Advantage	Disadvantage
Simple Flooding	• Simple • Reachability is high in sparse network	• Rebroadcasting is redundant • Reachability is low in congested network (collision)
Probability Based Method	• Eliminate some redundant rebroadcasting	• Rebroadcasting is redundant when probability to rebroadcast is high • Reachability is low when probability to rebroadcast is low • Reachability is low in sparse network • Reachability is low in congested network (collision)
Area Based Method	• Eliminate most redundant rebroadcasting	• Rebroadcasting node have to wait for some amount of time • Reachability is low in sparse network • Reachability is low in congested network (collision)
Cluster Based Method	• Eliminate most redundant rebroadcasting • Represent usual highway behavior of vehicles	• Cost to maintain the cluster structure is high • Reachability is low when mobility increases • Reachability is low in congested network (collision)
Topology Based Method	• Efficient in terms of redundancy and collision reduction • Reachability is high in sparse network	• High control traffic required for achieving the knowledge of the net work topology • Reachability is low in congested network (collision)
Cut-through Based Method	• Low delay in broadcasting	• Multiple Access Interference problem • Wide bandwidth is required

Chapter 5

PROPOSED METHODS FOR THE ALARM MESSAGE BROADCASTING

As discussed in Chapter 4 , all the existing conventional broadcasting methods have serious problems for the application of alarm message broadcasting for the VANETs. All these 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. To achieve the targets of safety application, we propose two new alarm message broadcasting methods that utilize multiple channels available e.g. in IEEE 802.11 standard as well as GPS function. These two proposed methods are different from each other in timing when the vehicles can start to rebroadcast the alarm message. In both methods, high priority to rebroadcast the message is given to some specific vehicles to avoid the interference problem and the multiple channels are utilized effectively in the proposed methods.

5.1. Assumptions for VANETs

This thesis 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 an arbitrarily 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.

5.2. 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 to receive the alarm message completely should be small and it should be at least less 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.

5.3. Proposed Methods

5.3.1. Proposed Method 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 rebroadcast the message. Moreover, the largest additional coverage area can be achieved.

The scenario in Fig. 15 will be used to further describe and illustrate the basic idea of the proposed method. In Fig. 15, *A* is assumed to have just had an accident, and *B* and *C* are assumed to be in the transmission range of the transceivers equipped on *A*. After *A* recognizes the accident event based on the information received from its 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* of the accident according to the time sequence shown in Fig. 16.

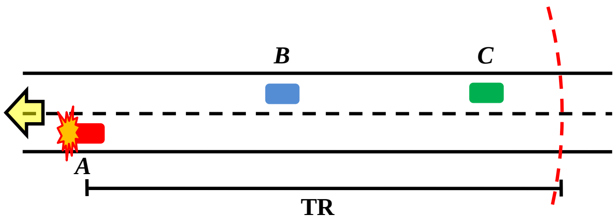


Fig. 15. Alarm message broadcasting scenario

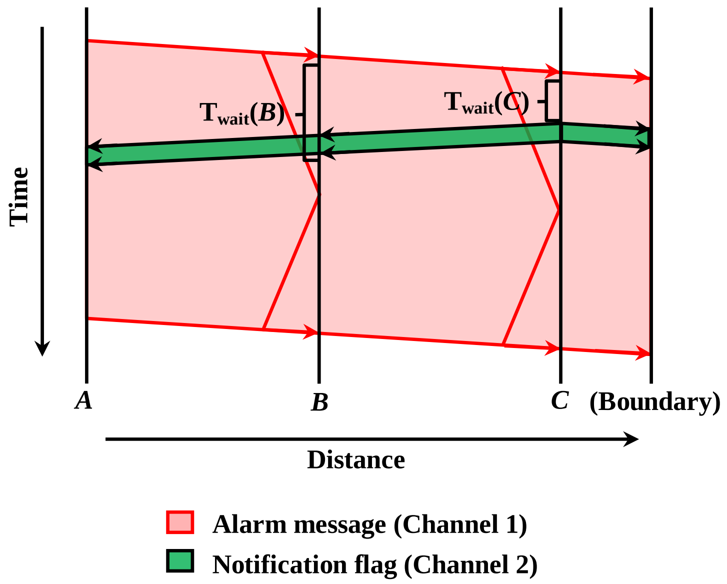


Fig. 16. Basic idea of the proposed method 1

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 the waiting time of a vehicle expires and it has not received 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 has received a notification flag before the expiration of its waiting time or before its complete reception of the alarm message, then it decides not to rebroadcast 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*.

5.3.2. Waiting Time Calculation for the Proposed Method 1

For the proposed method 1, the waiting time calculation is based on the basic idea that the notification flag 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 they completely receive the alarm message from the source vehicle. This basic idea can be elaborated as follows.

In Fig. 17, an imaginary vehicle is assumed to be located at the boundary of the transmission range of *A* and this assumed vehicle starts to broadcast the notification flag on channel 2 after it recognizes that the message it has started to receive is the alarm message. The notification flag will be received by all the vehicles between the assumed vehicle and the source vehicle. However, if all these intermediate vehicles rebroadcast the alarm message on the instant they finish receiving the message completely, this almost simultaneous multi-rebroadcasting will lead to high collision. In order to avoid such collision and achieve the largest additional coverage area, the notification flag is expected to be received by these intermediate vehicles before their complete reception of the alarm message. Thus the 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 the notification flag and the alarm message should be taken into account and the waiting time should become longer for an intermediate vehicle closer to the source vehicle.

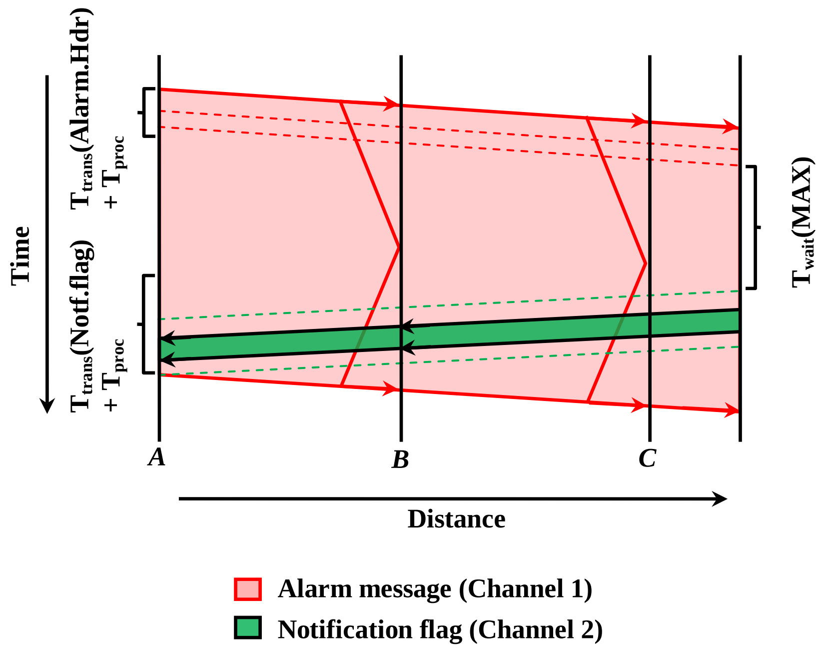


Fig. 17. Basic idea of waiting time calculation in the proposed method 1

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

$$T_{wait}(x) = \frac{(TR - D_{SX})}{TR} * MAX\{T_{wait}(MAX),\ T_{wait}(MIN)\} \tag{4}$$

$$T_{wait}(MAX) = T_{trans}(Alarm) - \left[T_{trans}(Alarm.Hdr.) + T_{proc} + T_{trans}(Notf.Flag) + \left(2 * \frac{TR}{V_{prop}}\right)\right] \tag{5}$$

$$T_{wait}(MIN) = T_{trans}(Alarm.Hdr) + T_{proc} + \left(2 * \frac{TR}{V_{prop}}\right) \tag{6}$$

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)

By utilizing (4), (5) and (6), 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.

5.3.3. Proposed Method 2

The proposed method 1 can shorten the broadcasting time by reducing the probability of collision in the alarm message broadcasting and assigning the highest priority to rebroadcast the alarm message to the furthest vehicle. The broadcasting time is defined as the total 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. The main objective of the proposed method 2 is to further shorten the broadcasting time than the proposed method 1. 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.

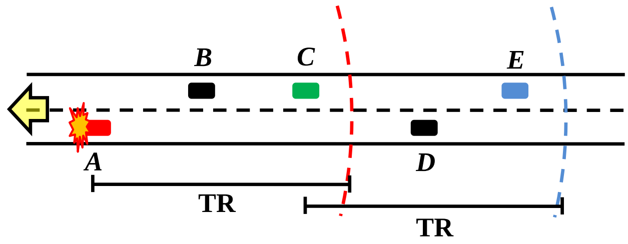


Fig. 18. Alarm message broadcasting scenario

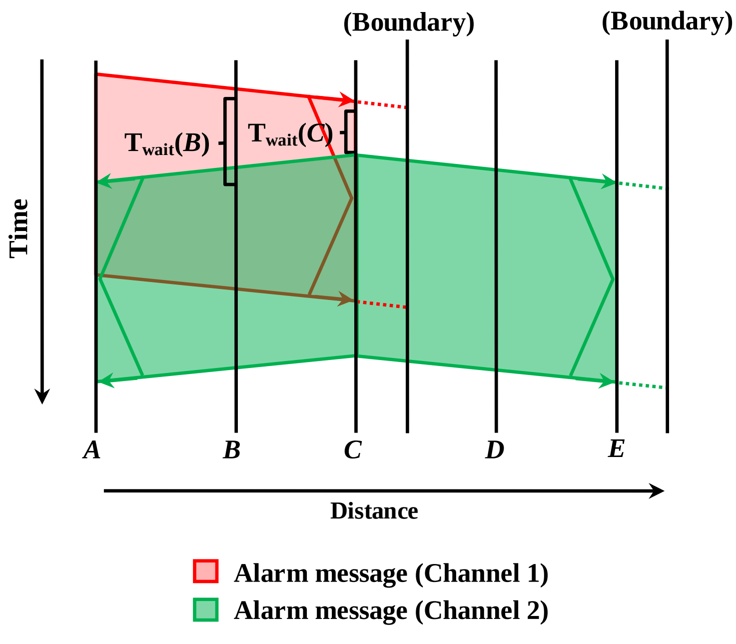


Fig. 19. Basic idea of the proposed method 2

The scenario in Fig. 18 will be used to further describe and illustrate the basic idea of the proposed method 2. In Fig. 18, *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 any other following vehicles before the expiration of its waiting time, then it decides not to rebroadcast the alarm message. In Fig. 19, 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*.

5.3.4. Waiting Time Calculation for the Proposed Method 2

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. 20, 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 be 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 area. 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 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.

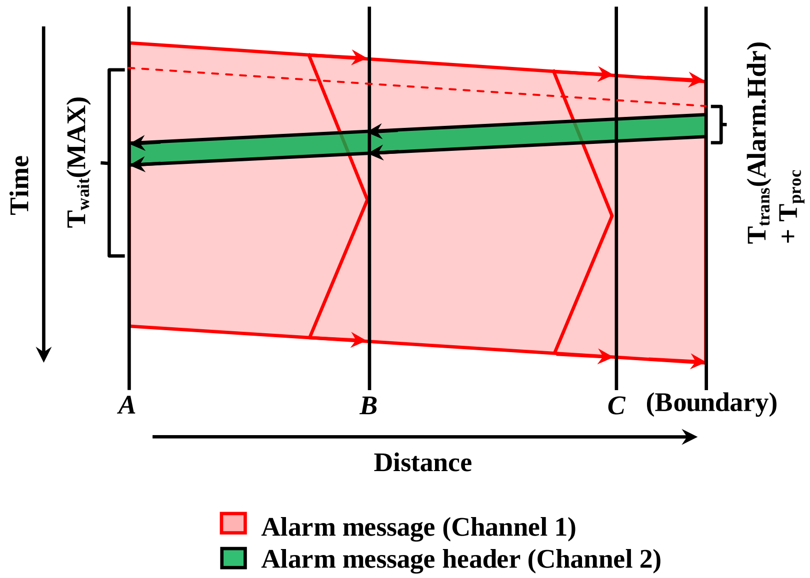


Fig. 20. Basic idea of waiting time calculation in the proposed method 2

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 Δ:

$$T_{wait}(x) = \frac{(TR - D_{SX})}{TR} * T_{wait}(MAX) \tag{7}$$

$$T_{wait}(MAX) = \left[T_{trans}(Alarm.Hdr) + T_{proc} + \left(2 * \frac{TR}{V_{prop}}\right)\right] * (1 + \Delta) \tag{8}$$

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

Similar to the waiting time calculation in the proposed method 1, by utilizing (7) and (8), 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.

After various experiments, 0.0 is chosen as the value of Delta about the broadcasting time required to cover the coverage distance. Further details about the value of Delta is described in Chapter 6

5.4. Frame Format

5.4.1. Format of Alarm Message and Notification Flag

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.

The frame format used in the proposed methods 1 and 2 is shown in Fig. 21 and is summarized as follows.

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

Type	Position X	Position Y	Position Z	Data
Alarm/Notf/Others	X	Y	Z	Alarm Info.
8 bits	32 bits	32 bits	32 bits	1,382 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

Fig. 21. Format of alarm message and notification flag

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 thesis 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.

5.4.2. Format of Alarm Message Data Field

The data field of the alarm message mentioned in Fig. 21 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).

Chapter 6

EVALUATION AND ITS RESULTS

6.1. Evaluation Scenario

In order to demonstrate the efficiency of the proposed methods, the average broadcasting time and the number of rebroadcasting vehicles of the proposed methods, 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 Chapter 4 . Schematic functional diagram of each vehicle or mobile node of the proposed methods is shown in Fig. 22, 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.

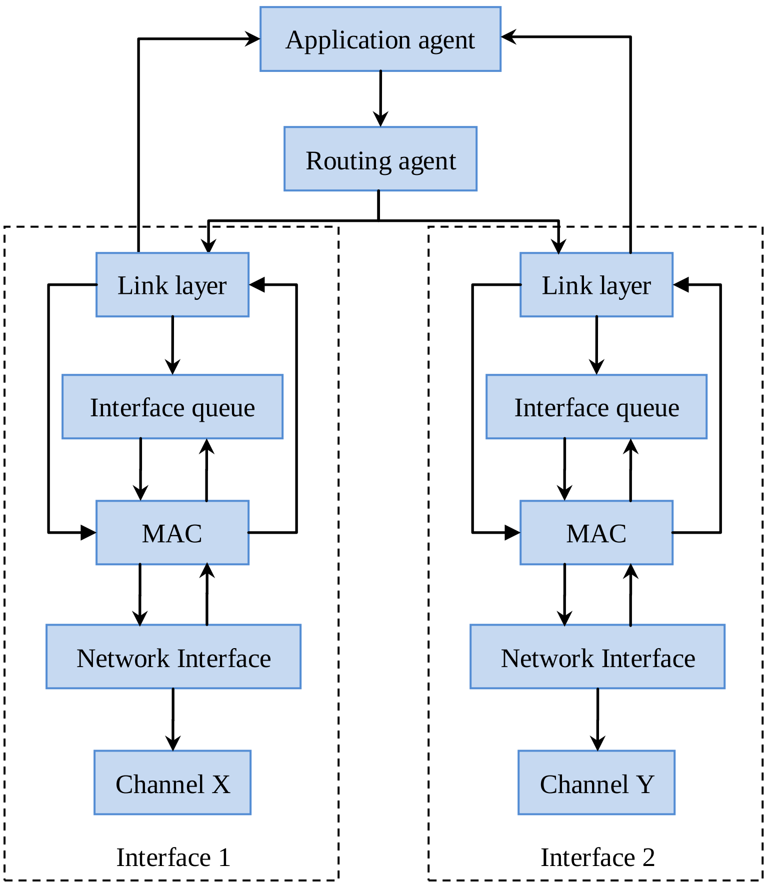


Fig. 22. Schematic functional diagram of a mobile node for the proposed method in NS-2 environment

Fig. 23 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 Chapter 5 , 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 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 II.

It should be noted that although the bandwidth of up to 54 Mbps has become realizable with the advent of hardware based on e.g. in IEEE 802.11 standard, the actual network bandwidth is usually much smaller than such maximum value. In the vehicular traffic scenarios, about 1 Mbps bandwidth can be achieved in the freeway or highway environment. In addition, the bandwidth shows a decreasing trend in accordance with the increasing distance between two consecutive vehicles [23].

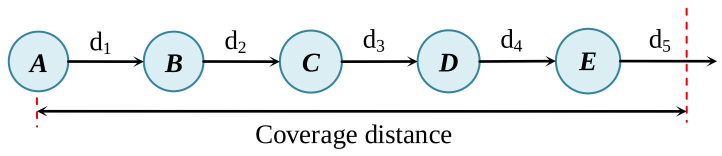


Fig. 23. Simulation topology

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

Simulation parameters	Value
Data speed	1 Mbps
Radio propagation speed	3×10^8 m/s
MAC layer	CSMA/CA
Propagation model	Two-ray ground
Antenna type	Omni antenna
Alarm message size	500-2500 bytes (default 1425 bytes)
Notification flag 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	-1.0-15.0 (default 0.0)
No. of channels	1 channel (Flooding method, ODAM), 2 channels (Proposed method 1), 3 channels (Proposed method 2)
Coverage distance	1000 m
Number of lanes	1-5 lanes (default 1 lane)
Lane width	3.5 m
No. of repetitions for simulation	100 times

6.2. Average Broadcasting Time

Fig. 24 shows the average broadcasting time of the above mentioned four 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. 24 and the following figures show the 95% confidence interval of the results concerned. It is understood that both of the proposed methods can achieve shorter broadcasting time than the pure flooding method, 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.

Fig. 25 and Fig. 26 illustrate the distribution of the broadcasting time of the proposed method 1 and the proposed method 2, respectively.

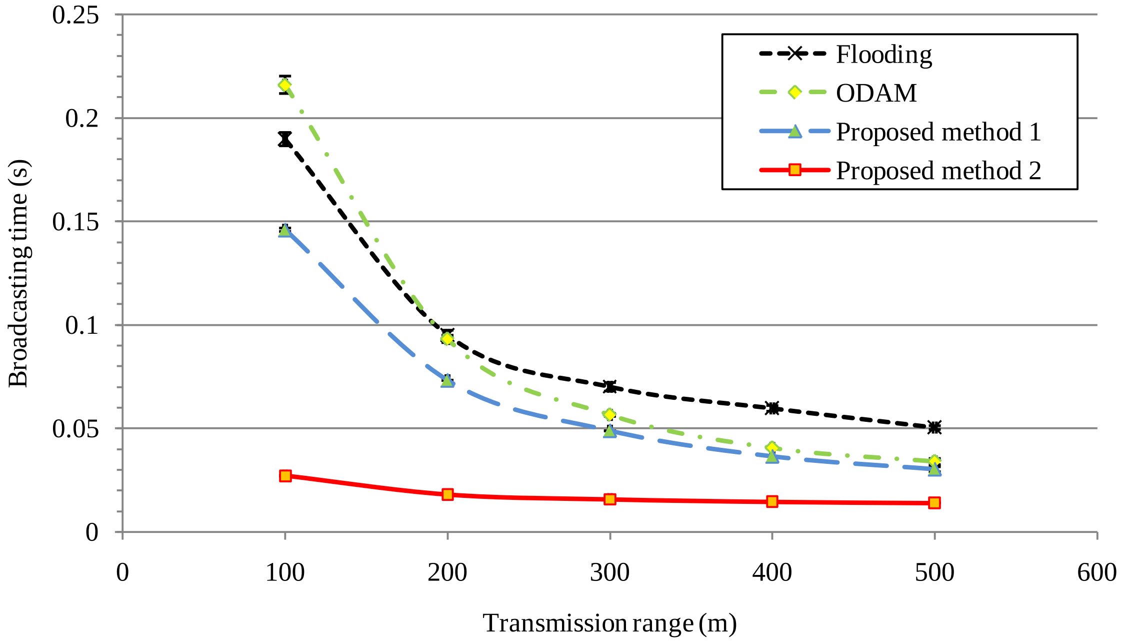


Fig. 24. Average broadcasting time of the proposed methods in comparison with flooding and ODAM

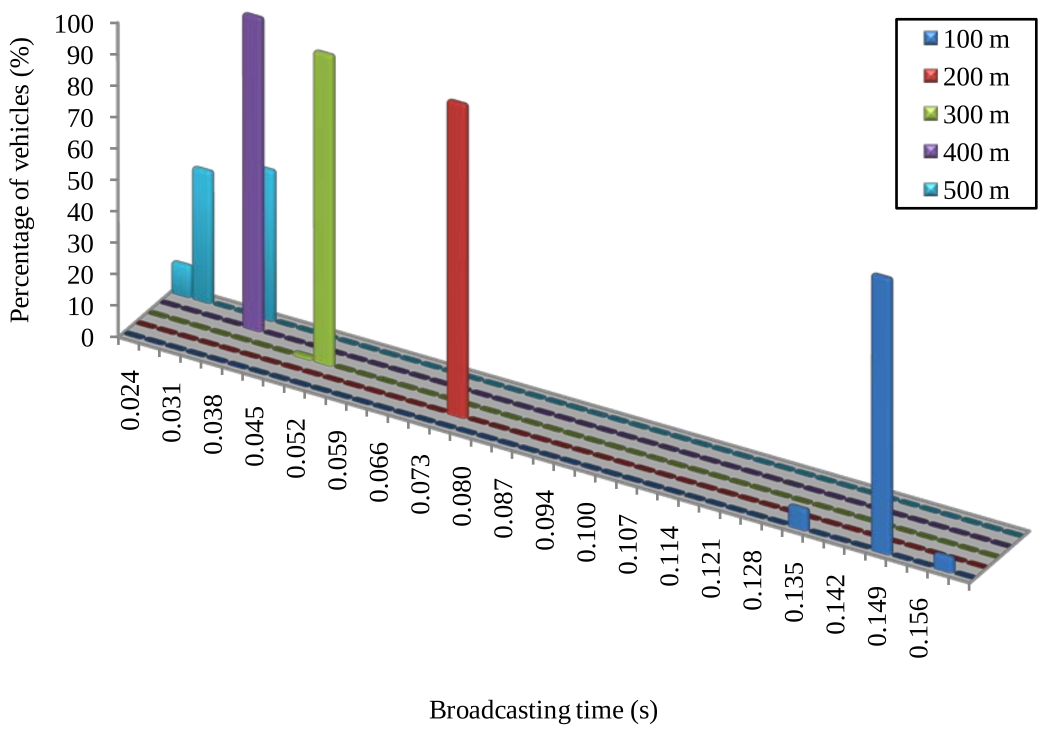


Fig. 25. Distribution of the broadcasting time of the proposed method 1

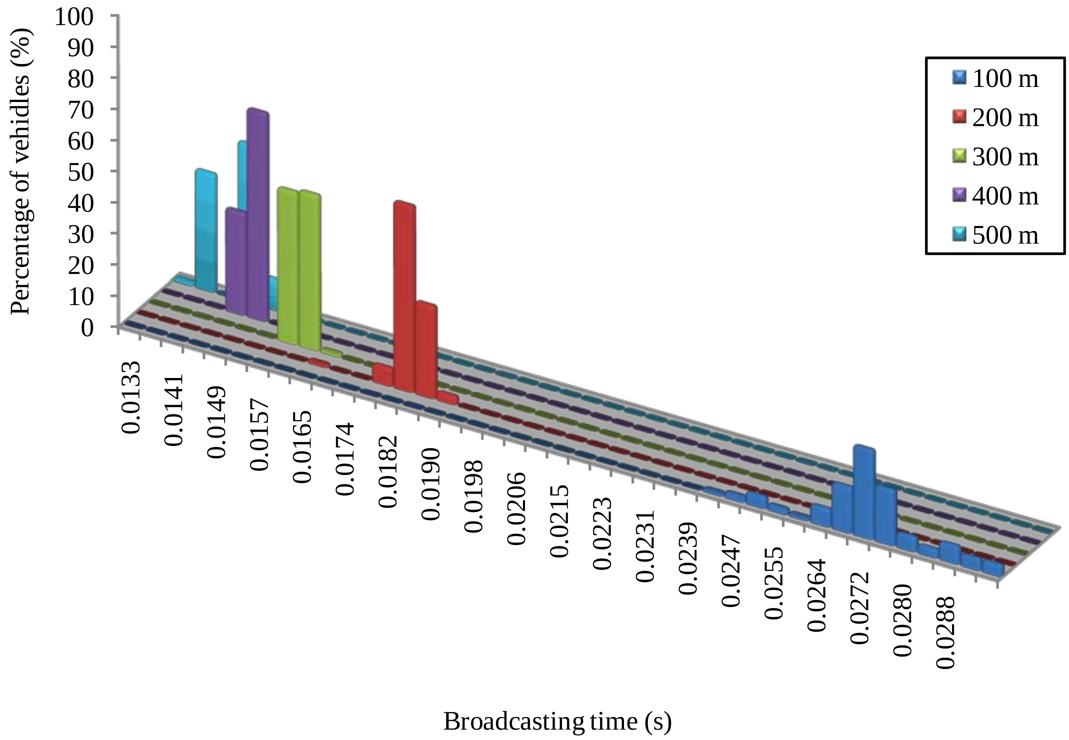


Fig. 26. Distribution of the broadcasting time of the proposed method 2

Compared with ODAM, the proposed method 1 can achieve the shorter average broadcasting time. The reason for this achievement is as follows. The proposed method 1 enables the intermediate vehicles in the transmission range from the source vehicle to make an appropriate decision on whether to rebroadcast the alarm message before their complete reception of the message by recognizing the notification flag and therefore the existence of the rebroadcasting vehicle. However, in ODAM, these intermediate vehicles have to completely receive the message and wait for the expiration of waiting time before they can make a decision on whether to rebroadcast the message. Furthermore, as the results of the overlap operation, the proposed method 2 can achieve much shorter average broadcasting time than the proposed method 1.

Because the proposed method 1 starts to rebroadcast the alarm message after the complete reception of the alarm message, main components of the average broadcasting time are the transmission time of the alarm message size 1,425 bytes and its processing time in each hop which are about 11.8 ms and 0.67 ms, respectively. However, in the proposed method 2 which 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 43 bytes, its processing time, waiting time in each hop and the transmission time of the alarm message size 1,425 bytes in the last hop, which are about 0.76 ms, 0.67 ms, less than 1.53 ms and 11.8, ms respectively.

The average broadcasting time of the proposed methods 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. The proposed method 1 can achieve shorter than 0.1 s average broadcasting time for the transmission range of over 200 m. However, the proposed method 2 can achieve much shorter than 0.1 s average broadcasting time for every transmission range in the evaluation.

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

Distance between any two consecutive vehicles:

Fig. 27 and Fig. 28 illustrate the influence of the distance between two consecutive vehicles on the average broadcasting time of the proposed methods. As the distance between any two consecutive vehicles 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. 29 and Fig. 30, resulting in the increase in the average broadcasting time of the proposed methods. The distribution of the number of hops of the proposed methods can be illustrated as in Fig. 31.

However, it can be noticed that the average broadcasting time of the proposed method 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 0.67 ms, respectively.

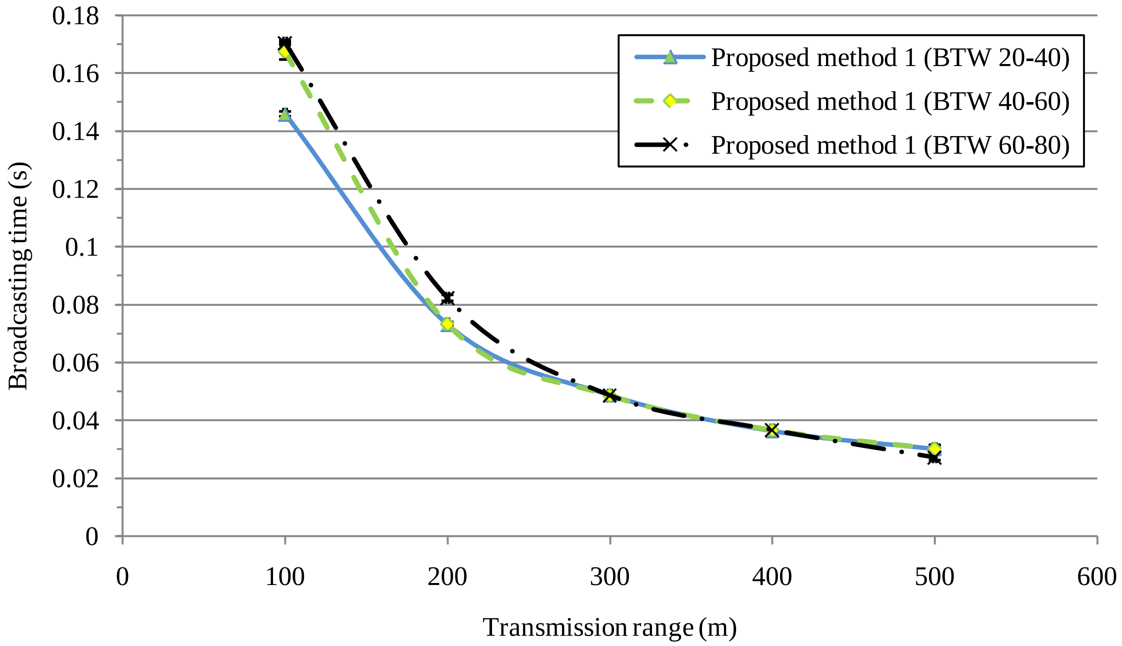


Fig. 27. Influence of the distance between any two consecutive vehicles on the average broadcasting time of the proposed method 1

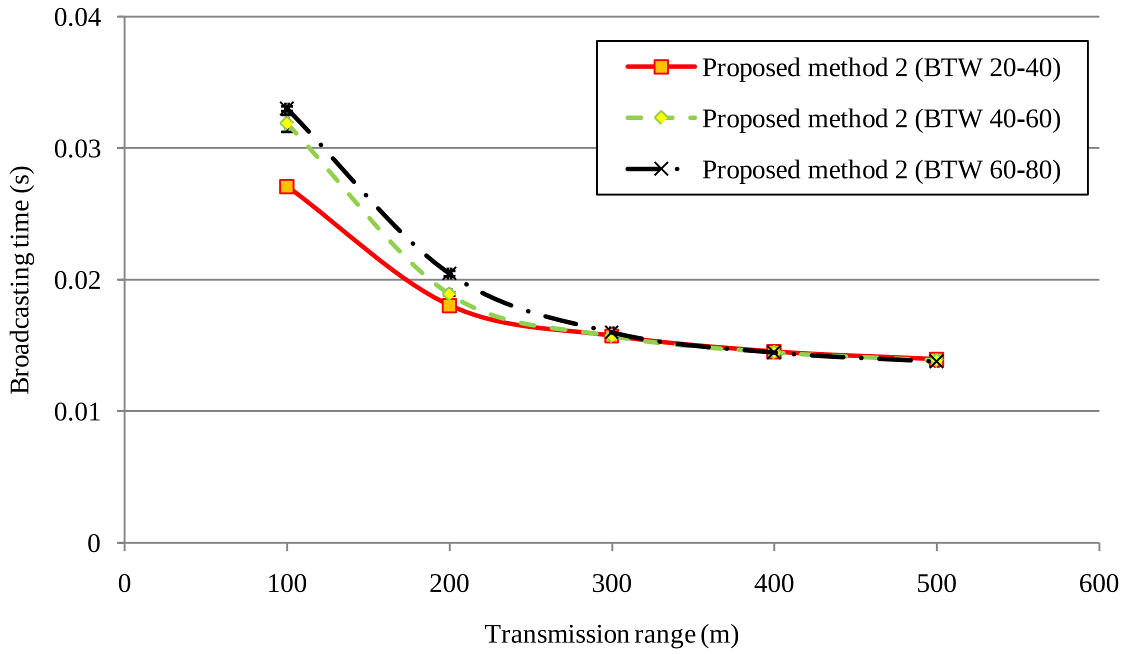


Fig. 28. Influence of the distance between any two consecutive vehicles on the average broadcasting time of the proposed method 2

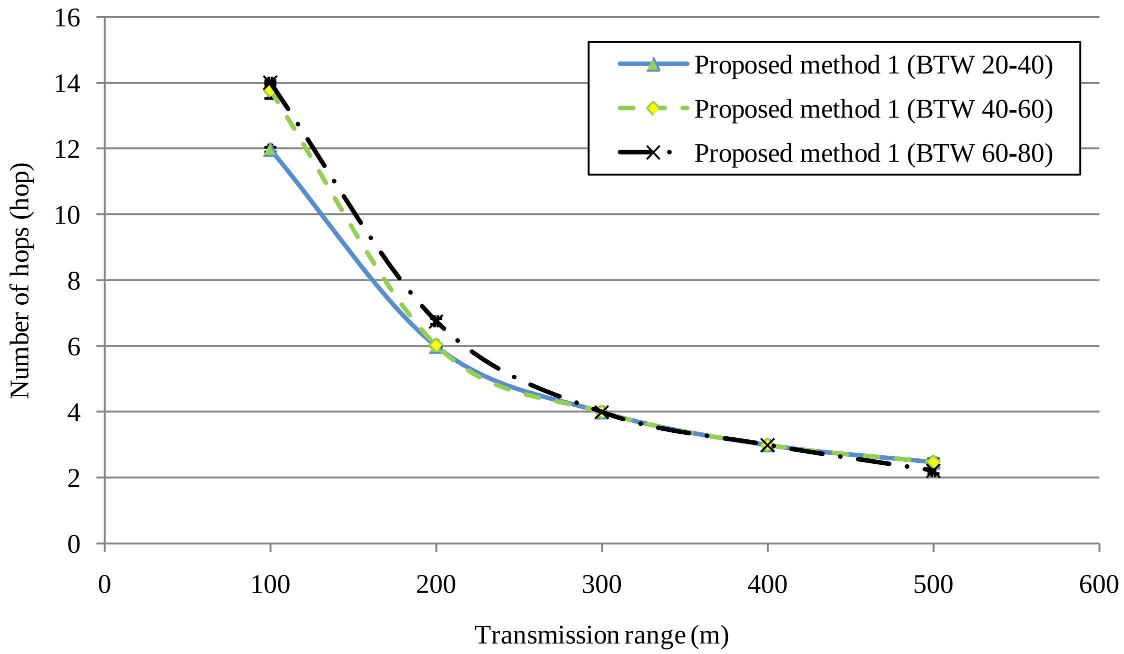


Fig. 29. Influence of the distance between any two consecutive vehicles on the number of hops of the proposed method 1

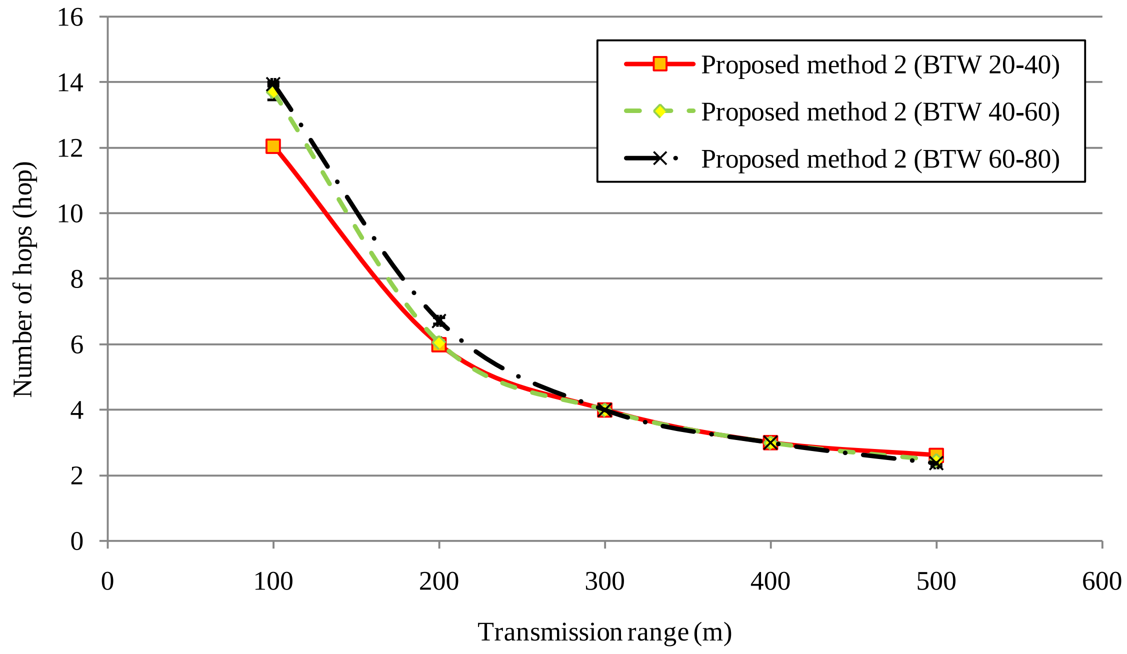


Fig. 30. Influence of the distance between any two consecutive vehicles on the number of hops of the proposed method 2

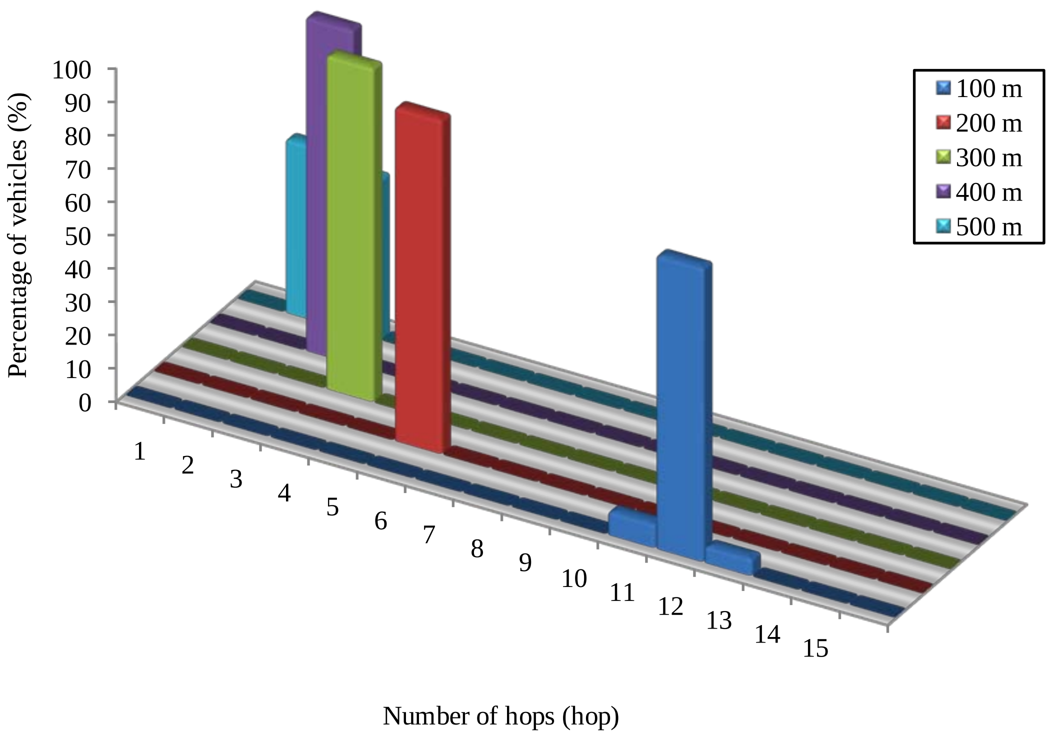


Fig. 31. Distribution of the number of hops of the proposed methods for the case where the distance between two consecutive vehicles is 20-40 m

Number of lanes:

According to Fig. 32 and Fig. 33 which illustrate the influence of the number of lanes on the average broadcasting time of the proposed methods, the average broadcasting time of both proposed methods 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 of the proposed method 1 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, for the proposed method 2, 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.

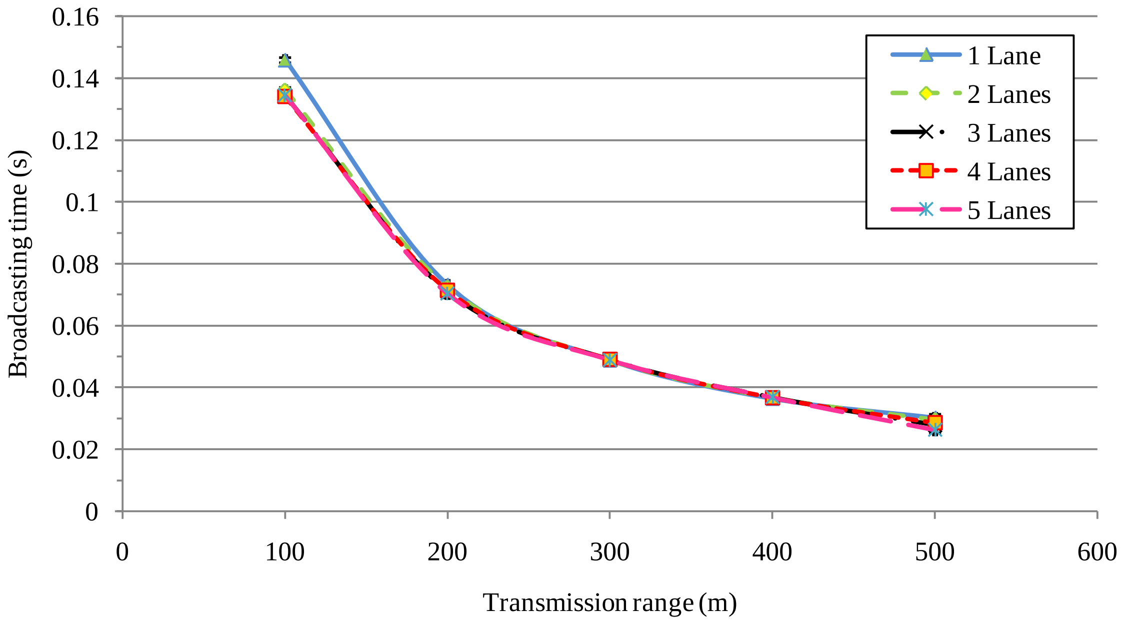


Fig. 32. Influence of the number of lanes on the average broadcasting time of the proposed method 1

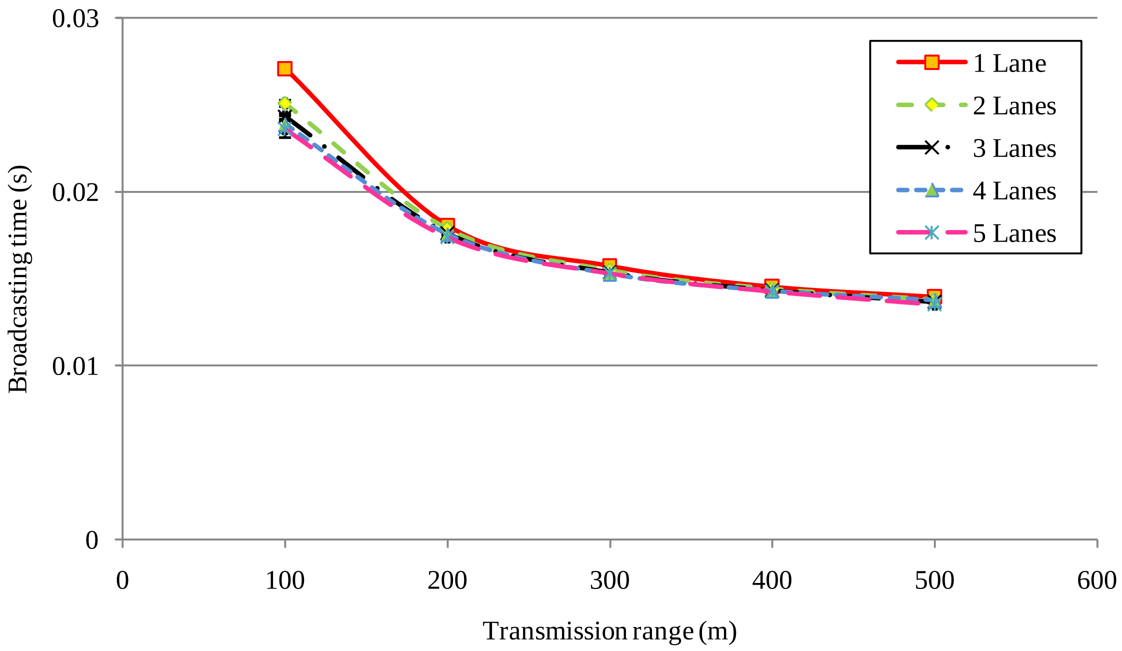


Fig. 33. Influence of the number of lanes on the average broadcasting time of the proposed method 2

Alarm message size:

Fig. 34 depicts the influence of the alarm message on the average broadcasting time of the proposed methods. As the alarm message size increases, the average broadcasting time of the proposed method 1 increase in accordance with the increase in the average alarm message transmission time in each hop. This is due to the fact that the rebroadcasting vehicle in each hop of the proposed method 1 starts to rebroadcast the alarm message after the complete reception of the alarm message. For the proposed method 2, due to the overlap rebroadcasting, the proposed method can reduce most of the alarm message transmission time in each hop. As a result, the average broadcasting time of the proposed method 1 increases more sharply than that of the proposed method 2.

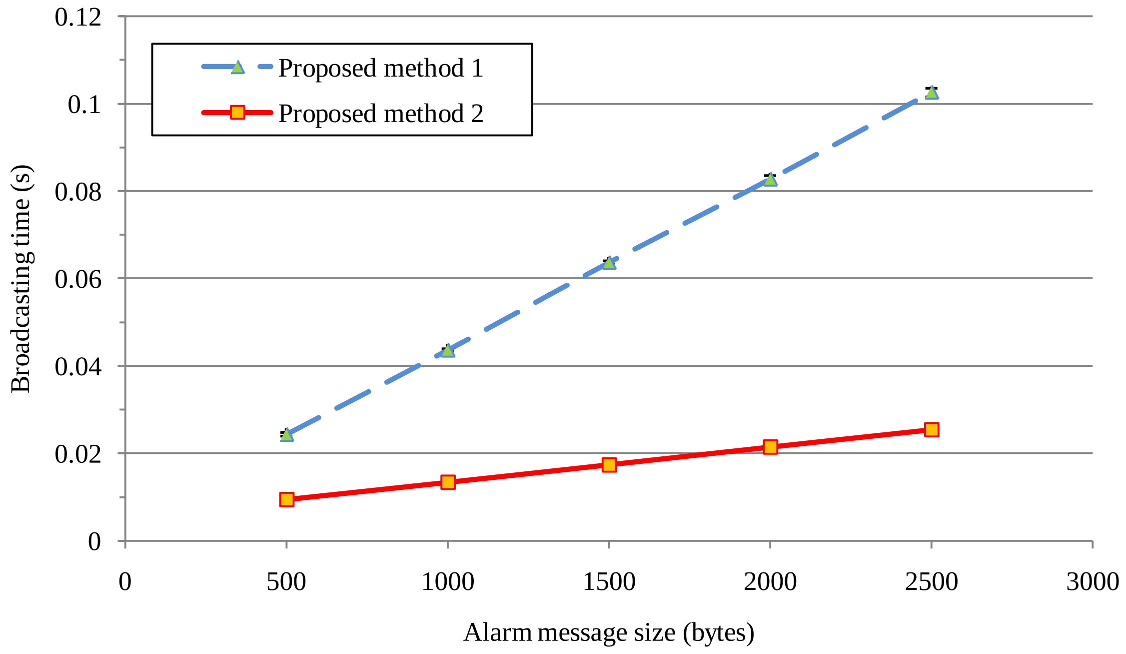


Fig. 34. Influence of the alarm message size on the average broadcasting time of the proposed methods

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 the proposed methods as shown in Fig. 35. The time required for both proposed methods to broadcast 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 that the propagation time of a message between two consecutive vehicles is negligibly small, influence of the mobility of the vehicles on the average broadcasting time of the proposed method is not significant in comparison with other required time.

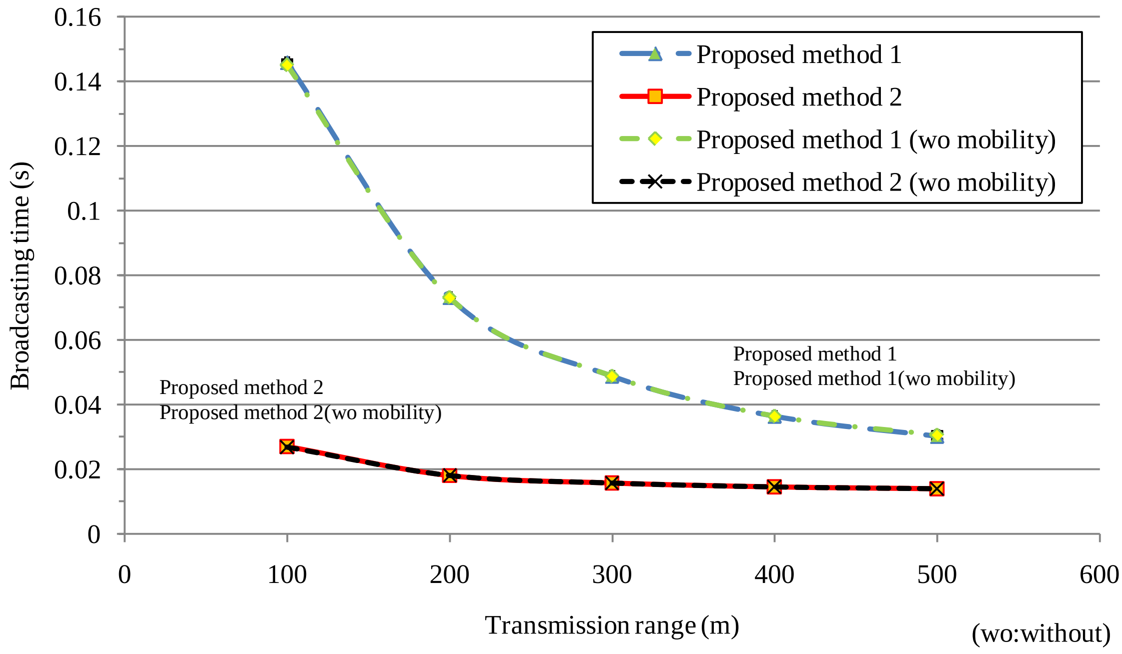


Fig. 35. Influence of mobility on the average broadcasting time of the proposed methods

Value of Delta:

Fig. 36, Fig. 37 and Fig. 38 illustrate the influence of the value of delta on the average broadcasting time of the proposed method 2. According to (8), $T_{wait}(MAX)$ increases as the value of Delta increases, resulting in the increase in the waiting time in each hop and the average broadcasting time of the proposed method 2. It should be noticed that, for the negative value of Delta, the average broadcasting time of the proposed method 2 does not significantly change when compared with the case of positive value of Delta.

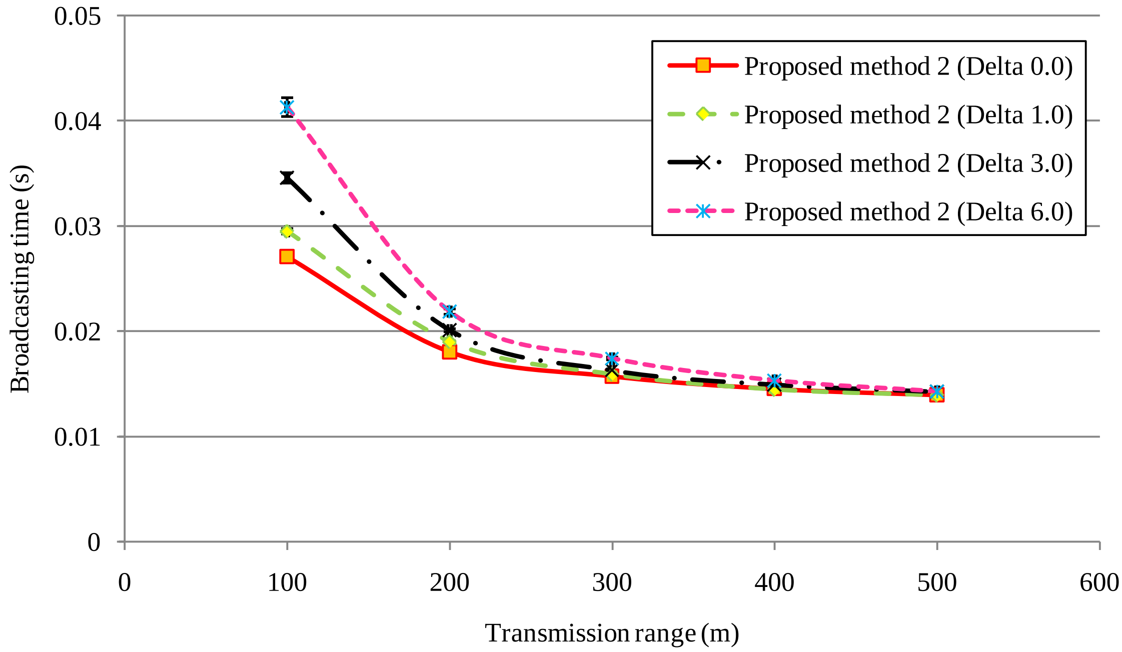


Fig. 36. Influence of the value of Delta on the average broadcasting time of the proposed method 2

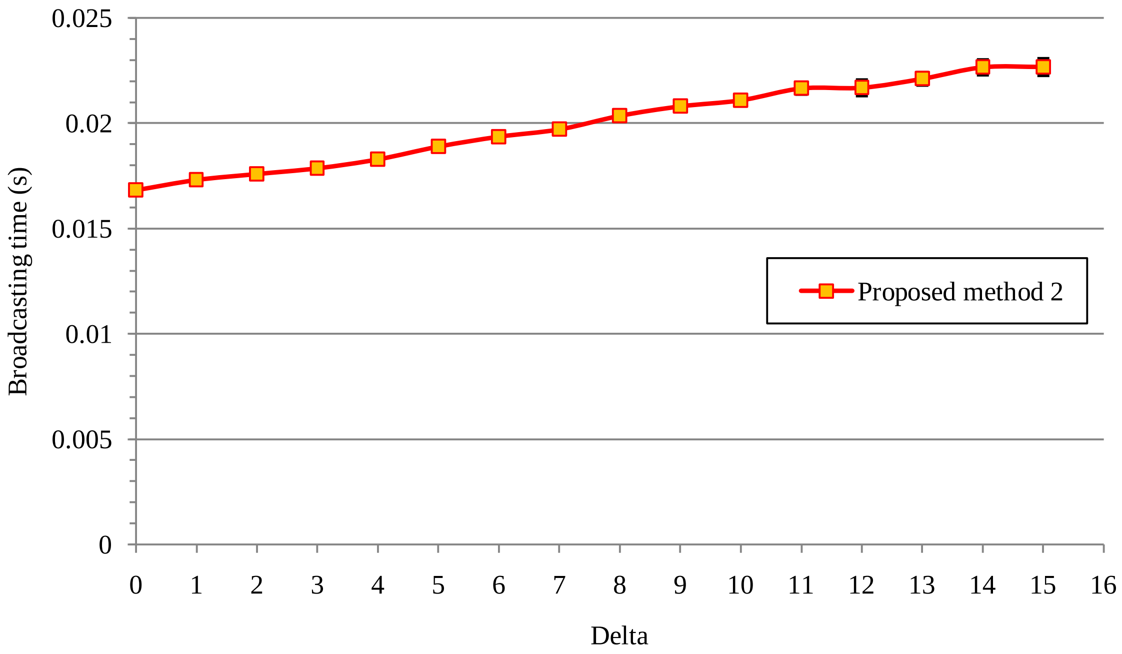


Fig. 37. Influence of the value of Delta on the average broadcasting time of the proposed method 2 for the positive value of Delta

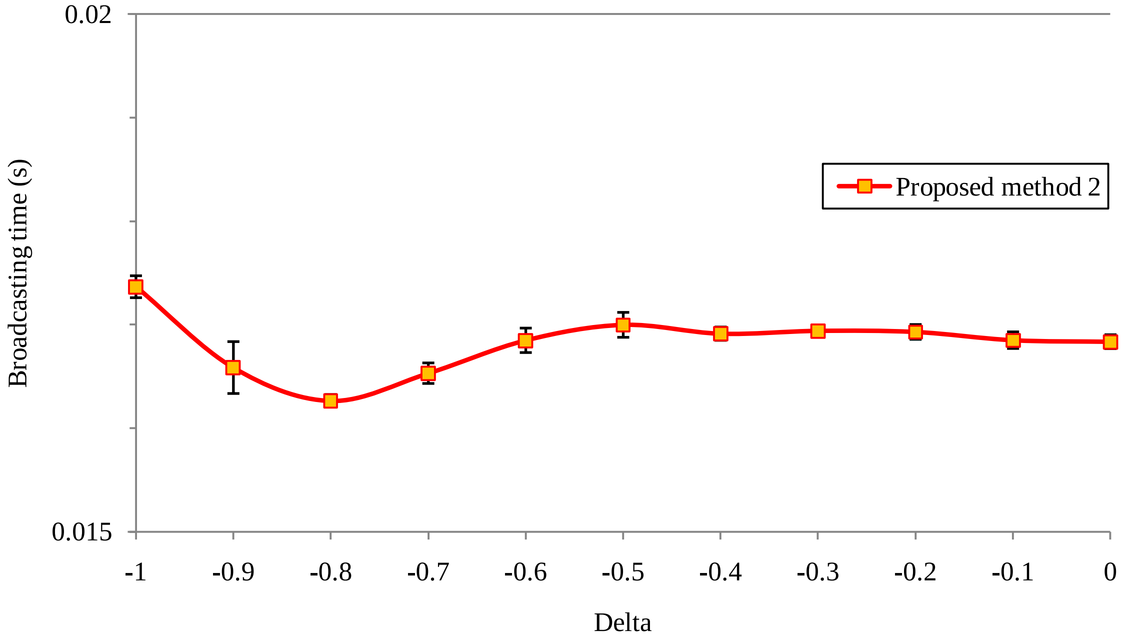


Fig. 38. Influence of the value of Delta on the average broadcasting time of the proposed method 2 for the negative value of Delta

6.3. Number of Rebroadcasting Vehicles

Fig. 39 illustrates the total number of vehicles which were located in the coverage distance 1000 m and rebroadcasted the alarm message by the above mentioned four methods and also the theoretically minimum value of the number of rebroadcasting vehicles for reference. The distribution of the number of rebroadcasting vehicles of the proposed method 1 and the proposed method 2 are shown in Fig. 40 and Fig. 41, respectively. By giving priority control in the alarm message rebroadcasting, the number of rebroadcasting vehicles of the proposed methods is significantly smaller than those of ODAM and the pure flooding method which obliges every vehicle to rebroadcast the alarm message. Notice that the proposed method 1 can achieve the optimum number of rebroadcasting vehicles and the minimum number of hops required to cover the whole coverage distance. The reason why the number of rebroadcasting vehicles by the proposed method 2 is larger than that by the proposed method 1 is as follows.

In the proposed method 1, a vehicle will start to rebroadcast the alarm message upon the complete reception of the alarm message from the source vehicle. If the vehicle receives the notification flag from the rebroadcasting vehicle before the complete reception of the alarm message, it decides not to 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. Meanwhile, in the proposed method 2, a vehicle will start to rebroadcast the alarm message upon the expiration of the waiting time. If the time required for transmitting the header of the alarm message from the rebroadcasting vehicle to any leading vehicle is longer than the difference between the waiting time of the leading vehicle and that of the rebroadcasting vehicle, the header of the alarm message will arrive at the leading vehicle after the expiration of its waiting time. Then, this leading vehicle will rebroadcast the alarm message, which is in practice redundant and should be avoided from the viewpoint of efficiency. Thus, the duration of time allowed for a vehicle to make a decision on rebroadcasting the alarm message is equal to the difference between its waiting time and that of the rebroadcasting vehicle. As the transmission time of the alarm message is longer than the difference between the waiting time of any two vehicles, the proposed method 1 allows the leading vehicles longer duration of time for making a decision on rebroadcasting the alarm message than that of the proposed method 2. Thus, the proposed method 1 can achieve smaller number of rebroadcasting vehicles than the proposed method 2.

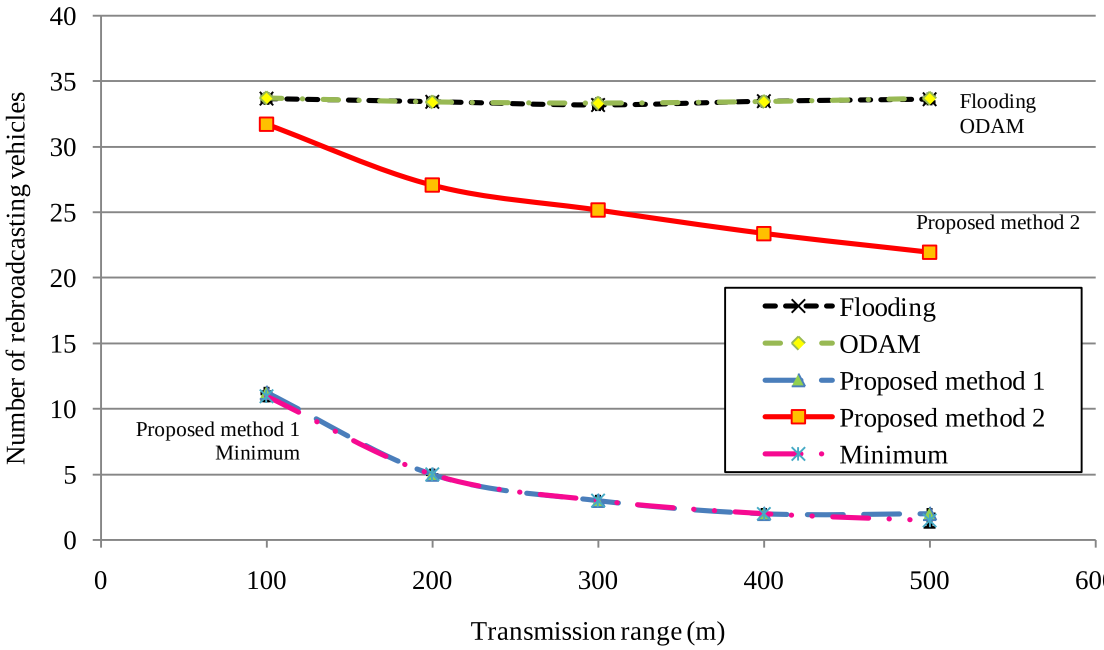


Fig. 39. Number of rebroadcasting vehicles required to cover the coverage distance of the proposed methods in comparison with flooding and ODAM

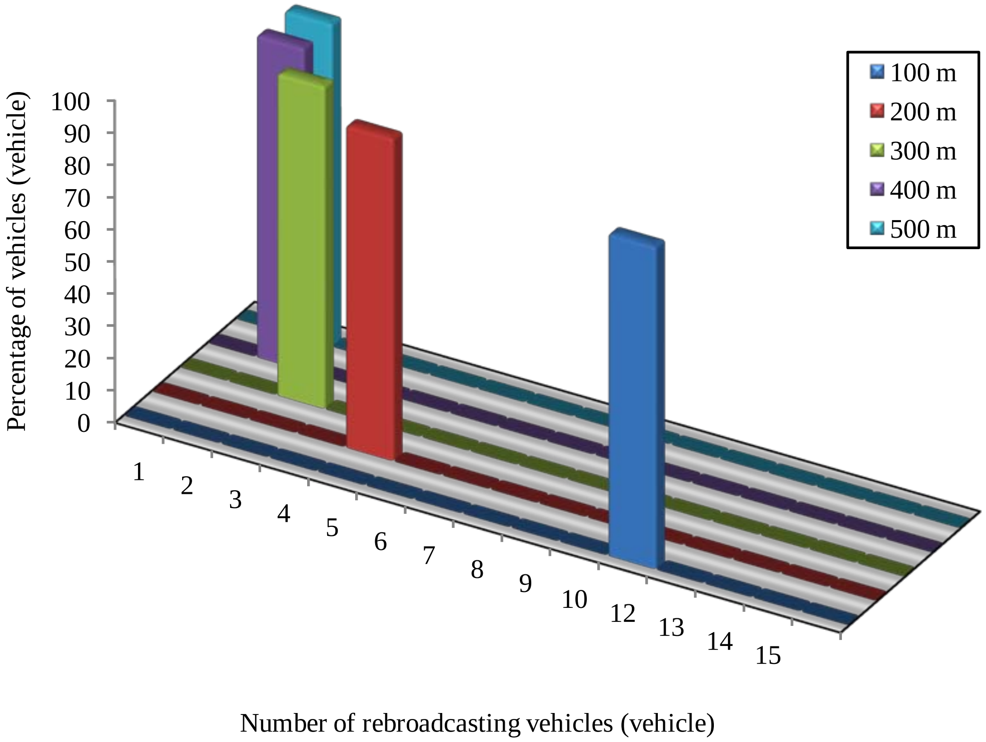


Fig. 40. Distribution of the number of rebroadcasting vehicles of the proposed method 1

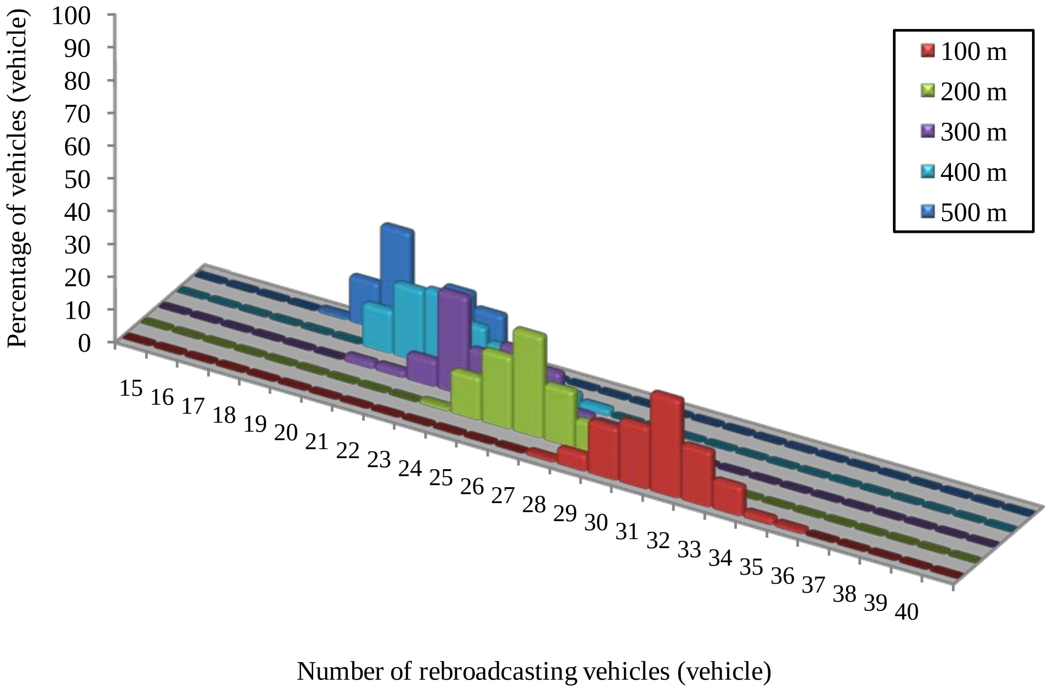


Fig. 41. Distribution of the number of rebroadcasting vehicles of the proposed method 2

It should be noted that alarm message size has a significant influence on the effectiveness of the proposed method 1. This is due to the fact that the waiting time in the proposed method 1 is calculated based on the transmission time of the alarm message. For the assumed alarm message size 1,425 bytes whose $T_{trans}(Alarm)$ is about 11.8 ms, $T_{wait}(MAX)$ is about 10 s and the difference of the waiting time between two consecutive vehicles is about 1.2 ms for the case where the transmission range is 250 m. Because the maximum time required for sending the notification flag which is about 1.5 ms (or less) is not significantly larger than the difference of the waiting time between two consecutive vehicles, the notification flag can be received by the leading vehicles with low probability of collision. Then, the alarm message rebroadcasting by the leading vehicles is effectively cancelled, resulting in minimum number of rebroadcast vehicles. However, smaller alarm message size will lead to smaller difference of the waiting time between two consecutive vehicles, which can result in the collision of the notification flag broadcasting and larger number of rebroadcasting vehicles. Thus, there is a possibility that the waiting time calculation approach should be changed to cope with such case.

As mentioned in the description of Waiting Time Calculation, the approach used in waiting time calculation also has an influence on the trade-off between the average broadcasting time and the number of rebroadcasting vehicles. In other words, there is some possibility that the longer becomes $T_{wait}(MAX)$ in (5) and (8), the larger becomes the difference of the waiting time between two consecutive vehicles and the longer becomes the duration of time allowed for each vehicles 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 the rebroadcasting vehicle before the expiration of their waiting time and do not rebroadcast the notification flag or the alarm message will increase and thus the number of rebroadcasting vehicles will become smaller if $T_{wait}(MAX)$ becomes larger. However, the broadcasting time increases as the waiting time increases. This result will be reverse for the situation with the decrease in $T_{wait}(MAX)$.

According to Fig. 39, although the number of rebroadcasting vehicles by the proposed method 1 is a little smaller than that by the proposed method 2, the average broadcasting time by the proposed method 2 is much smaller than that by the proposed method 1. Thus, it is concluded that the proposed method 2 should be taken as optimal from the viewpoint of fast dissemination of the alarm message.

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

Distance between any two consecutive vehicles:

According to Fig. 42, the number of rebroadcasting vehicles of the proposed method 1 is changed in accordance with to the number of hops shown in Fig. 29 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 of the proposed method 2 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 as shown in Fig. 43.

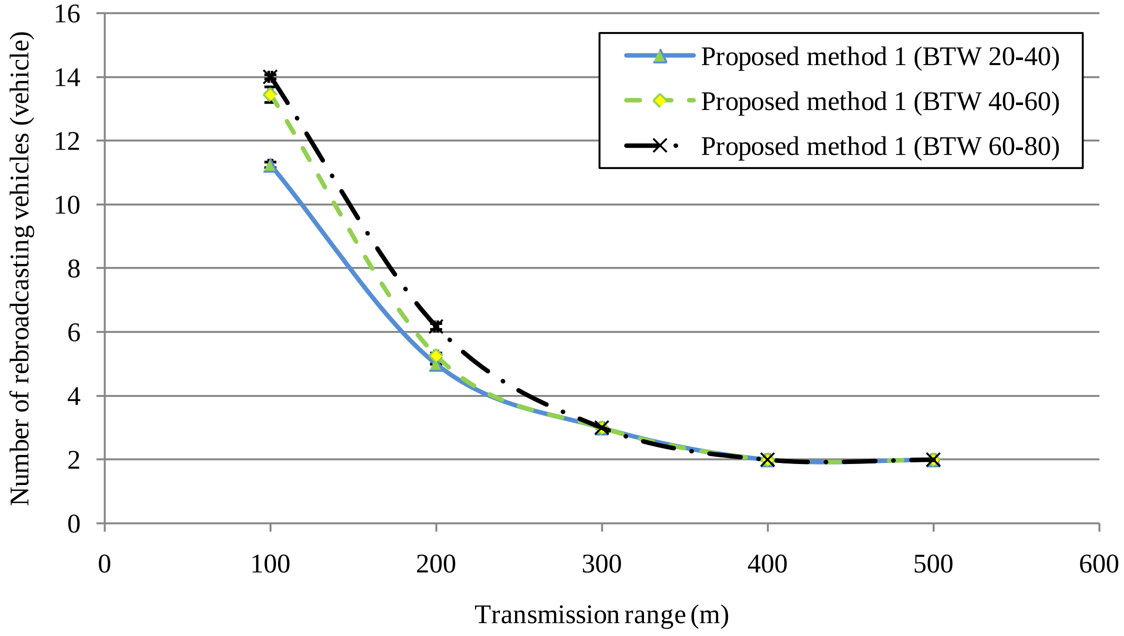


Fig. 42. Influence of the distance between any two consecutive vehicles on the number of rebroadcasting vehicles of the proposed method 1

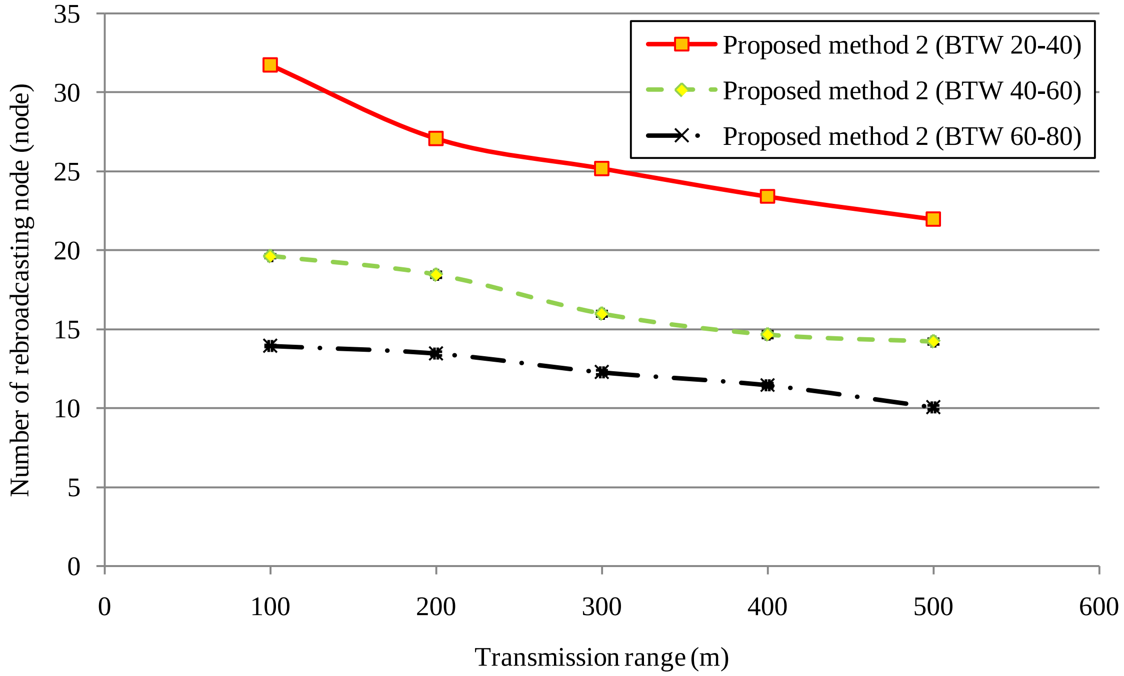


Fig. 43. Influence of the distance between any two consecutive vehicles on the number of rebroadcasting vehicles of the proposed method 2

Number of lanes:

In Fig. 44, as the number of lanes increases, it does not have a significant influence on the number of rebroadcasting vehicles in the proposed method 1. This is due to the reason that the duration of time allowed by the proposed method 1 for a vehicle to make a decision on rebroadcasting the alarm message is equal to the transmission time of the alarm message which is large enough for the intermediate vehicles in each hop to receive notification flag from the furthest vehicle and not to rebroadcast the alarm message.

However, for the proposed method 2, 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 of the proposed method 2 is shown in Fig. 45.

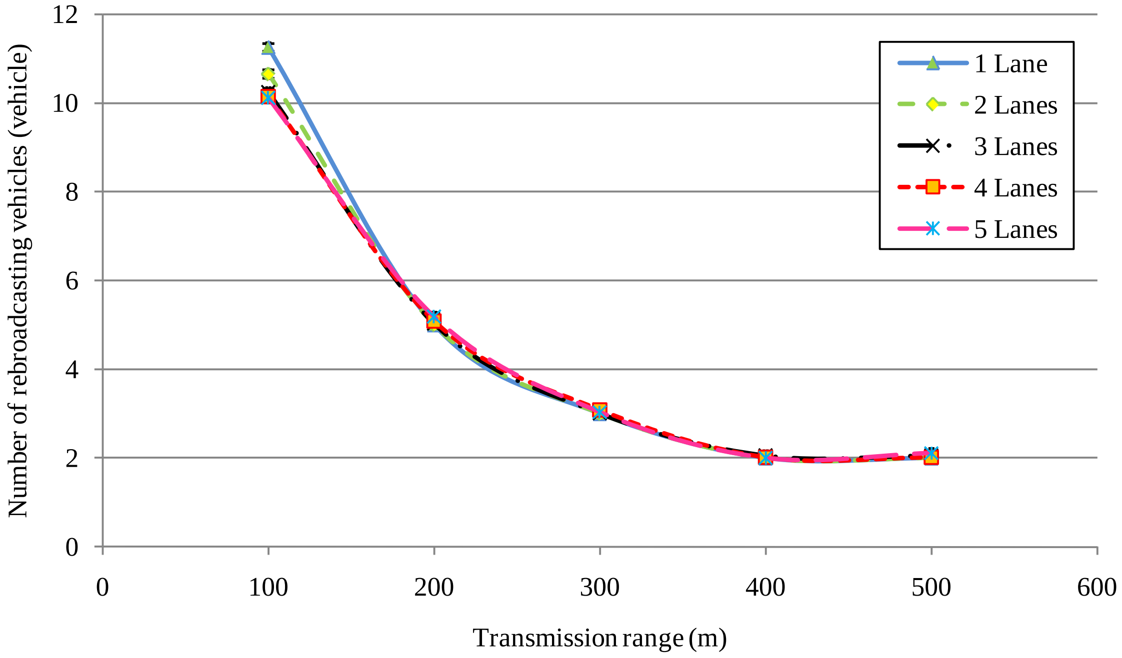


Fig. 44. Influence of the number of lanes on the number of rebroadcasting vehicles of the proposed method 1

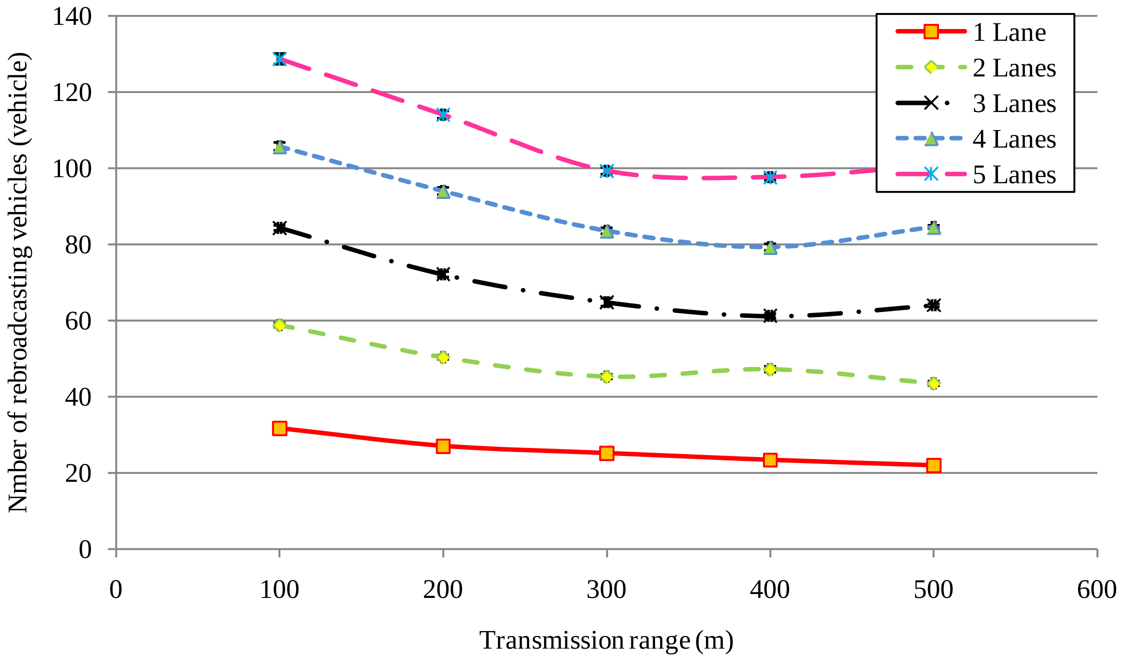


Fig. 45. Influence of the number of lanes on the number of rebroadcasting vehicles of the proposed method 2

Alarm message size:

For the proposed method 1, the alarm message size does not have a significant influence on the number of rebroadcasting vehicles for the case where the alarm message size is larger than 1000 bytes as shown in Fig. 46. However, for the case where the alarm message size is smaller than 1000 bytes e.g. 500 bytes, the alarm message size has an influence on the number of rebroadcasting vehicles. The reason is that the alarm message size is also used for the waiting time calculation. According to (5), $T_{wait}(MAX)$ decreases as the alarm message transmission time decreases, resulting in the decrease in the difference between the waiting time of any two consecutive vehicles. Thus, the possibility that the vehicle does not receive the notification flag from the rebroadcasting vehicle and starts to rebroadcast the alarm message will increase. Moreover, as the alarm message size decreases, there is the possibility that the notification flag will be suspended by the operation of CSMA/CA and be broadcasted after the alarm message is rebroadcasted to the next hop. This can lead to the collision of the notification flag in the next hop because the channel used for broadcast the notification flag is the same for every hop. However, this can be handled by the cancellation of broadcasting the notification flag after the reception of the notification flag if the broadcasting has not yet actually started and has been suspended by the operation of CSMA/CA in case of collision.

For the proposed method 2, the alarm message size does not have a significant influence on the number of rebroadcasting vehicles because the waiting time is not calculated based on the alarm message size.

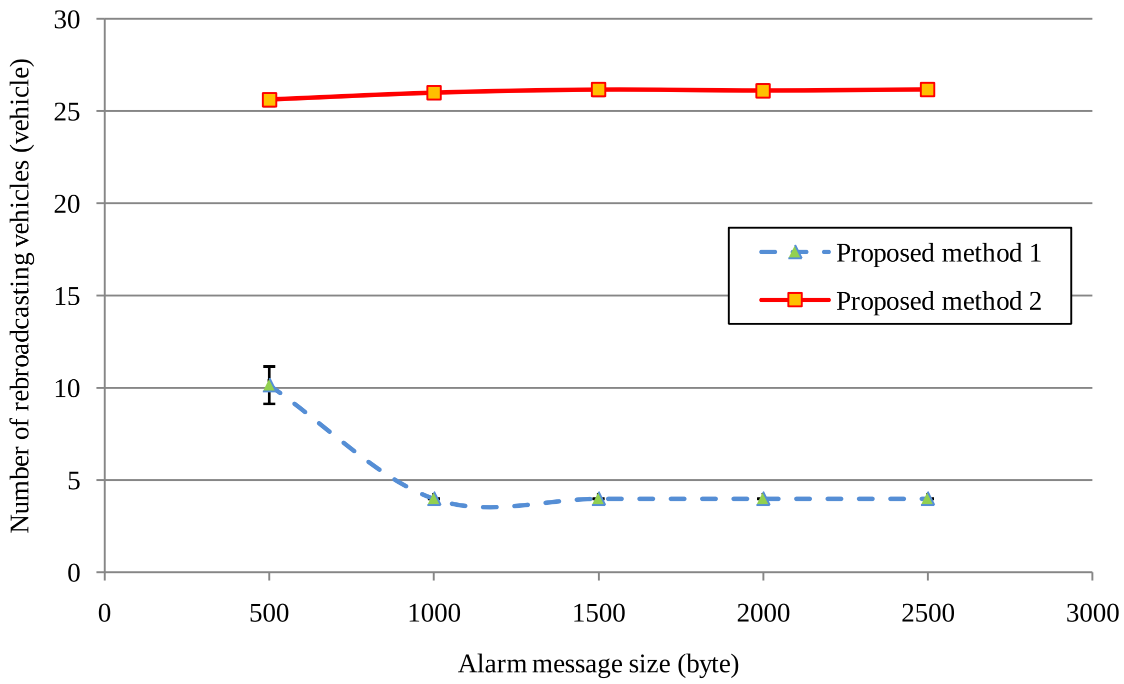


Fig. 46. Influence of the alarm message size on the number of rebroadcasting vehicles of the proposed methods

Mobility of the vehicles:

According to Fig. 47, the mobility of the vehicles does not have a significant influence on the number of rebroadcasting vehicles of both proposed methods. The reason can be described in the same way as the influence of mobility on the average broadcasting time of the proposed methods.

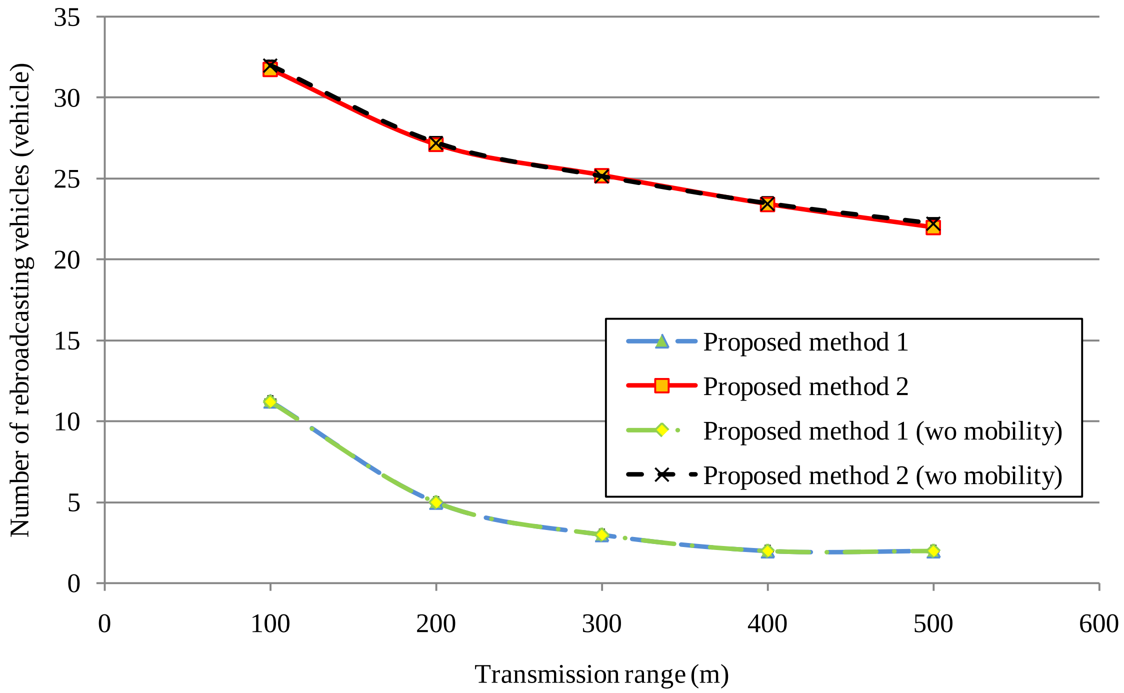


Fig. 47. Influence of mobility on the number of rebroadcasting vehicles of the proposed methods

Value of Delta:

According to Fig. 48, Fig. 49 and Fig. 50, the number of rebroadcasting vehicles increases as the value of Delta decreases. According to $T_{wait}(MAX)$ in (8), 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 (7), 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 of the proposed method 2 does not significantly change when compared with the case of positive value of Delta.

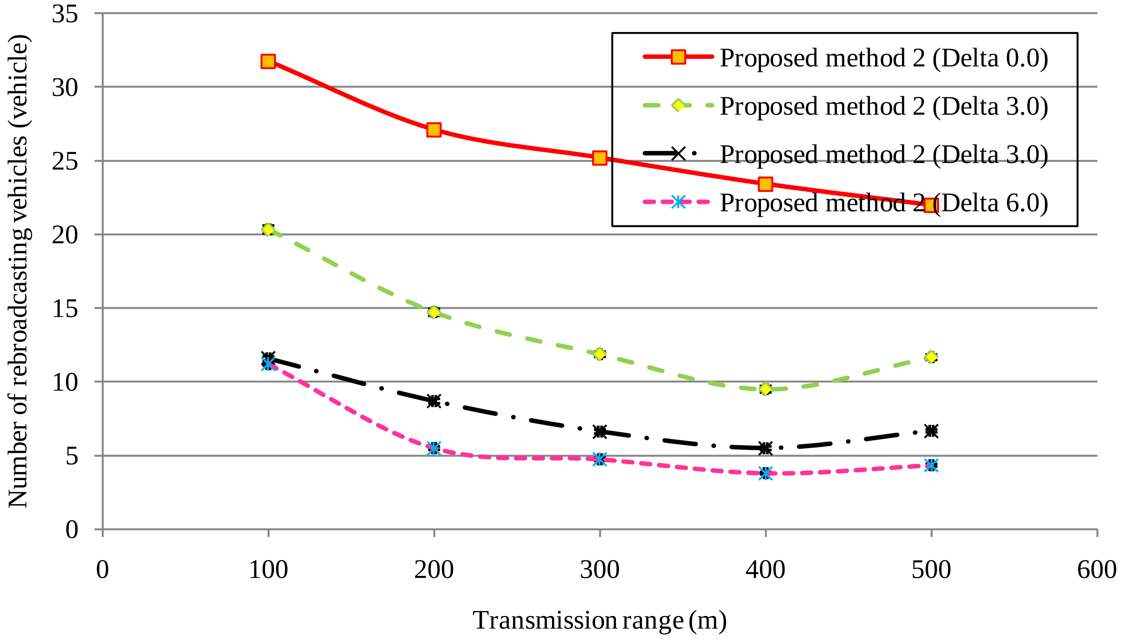


Fig. 48. Influence of the value of Delta on the number of rebroadcasting vehicles of the proposed method 2

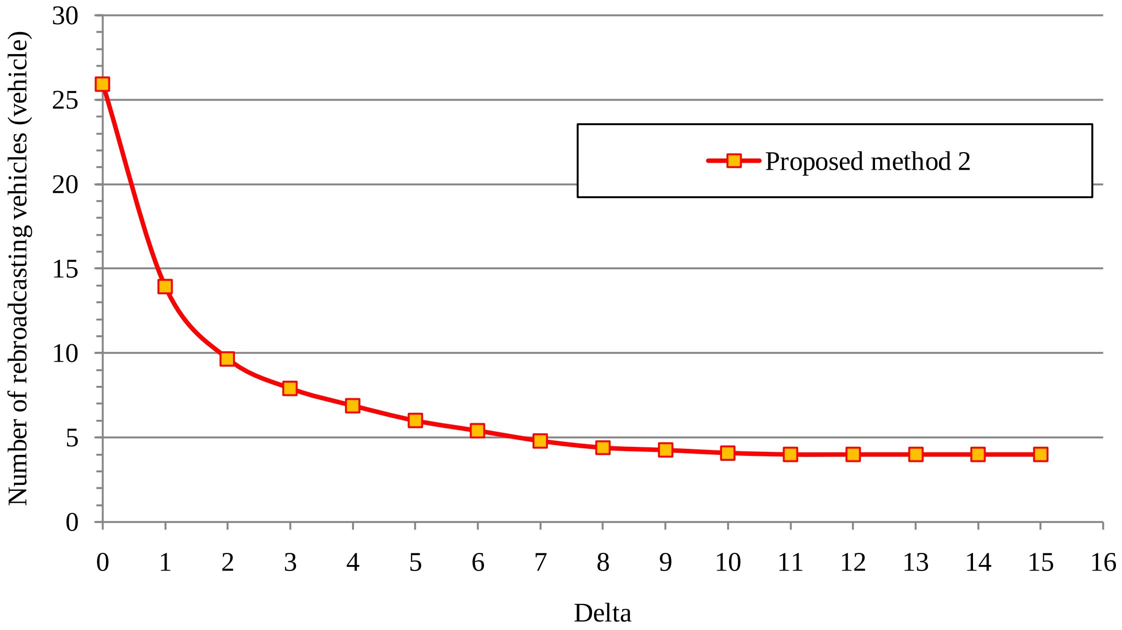


Fig. 49. Influence of the value of Delta on the number of rebroadcasting vehicles of the proposed method 2 for the positive value of Delta

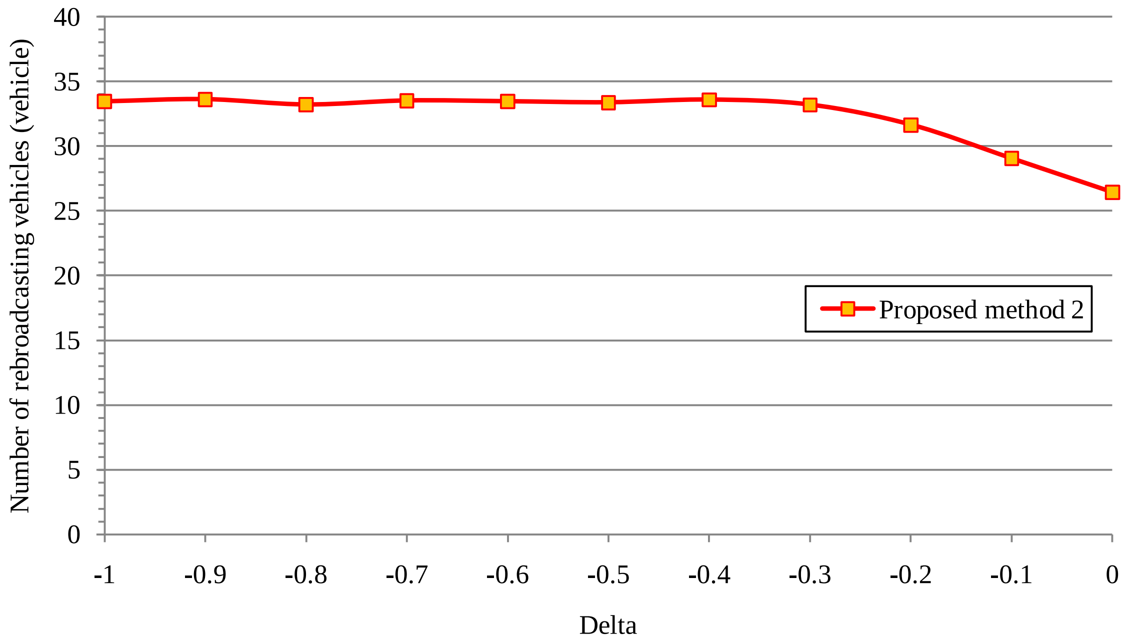


Fig. 50. Influence of the value of Delta on the number of rebroadcasting vehicles of the proposed method 2 for the negative value of Delta

According to the influence of the value of Delta on the average broadcasting time and the number of rebroadcasting vehicles, this thesis 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 mentioned in section 5.4.1. 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 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.

Chapter 7

ALARM MESSAGING FOR CURVE SCENARIOS

Until the previous chapter, the proposed methods have been studied only in the rectilinear highway scenario. If the proposed methods are applied to a curve scenario, there is some possibility that some vehicles located closer to the source vehicle do not receive the alarm message while the vehicles located further receive the alarm message. According to Fig. 51, after source vehicle *A* broadcasts the alarm message, *B* and *D* which are located in the transmission range of *A* will receive the alarm message. Unlike the rectilinear highway scenario where the vehicles located closer to the source vehicle e.g. *C* always receive the alarm message if the vehicles located further e.g. *D* receives the alarm message, there is a case where *D* receives the alarm message from *A* while *C* does not receive the alarm message. Moreover, *C* still does not receive the alarm message even from the alarm message rebroadcasting by *D* which is the furthest vehicle located from *A* and is given the highest priority as the rebroadcasting vehicle by the previous proposed methods. In order to cope with such cases, the extension of the proposed methods is considered.

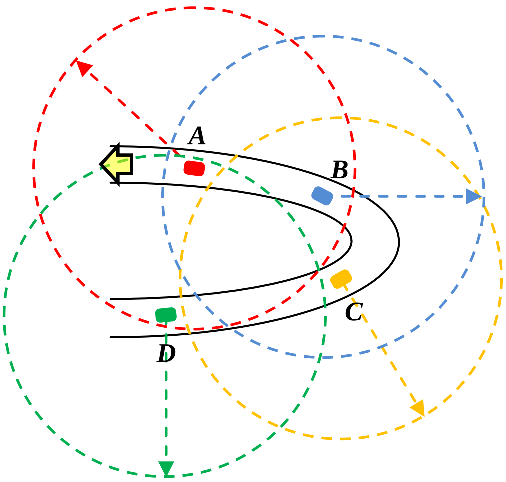


Fig. 51. Alarm message broadcasting in curve scenarios

7.1. *Assumption for Curve Scenarios*

Although the possibility to receive the alarm message by each vehicle depends on the structure of the curve, this thesis focuses on the structure of the curve which is composed of two rectilinear sections and the angle θ between the rectilinear sections is in the range of 0° and 180° as shown in Fig. 52.

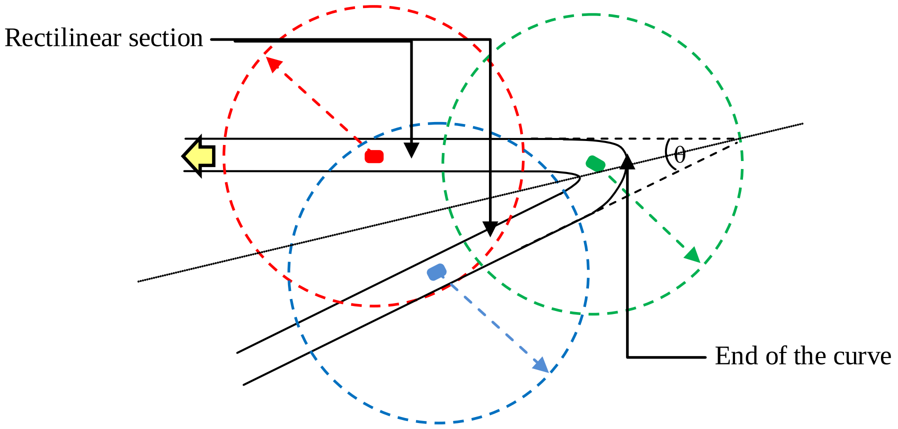


Fig. 52. Assumed structure of the curve

In this scenario, all the vehicles are assumed to have the information about the structure of the curve by utilizing GPS. Based on this information, each vehicle can determine in which section of the curve it is moving in.

7.2. Applicability of the Proposed Methods to Curve Scenario

Based on the assumed structure of the curve, the applicability of two previous proposed methods can be summarized as follows:

7.2.1. For the Case Where $\theta \geq 90°$

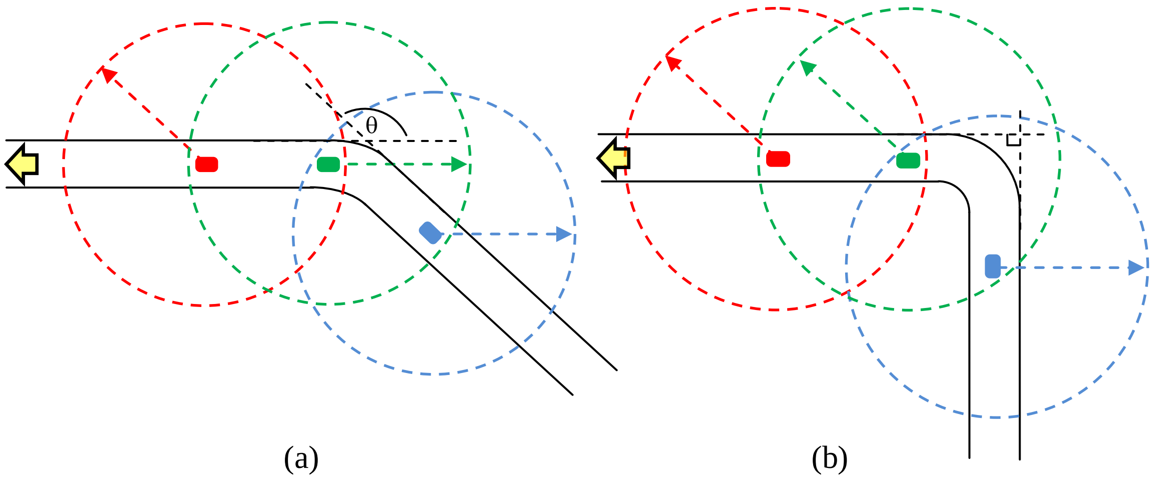


Fig. 53. (a) Structure of the curve where θ > 90°
(b) Structure of the curve where θ = 90°

According to Fig. 53(a) and (b), two previous proposed methods can be effectively applied with the case where $\theta \geq 90°$ because the vehicles located closer to the source vehicle always receive the alarm message from the source vehicle if the vehicles located further receive the alarm message.

7.2.2. For the Case Where $\theta < 90°$

For the case where θ < 90°, if we assume that the vehicles have the geometric information of the curve e.g. the distance from the source vehicle to the end of the curve d_c, the distance from the source vehicle to the vertex point of the two rectilinear sections d_θ, and θ as shown in Fig. 54, the two proposed methods can be efficiently applied in the curve scenario under the following two conditions:

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

If the above mentioned conditions are not completely satisfied, there is a possibility that the vehicles located closer to the source vehicle do not receive the alarm message while the vehicles located further receive the alarm message.

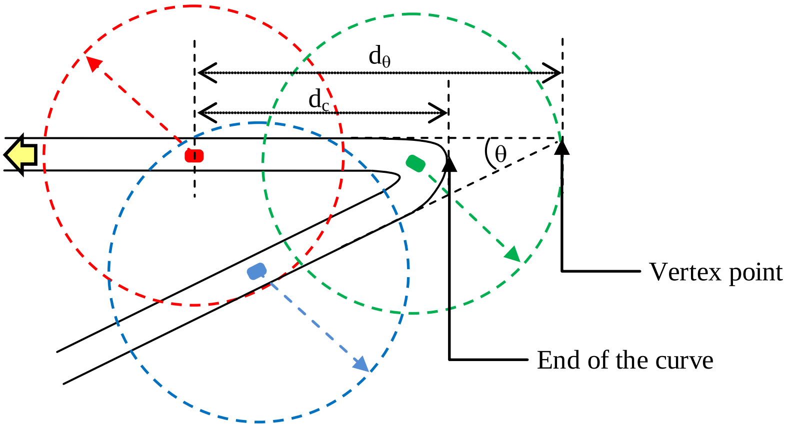


Fig. 54. Structure of the curve where θ < 90°

7.3. Proposed Method for the Curve Scenario

7.3.1. Message Receiving Direction

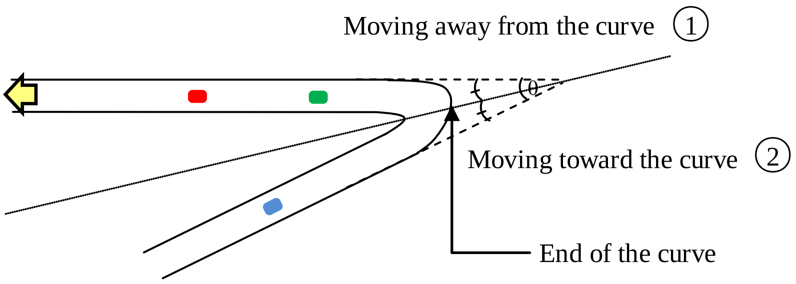


Fig. 55. Message receiving direction in the curve scenario

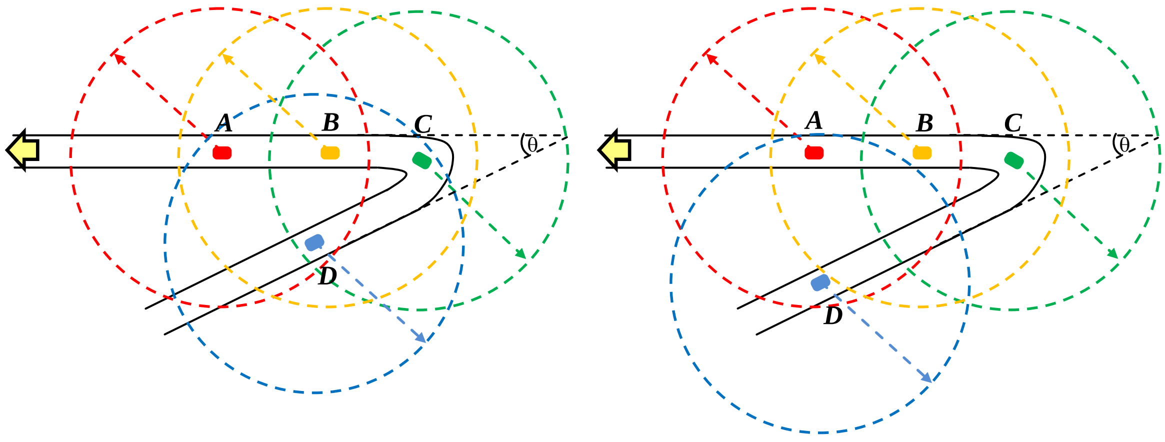
Because the characteristics of the vehicle e.g. moving direction are different in accordance with there current section of the curve and the section from which the alarm message is sent has an influence on the decision to rebroadcast the alarm message, this thesis proposes that the structure of the curve also should be divided into small sections based on the characteristics of the vehicle. In each section, the vehicles move in the same moving direction with the similar moving pattern. According to Fig. 55, the structure of the curve is divided into two sections by equally dividing the angle θ. The vehicles in the first section are moving away from the curve, while the vehicles in the second section are moving toward the curve. Moreover, we assume that a vehicle located at the boundary between the first section and the second section is assumed to be located in the first section.

Based on the above section division, the message receiving direction can be categorized into the following two cases.

a) Receiving the message from the source vehicle by a vehicle located in the same section as the source vehicle (The vehicle received the message and the source vehicle are both moving away from the curve or toward the curve).

b) Receiving the message from the source vehicle by a vehicle located in the section different from that of the source vehicle (The vehicle received the message is moving toward the curve while the source vehicle is moving away from the curve and vice versa).

7.3.2. Proposed method



(a) (b)

Fig. 56. Possible alarm message broadcasting scenarios in the curve scenario

According to the scenario in Fig. 56(a), after the alarm message broadcasting by the source vehicle *A*, the highest priority to rebroadcast the alarm message is given to only the furthest vehicle *D* as in the previous proposed methods and all the vehicles including *C* is covered by this rebroadcasting. However, for the scenario in Fig. 56(b), the highest priority to rebroadcast the alarm message to only the furthest vehicle *D* but some vehicles such as *C* is not covered by the rebroadcasting. Thus, this thesis proposes that the highest priority to rebroadcast the alarm message should be given to the furthest vehicles in both sections.

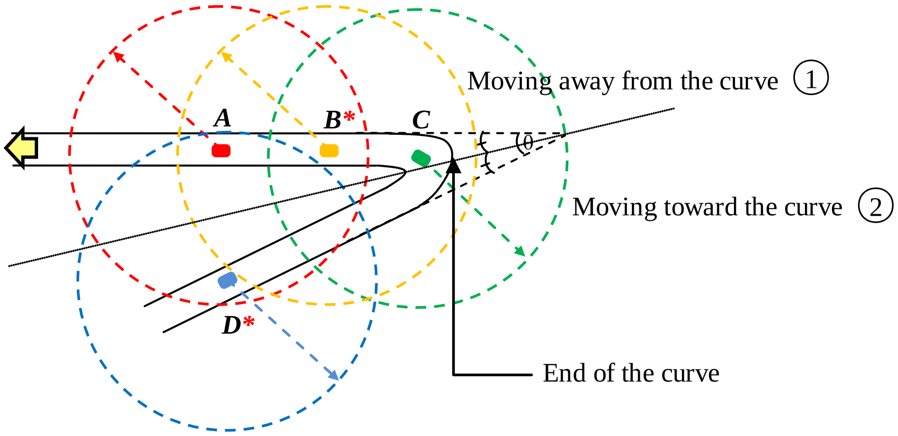


Fig. 57. Rebroadcasting vehicles in the curve scenario. The rebroadcasting vehicles are marked by “*”.

According to Fig. 57, in order to cope with the scenario in Fig. 56(b), the highest priority to rebroadcast the alarm message will be given to the furthest vehicle *B* moving away from the curve and the furthest vehicle *D* moving toward the curve. It should be noted that the priority to rebroadcast the alarm message is given to each of these vehicles based on the basic idea of waiting time calculation.

Similar to the previous proposed methods, the vehicle which received the alarm message will not rebroadcast the alarm message if it receives the notification flag or the alarm message header from the further vehicle located in the same section.

7.3.3. Waiting Time Calculation

The waiting time for each vehicle in the curve scenario is calculated based on the message receiving direction as follows:

7.3.3.1. Receiving the message from the source vehicle located in the same section

The waiting time for the vehicles in this case can be calculated in the same manner as the previous proposed methods.

7.3.3.2. Receiving the message from the source vehicle located in the difference section

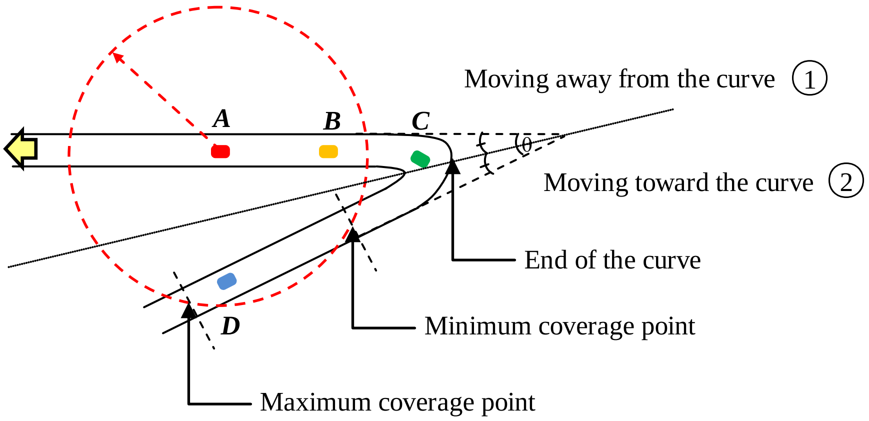


Fig. 58. Basic idea of waiting time calculation for the case where receiving the message from the source vehicle located in the difference subsection

According to Fig. 58, the maximum coverage point represents the furthest point located in the second section which can be covered by the transmission range of the source vehicle located in the first section, where the distance is taken along the road with the curve. Similarly, the minimum coverage point represents the closest point located in the second section which can be covered by the transmission range of the source vehicle located in the first section, where the distance is taken along the road with the curve.

Based on the same value of $T_{wait}(MAX)$ and $T_{wait}(MIN)$ in each previous proposed methods, the waiting time for vehicle X can be represented by the following equation:

Proposed method 1

$$T_{wait}\,(x) = \frac{(D_{MinMax} - D_{MinX})}{D_{MinMax}} * MAX\{T_{wait}\,(MAX), T_{wait}\,(MIN)\} \tag{9}$$

Proposed method 2

$$T_{wait}\,(x) = \frac{(D_{MinMax} - D_{MinX})}{D_{MinMax}} * T_{wait}\,(MAX) \tag{10}$$

where D_{MinMax} = distance from the minimum coverage point to the maximum coverage point (m)

D_{MinX} = distance from the minimum coverage point to vehicle X (m)

7.3.4. Other considerations

7.3.4.1. Safety Consideration

In general, the closer the vehicle is located from the source vehicle or an accident vehicle, the higher is the possibility that the secondary accident will happen. In other words, the vehicle located closer to the source vehicle should be able to receive the alarm message from the source vehicle earlier than the vehicle located further.

According to Fig. 57, after *A* broadcasts the alarm message, *B* and *D* will receive the alarm message and be given the highest priority to rebroadcast the alarm message as proposed above. Based on the waiting time calculation, there is a possibility that *D* will start to rebroadcast the alarm message before the alarm message rebroadcasting of *B*, then the rebroadcasting of *B* will be suspended by the operation like CSMA/CA. In addition, this kind of operation is also influenced by the channel assignment approach used in the proposed method. However, *B* should have a higher priority to rebroadcast the alarm message than *D* when the safety aspect mentioned above is considered.

It should be noted that this consideration will not be taken into account as the targets of the proposed method for the curve scenario in this thesis.

7.3.4.2. Channel Assignment

Based on the approach to assign the channel for rebroadcasting in the curve scenario, there is a possibility that the channel is not available on the time of rebroadcasting. Then, the rebroadcasting is suspended by the operation like CSMA/CA, which can result in the increase in the broadcasting time required for cover all of the vehicles in the coverage distance.

Chapter 8

CONCLUSION AND FUTURE 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. In order to achieve such reduction in the broadcasting time, this thesis has proposed two new broadcasting methods for the efficient and fast broadcasting of alarm message in VANETs.

The proposed methods are proposed to utilize multiple radio channels simultaneously by equipping each vehicle with multiple transceivers as well as the position information provided by GPS. 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.

Out of the two proposed methods, the proposed method 2 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. Moreover, the proposed method 2 is able to solve the Broadcast Storm Problem as well. In addition, the proposed method 2 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.

Besides the rectilinear highway scenario, this thesis has also proposed the basic idea for extension of the proposed methods to the curve scenario. However, there is a possibility that both the vehicle moving away from the curve and the vehicle moving toward the curve will rebroadcast the alarm message. Lacking of the efficient channel assignment approach can lead to the case where the channel which should be used for rebroadcasting is not available and the rebroadcasting is suspended by the operation like CSMA/CA, resulting in longer broadcasting time required to cover all of the vehicles located in the coverage distance. Thus our further researches will focus on the channel assignment approaches to cope with such a problem. Furthermore, further researches are also considered required to improve and evaluate the proposed extension of the proposed methods in detail.

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