A Fault-Tolerant Broadcast Protocol for Reliable Alert Message Delivery in Vehicular Wireless Networks

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Abstract

In this paper, we focus on the alert message dissemination in vehicular wireless networks. Generally, the flooding method is adopted to disseminate the alert message on highway. But the flooding method may cause the alert message redundancy, which may lead to broadcast storm problem. In this paper, we propose a fault-tolerant broadcasting protocol for disseminating the alert message on highway. The proposed protocol designates two vehicles which are the farthest and sub-farthest vehicles in the transmission range of the source vehicle as the relay candidates. In addition, we propose an exponential back-off method that can effectively reduce the number of alert messages. Finally, we implement the proposed protocol in the NS-2 simulator. The simulation results show that our proposed protocol not only reduces the number of the alert messages but also decreases the transmission delay of the alert messages and increases the reliability of system.

Key words*：*Vehicular Network, Alert Message, Broadcast Protocol.

1. Introduction

In vehicular wireless networks, highly mobility of nodes makes the network topology change rapidly and may cause wireless connection intermittent. For this reason, IEEE standard organization modifies IEEE 802.11 a, b and g [1] to establish the IEEE 802.11p [2][3] and the IEEE 1609 family of standards [4][5][6][7] for Wireless Access in the Vehicular Environment(WAVE).

Generally, vehicular network applications can be classified as safety applications and non-safety applications. The safety applications can be adopted to notify drivers of urgent events on highway to avoid accidents. The non-safety applications allow drivers or passengers to access wireless network for entertainment, such as browsing website, browsing E-mail, and playing games. In this paper, we focus on safety applications and adopt the alert messages to notify drivers of urgent event on the highway. The notification allows drivers have more time to react, to avoid accident, and to improve the safety of drivers and passengers.

In safety-related applications, the alert message transmission latency is an important issue. The transmission latency of the alert messages must be in a tolerable range. Otherwise, the probability of car accident may increase significantly. Generally, the average speed of vehicles range between from 100 km/hr to 120 km/hr on highway. The reaction time of drivers is about from 0.75 to 1.5 seconds [8]. Therefore, we must maintain the latency of transmission within the tolerable range.

In this paper, we propose a fault-tolerant broadcast protocol for the alert message disseminations which notify drivers to avoid the danger on highway in vehicular networks. In addition, we designate two candidates for relay to avoid the message loss in relay nodes. Thus, the proposed protocol can improve the reliability of the system. Moreover, the proposed protocol can mitigate the message redundancy and the broadcast storm problem [9].

The reminder of this paper is organized as follows. Section 2 briefly describes some existing message dissemination and broadcasting protocols. In Section 3, we proposed a fault-tolerant broadcast protocol for the alert messages dissemination in vehicular networks. Section 4 shows the simulation results. Finally, we conclude this paper in Section 5.

2. Related Work

The safety-related applications are usually adopted to avoid danger on the road, and to ensure the safety of the drivers on highway. When an accident occurred, the vehicle in danger may stop immediately. The accident may influence the vehicles behind, and cause another accident. Therefore, we use the alert messages to notify drivers of avoiding accidents on highway.

Generally, the alert message dissemination schemes can be classified as with GPS device and without GSP device. The vehicles equipped with GPS device are able to acquire accurate location information of vehicles. We can use the location information of vehicles to choose the relay vehicle to disseminate further alert messages.

In the following, we will briefly describe some existing messages dissemination schemes and discuss their problem.

1) Simple broadcast protocol [10]*(without GPS device assisted)*

The simple broadcast protocol can disseminate the alert messages without GPS device. When an accident occurred, the source vehicle will broadcast the alert message immediately to all vehicles which are approaching the source vehicle. Those vehicles will receive the alert message and decide whether to rebroadcast the alert message or not. If those vehicles receive the alert message, they rebroadcast the alert messages only at the first time. On receipt of duplicate messages, they drop the alert message and do not rebroadcast the alert message. As show in Figure 1, when the accident occurred, vehicle A broadcast the alert messages immediately. Vehicles B, C, D, E and F in the transmission range of vehicle A receive the alert message. On receipt of the alert message, the vehicles B, C, D, E and F decide whether to rebroadcast or not. If the first time Vehicles B、C、D、E and F receive the alert message, they will rebroadcast the alert messages. The weakness of this manner is the redundancy of alert message. The serious alert message redundancy may cause the broadcast storm problem.

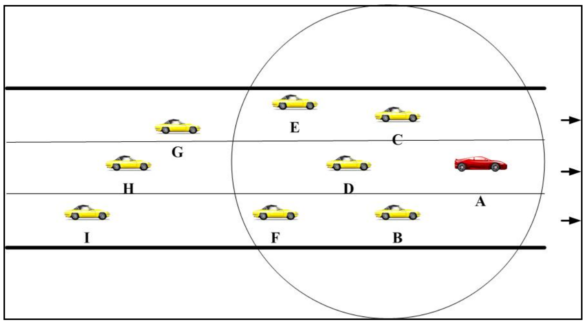

Fig. 1. Broadcasting in VANETs

2) ACK-based broadcast protocol [11] *(with GPS device assisted)*

The ACK-based broadcast protocol needs the accurate location information to calculate the next candidates. Therefore, ACK-based broadcast protocols must use GPS device or other location system to acquire accurate location information.

As show in Figure 1, when an accident occurred at vehicle A, vehicle A broadcasts the alert message immediately. Other vehicles B, C, D, E and F in the transmission range of vehicle A receive the alert message. On receipt of the alert messages, vehicles B, C, D, E and F decide whether to rebroadcast the alert message or not. If vehicles B, C, D, E and F receive the alert message, they rebroadcast the alert messages only at the first time. The alert message consists of location information of vehicles B, C, D, E and F. Upon receiving the alert message, vehicle A stores the location information into its queue. Using the location information, vehicle A calculates the distance between itself and those vehicles and chooses the farthest one in its queue. Vehicle A inserts vehicle-id of the farthest one into the farthest-node field in ACK message and broadcasts the ACK message. In the Figure 1, vehicle F is the farthest vehicle in the transmission range of the vehicle A. Vehicle A inserts vehicle-id of vehicle F into the farthest-node field in the ACK message and broadcasts the ACK message. On receipt of the ACK message, vehicles B, C, D, E and F check the vehicle-id field in the ACK message. Then, vehicles B, C, D, E and F learn the result by the ACK message. Since the ID of the farthest-node field in ACK message is the vehicle F, vehicle F becomes the relay vehicle. The relay vehicle will broadcast the periodic alert message and use above steps to choose the next relay vehicle in its transmission range.

The drawback of ACK-based broadcasting protocol is the redundancy transmission of alert and ACK messages. This problem will degrade the performance of the alert message system.

3. Fault-Tolerant Broadcast Protocol

In the fault-tolerant broadcast protocol, we try to reduce the number of the ACK messages by choosing farthest node and sub-farthest node. We also propose an exponential back-off method to reduce the number of the alert messages to avoid the alert message redundancy.

In the proposed protocol, we define two messages, the alert message and the ACK message. The alert message adopts to warn vehicles behind the dangerous vehicle to avoid the possibility of an accident on highway. The alert message consists of the ID of source vehicle, the position of source vehicle, the ID of event, the position of event. The ACK message is used for notifying the relay vehicle to broadcast alert messages. The ACK message includes the farthest-node field, sub-farthest-node field and the ID of event.

3.1 Concept of Fault-Tolerant Broadcast Protocol

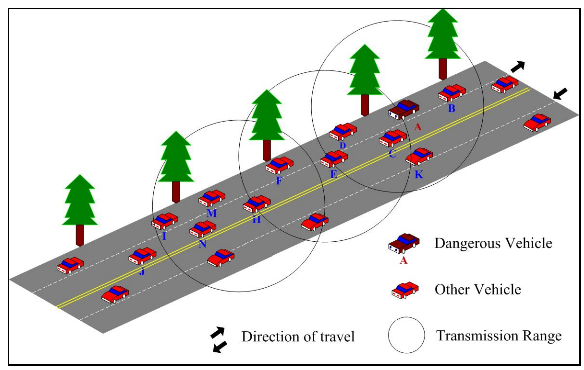

Fig. 2. Fault-Tolerant Broadcast Protocol.

When an accident occurred, the source vehicle broadcasts the alert message immediately. As show in Figure 2, when vehicle A becomes a dangerous vehicle, it will broadcast the alert messages immediately and start the timer t. The vehicles B, C, D, E and K within transmission range of vehicle A receive the alert messages. On receipt of the alert message, vehicles B, C, D, E and K decide whether to rebroadcast it or not. Because the accident only affects the vehicles behind vehicle A, only the vehicles behind vehicle A will rebroadcast the alert message. Vehicle B is in front vehicle A, and vehicle K is in opposite travel direction with vehicle A. They won't be affected by the accident, thus they do not rebroadcast the alert message. The other vehicles C, D and E should be aware of the accident since they are behind vehicle A and in the same direction with vehicle A. Thus, vehicles C, D and E rebroadcast the alert message. The alert message consists of location information of vehicles C, D and E. Upon receiving the alert messages, vehicle A stores the location information of vehicles C, D and E into its queue.

Using the location information, Vehicle A calculates the distance between itself and those vehicles. When the timer t expired, vehicle A chooses the farthest vehicle and the sub-farthest vehicle from its queue. Vehicle A inserts ID of the farthest and the sub-farthest vehicles into the farthest-node field and the sub-farthest-node field in ACK message respectively. And then, vehicle A broadcasts the ACK message. In order to ensure that the farthest vehicle and the sub-farthest vehicle receive the ACK message successfully, vehicle A broadcasts the ACK message periodically (TOack timer). Consequently, the vehicles within the transmission range of vehicle A will receive the ACK message. Upon receiving the ACK message, the vehicle checks the farthest and sub-farthest field in the ACK message to learn the result. If the farthest vehicle receives the ACK message successfully, it will become relay vehicle. Otherwise, if the sub-farthest vehicle receives the ACK message, it will start the TOc timer. After the TOc timer timeout, if the sub-farthest vehicle does not receive the ACK_response message from the farthest vehicle, it will replace the farthest vehicle to become the relay vehicle.

As show in Figure 2, the farthest vehicle and the sub-farthest vehicle in transmission range of vehicle A are vehicle E and D. Thus, vehicle A inserts ID of vehicles E and D into farthest-node field and sub-farthest field in the ACK message respectively. Then, vehicle A broadcasts the ACK message periodically. Along this process that may result in three cases：

Case 1: Farthest Vehicle Receive the ACK Message

If the farthest vehicle E receives the ACK message from vehicle A, the farthest vehicle E becomes the relay vehicle. The relay vehicle will broadcast the ACK_response message. On receipt of the ACK_response message, vehicle A cancels to broadcast the periodic ACK message (TO_{ack} timer); the sub-farthest vehicle D cancels the TOc timer. The sub-farthest vehicle D does not become relay vehicle.

Case 2: Farthest Vehicle Fails to Receive the ACK Message

If the Farthest vehicle E fails to receive the ACK messages, the sub-farthest vehicle D replaces the farthest vehicle E to become the relay vehicle after TO_c timer timeout. The relay vehicle will broadcast the ACK_response message. On receipt of the ACK_response message, vehicle A cancels to broadcast the periodic ACK message (TO_{ack} timer).

Case 3: Both Farthest Vehicle and Sub-Farthest Vehicle Fails to Receive the ACK Message

It is the worst-case that both the farthest vehicle E and the sub-farthest vehicle D fails to receive the ACK message. In this case, after TO_{ack} timer timeout, vehicle A broadcasts next round ACK messages, which may cause the ACK message redundancy and waste the wireless resource.

Finally, the relay vehicle will broadcast the alert messages periodically with period T to notify vehicles behind to avoid danger on highway. Furthermore, the relay vehicle will choose the next relay vehicle to further disseminate the alert message.

The Fault-tolerant broadcast protocol different from the ACK-based broadcast protocol. The fault-tolerant broadcast protocol adopts the sub-farthest vehicle to avoid the ACK message loss in the farthest vehicle. When the sub-farthest vehicle replaces the farthest vehicle to become the relay vehicle, it will send a reply (ACK_response message) to source vehicle. Thus, the source vehicle stops to broadcast the periodic ACK messages. Therefore, the Fault-tolerant broadcast protocol avoids the redundant ACK messages.

3.2 Exponential Back-off Method

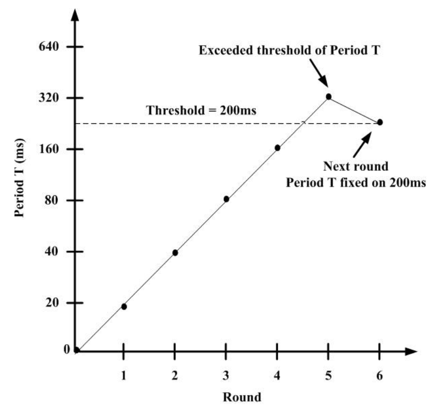

Fig. 3. Exponential back-off method.

In this section, we briefly describe the exponential back-off method. The exponential back-off method can effectively reduce the number of the alert messages and mitigate the broadcast storm problem.

When an accident occurred, the dangerous vehicle may affect the vehicles behind and cause another accident. Thus, the dangerous vehicle and the relay vehicles must broadcast periodic alert messages with period T to notify the vehicles behind. But, broadcasting periodic alert messages may cause a large number of redundant alert messages. The serious alert message redundancy leads to the broadcast storm problem. For this reason, we propose an exponential back-off method to reduce the number of alert messages.

If the dangerous vehicle and the relay vehicles broadcast the alert message with a short period time, it may cause a large number of redundant alert messages. On the other hand, if the period time is large, the probability of another accident will be high. Therefore, we use an exponential back-off method as showed in Figure 3. At the first time, the dangerous vehicle and the relay vehicles will broadcast the alert message immediately to avoid another accident. In the subsequent rounds, period T will increase exponentially since the urgent level of the accident decreases as the time passes by. For an example, in the first round, period T is 20ms, then period T will be 40ms in the second round, and so on. Unfortunately, this method would increase the transmission delay of the alert message as well. If we do not set the upper limit of the period time, the probability of vehicle chain collision will increase significantly. In order to avoid the highly transmission delay, we define the threshold of the period T to 200ms. If T exceeds the threshold, period T will be fixed on 200ms in the subsequent rounds. After then, the dangerous and relay vehicles broadcast the alert message periodically every 200ms.

3.3 Pseudo Code of the Proposed Protocol

```
//the source vehicle chooses the relay vehicle
When an accident occurred, source vehicle broadcasts the alert
message with T (T=20ms) and waits for t (30ms) to receive the same
alert messages from behind vehicles.

if (timer t is not expired){
Listen to the channel
if (receipt of the alert message from behind vehicles){
      if (the same event-id){
          if ( different vehicle-id){
                Buffer the location information into queue;
                Calculate the distance between from those vehicles;
          }}
      else { Broadcast the alert message; }
   else { Listen to the channel for passing-by alert message;}
 }
else if (t is expired){
      Choose the farthest and sub-farthest vehicles from queue;
      Insert those vehicle-id's into the ACK message;
      Broadcast the ACK message and start the TOack timer;
}
```

Fig. 4. Pseudo code for selecting relay vehicles.

In this section, we will briefly describe the pseudo code of the proposed protocol, FTBP. The process is divided into two steps. In Figure 4, we briefly describe the process for selecting relay vehicles. In Figure 5, we briefly describe the process of relay vehicles.

As shown in Figure 4, when an accident occurred, the source vehicle broadcasts the alert message immediately and starts timer T for broadcasting the alert message periodically, and starts timer t for receipt of the alert message from the behind vehicles. The alert message consists of the vehicle-id, event-id and the location information of vehicles. During the time t (the timer t is not expired), source vehicle will listen to the channel for receipt of the alert message from behind vehicles. On receipt of the alert message with the same event-id, the source vehicle stores the location information into its queue and calculates the distance between those vehicles. When the timer t is expired, the source vehicle chooses the farthest and sub-farthest vehicles from its queue and inserts the vehicle-id of the farthest and the sub-farthest vehicles into the farthest node and sub-farthest node field in the ACK message, respectively. The ACK message informs other vehicles that the farthest and the sub-farthest vehicle have been chosen. Finally, the source vehicle broadcasts the ACK message and starts the timer TOack for broadcasting the ACK messages periodically.

```
//Vehicles checks the ACK message to become the relay vehicle

if (Vehicle receive message){
    if (message == alert message)
        if (the alert message with event-id is same)
            Drop the alert message;
        else Broadcast the alert message;
    else if (message == ACK message){
        if (farther node field == itself's vehicle-id){
            Become the relay vehicle;
            Broadcast ACK_response message;
        }else if (sub-farther node field == itself's vehicle-id) {
            start TOc timer;
            if (TOc timer expire){
                Become the relay vehicle;
                Broadcast ACK_response message; }
        }
  }else if (message == ACK_response){
      if (broadcast from the farthest vehicle){
          The sub-farthest vehicle cancel TOc timer;
          The source vehicle cancel TOack timer;
      } else if (broadcast from the sub-farthest vehicle){
          The source vehicle cancel TOack timer;
      }
  }
}
```

Fig. 5. Pseudo code for process of relay vehicles..

The vehicles in transmission range of the source vehicle will eventually receive the ACK message. On receipt of the ACK message, those vehicles check the farthest node and sub-farthest node field in the ACK message and learn the result as shown in Figure 5. The duty of the relay vehicle is to broadcast the alert messages periodically and the ACK_response message to inform other vehicles that the relay vehicle has been chosen. We briefly describe the process in the following statement.

1) Vehicle is the farthest vehicle

If the vehicle is the farthest vehicle, it will become the relay vehicle. The relay vehicle broadcasts the alert message and the ACK_response message periodically. On receipt of the ACK_response message, the sub-farthest vehicle cancels the timer Toc, while the source vehicle cancels the timer TOack. In this case, the sub-farthest vehicle cannot become the relay vehicle, and the source vehicle stops to broadcast the ACK message periodically.

2) Vehicle is the sub-farthest vehicle

If the vehicle is the sub-farthest vehicle, it starts the timer TOc and waits a period time for timeout. If the sub-farthest vehicle does not receive the ACK_response message from the farthest vehicle after the timer TOc expired, it will replace the farthest vehicle to become the relay vehicle. Hereafter, the relay vehicle broadcasts the alert message and the ACK_response message periodically. On receipt of the ACK_response message, the source vehicle cancels the timer TOack and stops to broadcast the ACK message periodically.

4. Simulation Results

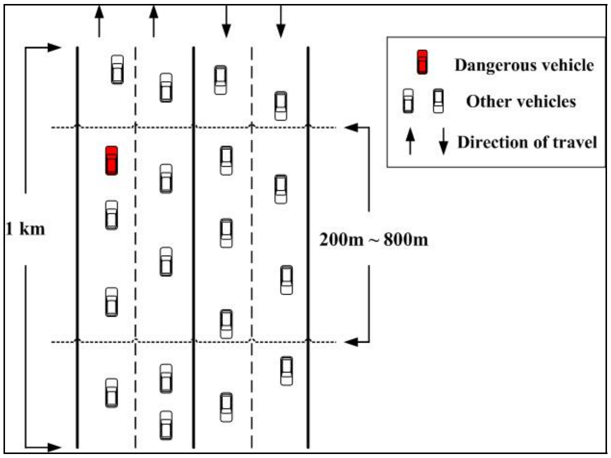

Fig. 6. The Topology of Simulation

In this section, we adopted Network simulation 2 (ns2 version 2.34) [12] to implement the simulation experiment, We use the mobility generator tool to create the freeway mobility model for simulation. As show in Figure 6, the freeway model has 2 lanes in each travel direction; the length of freeway model is 1 km. The dangerous vehicle is located at range between from 200m to 800m randomly on the freeway model. The other vehicles are located on the freeway randomly. The simulation time is 10 seconds. The detailed simulation parameters are shown in Table 1.

We compare the simple broadcast protocol (Flooding), ACK-based broadcast protocol (ACK-based), and the proposed protocol (FTBP) in terms of the performance metric including the number of the alert messages, the number of the ACK messages, the total number of the message, the transmission delay of the alert message and the penetration rate. (1) The number of the alert messages denotes the total number of the alert messages broadcasted during the entire simulation. (2) The number of the ACK messages denotes the total number of the ACK message broadcasted during the entire simulation. (3) The total number of the messages represents the total number of the messages broadcasted during the entire simulation. The message includes the alert message, ACK messages and the ACK_response messages. (4) The alert message transmission delay denotes the time from the first alert message was broadcasted to the last vehicle received the alert message. (5) The penetration rate is defined as the ratio between the number of vehicles which receive the alert messages in the risk zone and the total number of vehicles in the risk zone. The risk zone is defined as an area behind the dangerous vehicle and in the same direction with the dangerous vehicle.

4.1 Number of the alert messages

Table 1. Simulation Parameters

Variables	Values
Mobility model	Freeway model
Range of communication	200m
Avg. speed (m/s)	30m/s (108km/hr)
Number of vehicles	20, 40, 60, 80, 100
Time t	30ms
MAC protocol	IEEE 802.11p
ACK period	30ms
Period T	20ms ~ 200ms
Simulation time	10s

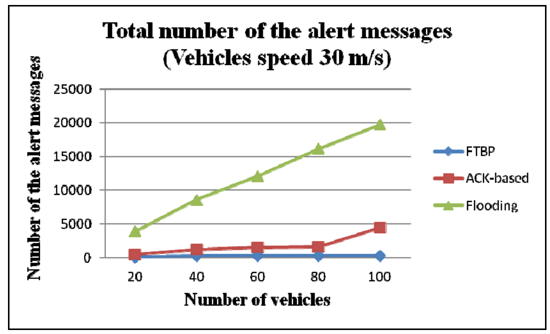

Fig. 7. Number of alert messages

In the simulation, we set the average vehicles speed to 30m/s (108km/hr), and the numbers of the vehicles are from 20 to 100. Figure 7 shows the number of the alert message broadcasted during entire simulation for different protocols. Note that FTBP achieves the lowest number of the alert message which is much lower than that of the ACK-based broadcast protocol and flooding method. The reason is that FTBP adopts the exponential back-off method to reduce the number of alert messages greatly.

4.2 Number of the ACK message

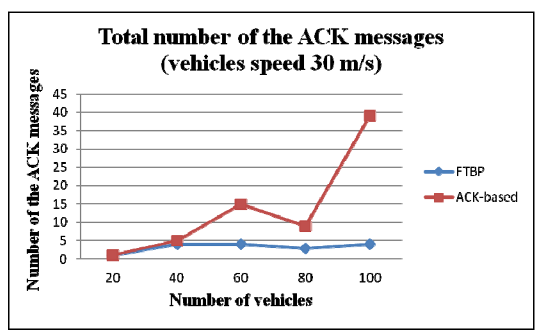

Fig. 8. Number of ACK messages

Figure 8 shows the number of the ACK messages broadcasted during the entire simulation for FTBP and ACK-based broadcast protocols. We can see that FTBP performs better than the ACK-based broadcast protocol. The reason is that FTBP adopts the sub-farthest node to replace the farthest node to avoid the loss of the ACK message in the farthest node. The loss of the ACK messages in the farthest node may cause the ACK messages redundancy.

4.3 Total number of the messages

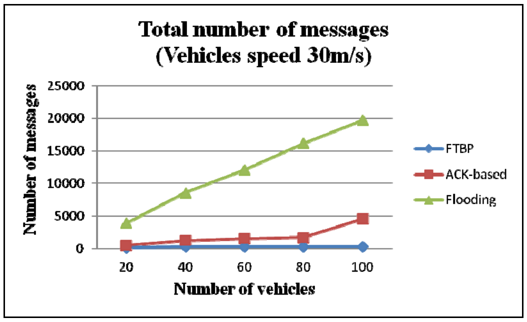

Fig. 9. Total number of messages

The total number of the messages includes the alert messages, the ACK messages and the ACK_response messages. Figure 9 shows the total number of the messages broadcasted during the entire simulation for the FTBP, the ACK-based broadcast protocol and the flooding method. We can see the FTBP always performs better than the other methods. The reason is that FTBP adopts the sub-farthest node and exponential back-off method. The sub-farthest and the exponential back-off method can extremely reduce the number of messages.

4.4 Transmission delay of the alert messages

Figure 10 shows the transmission delay of the alert messages. In the simulation, the average speed of vehicles is 30m/s, and the number of vehicles is from 20 to 100. We can see that FTBP and the ACK-based broadcast protocol are the same and outperform the flooding method in transmission delay.

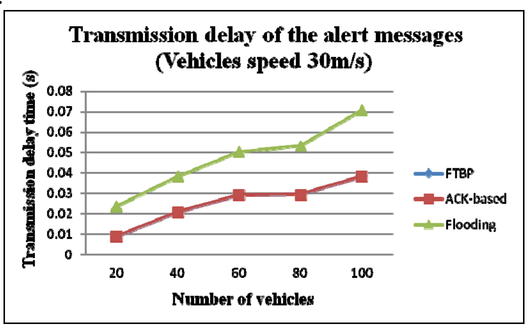

Fig. 10. Transmission delay of the alert messages

4.5 Penetration rate

Figure 11 shows the penetration rate of the alert messages for different protocols. Note that all protocols have high penetration rates that approaches 100% in the environment of high density. On the other hand, the penetration rate dropped slightly in the environment of low density due to the isolation of nodes in low density.

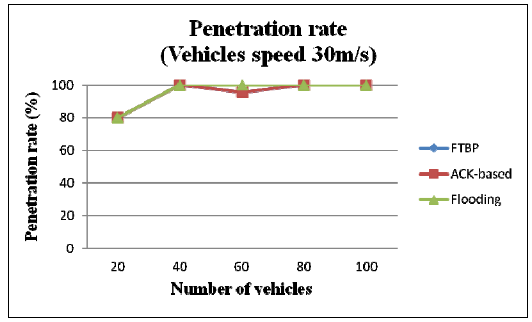

Fig. 11. Penetration rate

5. Conclusions

In this paper, we proposed a fault-tolerant broadcast protocol which improves not only the transmission delay of the alert messages but also the number of the alert messages in vehicular wireless networks. Simulation results showed that the fault-tolerant broadcast protocol outperforms the flooding method and the ACK-based broadcast protocol, in terms of the number of the alert messages, the number of the ACK messages and the total number of messages.

6. Acknowledgement

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