Broadcast Methods for Inter-Vehicle Communications System

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Abstract— This paper presents novel broadcast methods for an inter-vehicle communications system for ITS. During inter-vehicle communications, it is essential that emergency information be broadcast to surrounding vehicles. Emergency information such as emergency-vehicle-approach information and traffic accident information are needed by vehicles in a particular area. By limiting the broadcast direction, the proposed methods can provide broadcasts to a particular area and avoid mistakenly notifying other areas where the information is not needed. We developed a simulation and experimental system for the proposed method and confirmed that the information is broadcast to the desired area.

Keywords-ITS, Inter-vehicle communications, Broadcast method, Emergency Information

I. INTRODUCTION

Many new technologies have been studied for Intelligent Transport Systems (ITS) to increase vehicle safety and comfort. In roadside-to-vehicle communications, Internet services are available from cars via cellular phone to obtain necessary information, and even updated map information can be downloaded to car navigation systems. It is also important to communicate with surrounding vehicles to avoid traffic accidents. However, it is difficult to communicate with surrounding vehicles by using only roadside-to-vehicle communications systems. Inter-vehicle communications systems will therefore be needed. In addition to the client-server type services between a terminal on a vehicle and accesses servers on the Internet, many useful inter-vehicle peer-to-peer applications are conceivable for the ITS, and these have the potential to make transportation systems safer and more convenient. Technologies for broadcasting emergency information also have been the focus of much recent attention especially because they can maintain vehicle safety. In large cities, traffic congestion is a serious problem. Even emergency vehicles such as ambulances, fire engines, and police cars can be caught in traffic jams, and the resulting delay can lead to inestimable loss of life or injury. Drivers often hear the siren of an emergency vehicle but cannot determine where it is coming from or the best way to let it through. Notifying drivers well in advance of the approach of an emergency vehicle via an inter-vehicle Ad Hoc network would help drivers systematically clear the way for an emergency vehicle. The occurrence of a traffic accident should be immediately reported to approaching vehicles to prevent secondary accidents, and this information can also be transmitted by an inter-vehicle communications system. The accident information should also be passed to the road-control operator through road-control networks so that the operator can take systematic action over a wide area to prevent further traffic disorder. An inter-vehicle communications system can provide instant information in such situations and enhance the roadside communication infrastructure.

We have studied and developed a roadside-to-vehicle and inter-vehicle communication system[1][2]. In this system, the vehicle selects an optimum communication media between vehicles or between the vehicle and a server in the Internet. This paper proposes novel broadcast methods for inter-vehicle communication system. These methods restrict the broadcast area to avoid mistakenly notifying vehicles in areas where the information is not needed. This paper explains the application of such methods to emergency information notification systems.

II. PROPOSED METHODS

A message notifying other vehicles of emergency information is transmitted by the information source vehicle and relayed by other vehicles. A vehicle receiving this information can then determine the presence, location and forward (route) direction of the emergency vehicle. Emergency information, such as emergency-vehicle-approach information, and traffic accident information are needed by vehicles in a particular area. In a conventional broadcast, emergency information is relayed and notified in all directions. In areas where vehicles do not need emergency information, notification of emergency information can divert the drivers' attention and cause secondary accidents. In this section, principles and procedures of the proposed method both for emergency-vehicle-approach information and for traffic accident information are explained.

A. *Emergency-vehicle-approach Information*

1) *Principle of Proposed Method*

Notification of emergency-vehicle-approach including information on the location and route (or forward direction) of the emergency vehicle is intended to help other vehicles avoid disturbing the smooth passage of the emergency vehicle. Drivers receiving such information become aware of the presence, location and route of the emergency vehicle. In the area behind the emergency vehicle, drivers do not need this information and can in fact be confused by it. Emergency-vehicle-approach information is most important for vehicles in the area where the emergency vehicle will pass. This paper therefore proposes a broadcast method for relaying emergency-vehicle-approach information only towards the front of the emergency vehicle travel direction or of its destination. Fig. 1 shows the broadcast area for emergency-vehicle-approach information.

In this proposed method, the emergency vehicle transmits a broadcast packet including its own location, forward movement direction, available relay range and available notification range. The information is notified only to vehicles which are both within the available notification range and in front of the emergency vehicle.

Vehicles in front of emergency vehicle are vehicles where the difference angle between the relative location vector from the emergency vehicle and the forward direction vector of emergency vehicle is within 90 degrees. This means that the inner product of the relative location vector and the forward (route) direction vector is greater than 0. Utilizing the available notification range avoids mistakenly notifying other vehicles which are far enough away that they do not need to be notified. In addition, by utilizing the location offset α, the vehicle α [m] behind the emergency vehicle can be notified. Besides this notification, broadcast packet is relayed only by vehicles which are both within the available relay range and in front of the emergency vehicle. Utilizing the available relay range avoids wasting radio resources.

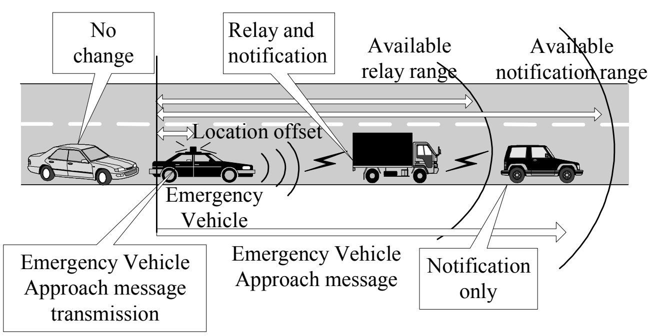

Figure 1. Broadcast area for emergency-vehicle-approach information

2) Procedure of Proposed Method

Fig. 2 shows definitions of parameters in the calculation. A broadcast packet with emergency-vehicle-approach information is relayed and notified to the driver by the following procedure.

1. Emergency vehicle transmits a broadcast packet including parameters of its own location vector $\overrightarrow{X_2}$ and unit forward direction vector $\overrightarrow{V_2}$, as well as the available notification range $R_{Notification}$, available relay range R_{Relay} and location offset α.

2. Vehicle receiving the broadcast packet determines the following expressions.

$$\left(\vec{X}_1 - \vec{X}_2 + \alpha\vec{V}_2\right)\bullet\vec{V}_2 > 0 \quad (1)$$

$$\left|\vec{X}_1 - \vec{X}_2 + \alpha\vec{V}_2\right| < R_{Notification} \quad (2)$$

$$\left|\vec{X}_1 - \vec{X}_2 + \alpha\vec{V}_2\right| < R_{Relay} \quad (3)$$

,where $\overrightarrow{X_1}$ is its own location vector.

3. The emergency-vehicle-approach information is notified to the driver when the expressions (1) and (2) are satisfied, which indicates that the vehicle is within the available notification range.

4. The emergency-vehicle-approach information is relayed when the expressions (1) and (3) are satisfied, which indicates that the vehicle is within the available relay range.

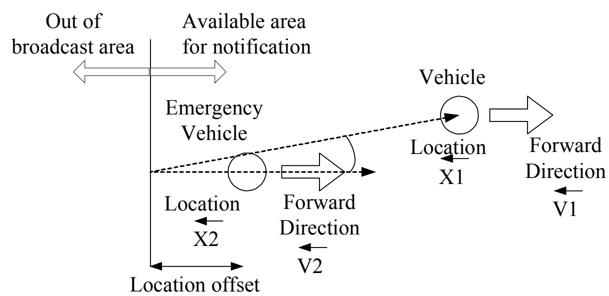

Figure 2. Definition of calculation parameters

B. *Traffic-accident-notification Information*

1) Principle of Proposed Method

Notification of traffic accident information is intended to alerts drivers of the location of the accident vehicle. Drivers receiving this information become aware of the presence and location of the accident vehicle. Drivers whose vehicles are far away for the traffic accident area do not need this information and may in fact be confused by it. Traffic accident information is most important for vehicles approaching the accident area. This paper therefore proposes the broadcast method for traffic accident information that is relayed only by vehicles approaching the traffic accident area. Fig. 3 shows the broadcast area for traffic accident information.

In the proposed method, the traffic accident vehicle transmits a broadcast packet including its own location, available relay range and available notification range. The information is notified only to vehicles which are both within the available notification range and approaching the traffic accident area. A vehicle approaching the traffic accident area is a vehicle where the difference angle between the relative location vector from itself to the traffic accident vehicle and its own forward direction vector is within 90 degrees. This means that inner product of the relative location vector and the forward direction vector is greater than 0. Utilizing the available notification range avoids notifying vehicles which are far enough away not to need this information. In addition, by utilizing the location offset α, the vehicle α [m] that passed the traffic accident vehicle can be notified. Besides this notification, the broadcast packet is relayed only by vehicles which are both within the available relay range and approaching the traffic accident vehicle. Utilizing the available relay range also avoids wasting radio resources. This is especially efficient with one-way traffic.

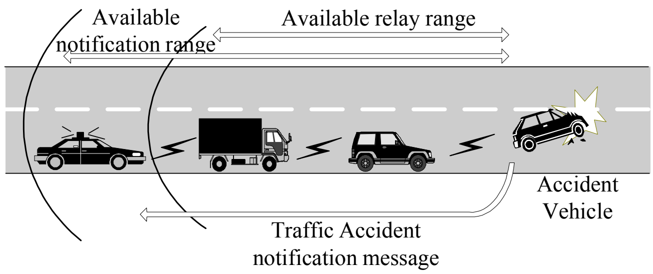

Figure 3. Broadcast Area for Traffic Accident Information

2) Procedure of Proposed Method

Fig. 4 shows the definition of parameters in the calculation. A broadcast packet for emergency-vehicle-approach information is relayed and notified to driver by following procedure.

1. Emergency vehicle transmits a broadcast packet including the parameters of its own location vector $\overrightarrow{X_2}$, available range $R_{Notification}$ for notification, available range R_{Relay} for relay and location offset α .

2. Vehicle receiving broadcast packet determines the following expressions.

$$\left(\vec{X}_2 - \vec{X}_1 + \alpha\vec{V}_1\right)\bullet\vec{V}_1 > 0 \quad (4)$$

$$\left|\vec{X}_2 - \vec{X}_1 + \alpha\vec{V}_1\right| < R_{Notification} \quad (5)$$

$$\left|\vec{X}_2 - \vec{X}_1 + \alpha\vec{V}_1\right| < R_{Relay} \quad (6)$$

,where $\overrightarrow{X_1}$ is the location vector and $\vec{V_1}$ is its own unit forward direction vector.

3. The emergency-vehicle-approach information is notified to the driver when the expressions (4) and (5) are satisfied, indicating that the vehicle is within the available notification range.

4. The emergency-vehicle-approach information is relayed if both the expressions (4) and (6) are satisfied, indicating that the vehicle is within the available relay range.

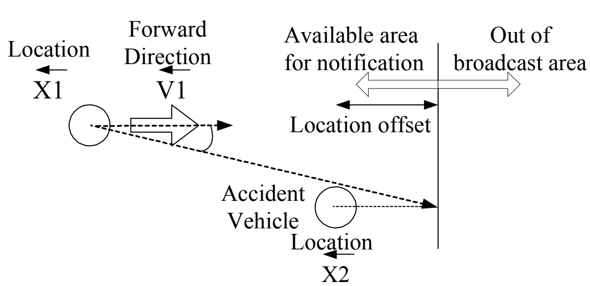

Figure 4. Definition of parameters in calculation

III. SIMULATION RESULTS

A simulation system was developed for evaluating the performance of the proposed methods. The simulation system consists of an evaluation node and pseudo-node simulator. The pseudo-node simulator can provide traffic simulations with multiple virtual vehicles and can create Ad Hoc links between the virtual vehicles or with the evaluation node. The evaluation node acts as a vehicle node and is connected to the pseudo-node simulator by a Wireless Local Area Network (WLAN) for Ad Hoc mode communications. The routing protocol in the Ad Hoc network is based on the Ad Hoc On-demand Distance Vector (AODV) protocol[3][4]. The AODV protocol searches for a multi-hop route as the hop count of the route becomes minimal. During the simulation, the received RF power of each link is based on the distance between the vehicles. In this study, pseudo-nodes were allocated in the straight line to evaluate the broadcast area performance of the proposed method.

Fig. 5 shows the GUI on the pseudo-node simulator, when the emergency-vehicle-approach notification packet is transmitted from the evaluation vehicle (vehicle 1). In the simulation, the distance between adjacent vehicles is 100 meters except for vehicle 2. All vehicles run from left to the right. The communication range is 300 meters. In Fig. 5, the evaluation node notifies other vehicles of the emergency-vehicle-approach information. In the GUI, “Location of all vehicles” displays the location of all vehicles in the simulation. “Location of vehicles notified” displays the location of the vehicle that was notified of the emergency-vehicle-approach information or traffic accident information. The available notification range is set to 500 meters. Fig. 5 shows that emergency-vehicle-approach information was notified to vehicles within 500 meters to the front of the evaluation node. Even though actually received by vehicles 3, 4, 5, 11, 12 and 13, the information is discarded by vehicles that are behind or more than 500 meters away. Results show that the proposed method successfully limits the broadcast area in front of the emergency vehicle. Fig. 6 shows the GUI on the pseudo-node simulator, when the traffic-accident-notification packet is transmitted from the evaluation vehicle (vehicle 1). This figure also shows that the proposed method effectively limits the broadcast area at the rear of the emergency vehicle.

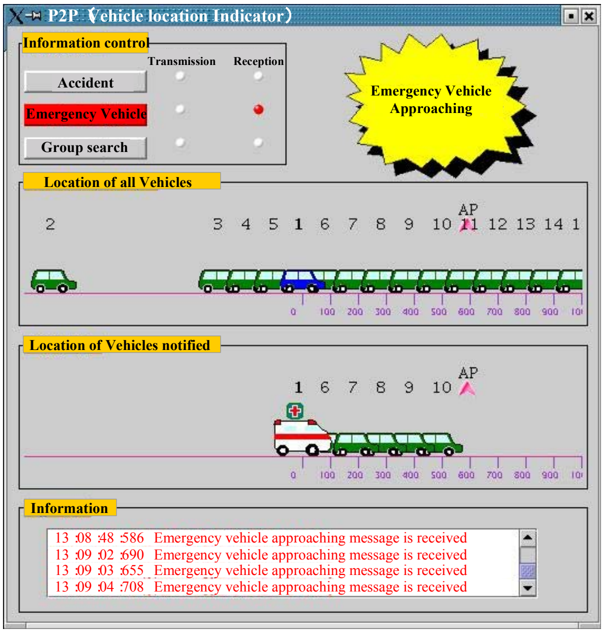

Figure 5. GUI on pseudo-node simulator when there is an emergency-vehicle-approach message from vehicle 1

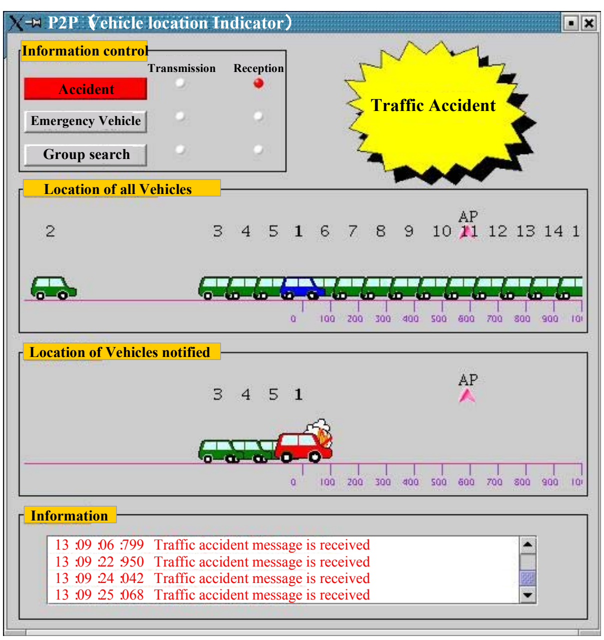

Figure 6. GUI on the pseudo-node simulator when there is a traffic-accident-notification message from vehicle 1

IV. EXPERIMENTAL SYSTEM

The experimental system for inter-vehicle communications was implemented on a PC in a vehicle. Fig. 7 and Fig. 8 respectively show the appearance of the experimental vehicle and terminal. In this system, the terminal has three communication devices: a Wireless Local Area Network (WLAN) for Ad Hoc mode communications, WLAN for infrastructure mode communications and PHS (Personal Handy-phone System in Japan). Here, IEEE802.11b devices are adopted as WLAN systems. Two antennas for the WLANs and a GPS antenna were installed on the roof of the vehicle. GPS was adopted as the location acquisition system. Omni antennas are used for WLANs and the height is approximately 1.9 [m]. In inter-vehicle peer-to-peer communications in the experimental system, the node can automatically select the communication media from among the three communications devices. During broadcasts, the node only uses WLAN for Ad Hoc mode communications. In Ad Hoc communication, the routing protocol is based on the AODV protocol. In AODV protocol, the communication path is searched by the following procedure.

(a) The source S searches for a path by broadcasting a Route Request (RREQ) message which floods in all directions. Each node that receives the RREQ message registers the reverse link information to S in the routing table. The node except the destination D forwards the RREQ message by broadcasting it.

(b) Here, it is assumed that the RREQ message arrives at D along Path 1. D registers the reverse link information to S in the routing table.

(c) A Route Reply (RREP) message is unicast from D to S along Path 1, after the RREQ message is received by D. Upon receiving the special RREP message, each node of Path 1 registers the forward link information to D with the routing table, and forwards the RREP message to the next hop of the reverse link. When S receives the RREP message, the bi-directional Path 1 is established.

The broadcast methods implemented on the experimental system are based on procedure (a) of the AODV protocol and the proposed broadcast methods. The source S transmits the RREQ packet including the emergency information, location vector, forward (route) direction, available notification range, available relay range and location offset. The RREQ message does not include the information of a particular destination, because the proposed method provides broadcasts not to a particular vehicle but to a particular area. The RREQ message is relayed according to the criteria in the methods described in Section 2 using the position and route direction of the node obtained by the GPS receiver. In the experimental system, the unit forward direction vector is calculated in the relay node from the route direction.

The outdoor experiment was conducted on the premises of the Yokosuka Research Park (YRP) where the ITS Research Center NiCT is located. Fig. 8 also shows the display on the experimental terminal. The terminal used Linux OS version 2.4.21, and the display was programmed with JAVA. Fig. 9 shows the GUI which controls transmission of emergency-vehicle-approach information and traffic accident information. The map of the experimental course was displayed on the terminal, and an icon of its own vehicle is positioned on the map utilizing GPS data just as in a car navigation system.

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The latitude and longitude of four turning points in Fig. 9 are [E139°40′42″, N35°13′14.5″], [E139°40′40.9″, N35°13′10.7″], [E139°40′52.9″, N35°13′14″] and [E139°40′51.8″, N35°13′9.1″]. Fig. 10 shows plot of the GPS data obtained during the vehicle runs in the test course. The velocity of the experimental vehicle is approximately from 10 to 30 [km/h]. When the emergency-vehicle-approach information is received, the icon of emergency vehicle is displayed on the map to match the notified location information, and the caution message "emergency vehicle is approaching" is flashed on the display. When the traffic accident information is received, the icon of the accident vehicle is displayed on the map according as the notified location information and the caution message "traffic accident information!" also appears on the display.

Fig. 11 shows the display on the GUI in vehicle 1, when vehicle 2 has transmitted the emergency-vehicle-approach information. The display on the GUI prior to vehicle 2 transmitting the emergency-vehicle-approach information is shown in Fig. 9. It was also confirmed that the emergency vehicle icon and the caution message disappeared after the emergency vehicle passed vehicle 1. The display on the GUI in Fig. 9 did not change either before and after vehicle 2 transmitted the traffic accident information to the rear of vehicle 1. Fig. 12 shows the display on the GUI in vehicle 2, when vehicle 1 transmitted the traffic accident information while to the front of vehicle 2. The GUI display however does not change, even if vehicle 1 transmits the emergency-vehicle-approach information. It was consequently confirmed that in the experimental outdoor system, emergency-vehicle-approach information is notified to vehicles forwards (to the front) of the emergency vehicle and that traffic accident information is notified to vehicles to the rear of the accident vehicle.

Figure 7. Appearance of experimental vehicle

Figure 8. Display on experimental terminal

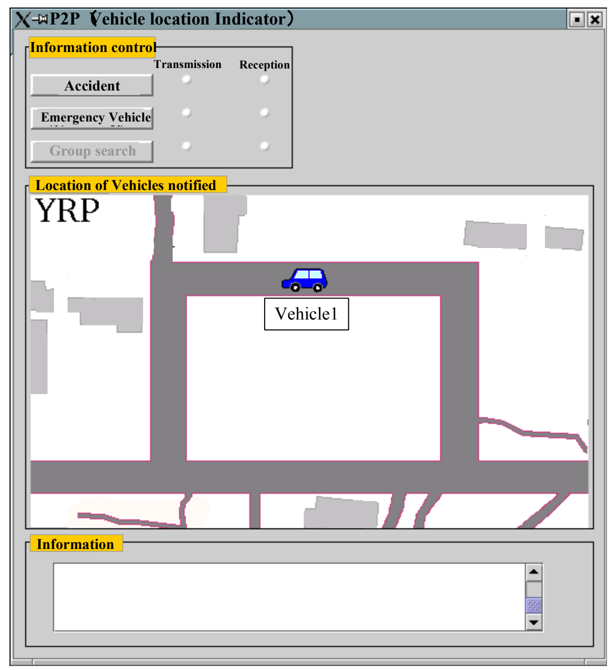

Figure 9. Experimental terminal GUI for controlling transmission of emergency-vehicle-approach information and traffic accident information

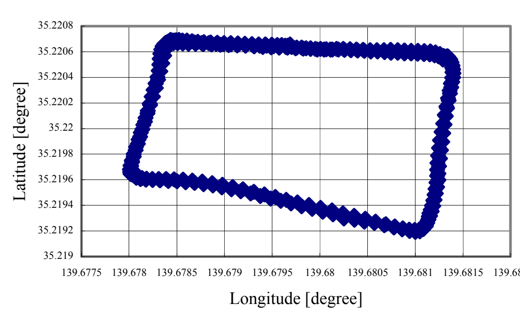

Figure 10. GPS data obtained during the vehicle runs in the test course

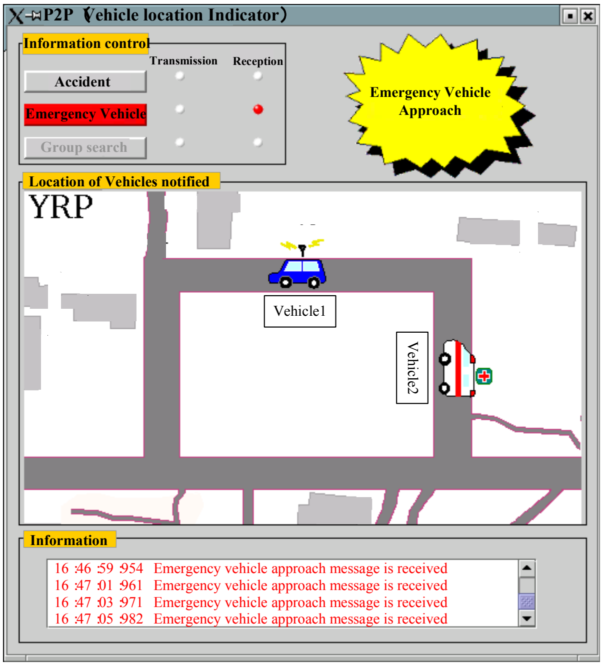

Figure 11. Display on GUI in vehicle 1 when vehicle 2 transmits emergency-vehicle-approach information

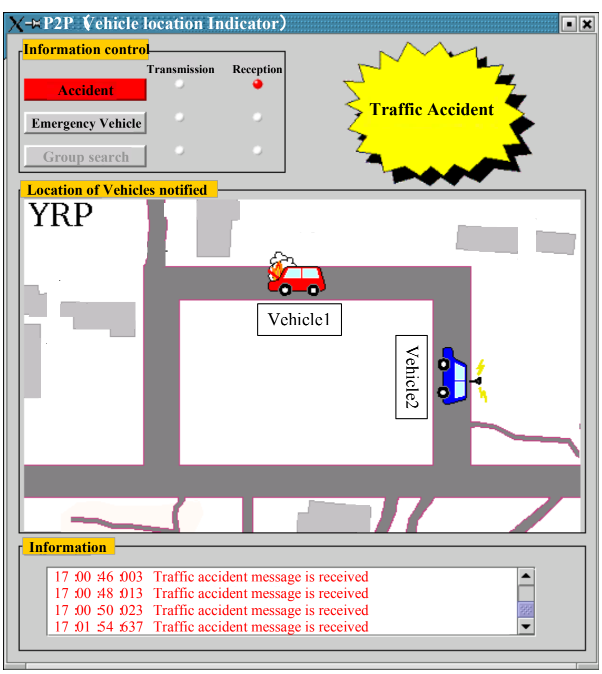

Figure 12. Display on GUI in vehicle 2, when vehicle 1 transmits traffic accident information

V. CONCLUSIONS

We proposed novel broadcast methods for inter-vehicle communication over ITS. The proposed methods allow more efficient emergency broadcasts by limiting the broadcast area. When the emergency-vehicle-approach information is broadcast, that information is relayed and received only by vehicles forward of the emergency vehicle. When information on a traffic accident is broadcast, it is relayed and received only by vehicles headed towards the position of the accident vehicle. A simulation and experimental system were developed for evaluating the proposed system. Results from the simulation and experiment system confirmed that information is broadcast to the desired area.

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