Inter-Vehicle P2P Communication
Experimental On-Board Terminal

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Abstract—It is expected that vehicles have on-board terminals to communicate with the fixed network and also with surrounding vehicles in the near future. This paper explains our developed inter-vehicle P2P (peer-to-peer) communication experimental on-board terminal, we nicknamed it “V-ant”, which has the feature of adopting AODV (Ad-hoc On-Demand Distance Vector) protocol, control of AODV packets transmission direction using GPS data, and adaptive media switching between vehicle-to-vehicle ad-hoc communication, communication through access points, and PHS (Personal Handy-phone System in Japan).

Keywords- AODV; P2P; vehicle-to-vehicle communication

I. INTRODUCTION

Many new technologies have been brought to automobiles and that increased the comfort and safety of vehicles. Internet services are available from cars via cellular phone to get necessary information, and even updated map information of car navigation systems can be downloaded. However, vehicles have almost no effective ways to communicate with surrounding vehicles. This kind of communication function is thought to be introduced into vehicles in the near future.

In addition to the client-server type services, a terminal on a vehicle being a client and accesses servers in the Internet, many useful inter-vehicle peer-to-peer applications are conceivable for the ITS (Intelligent Transport Systems), and they have the potential to make transportation systems safer and more convenient.

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 delays can lead to irreparable losses. Drivers often hear the siren of an emergency vehicle, but cannot determine where it is coming from and the best way to accommodate its passage. Notifying drivers well in advance of the approach of an emergency vehicle via a vehicle-to-vehicle ad-hoc network would help drivers systematically clear the way for an emergency vehicle [1].

The occurrence of a traffic accident should be immediately reported to the following vehicles to prevent secondary accidents, and this information can also be transmitted through a vehicle-to-vehicle ad-hoc network. In addition, 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. Vehicle-to-vehicle ad-hoc networks can provide instant information in such situations and may enhance the roadside communication infrastructure.

If a vehicle fails to obtain information on traffic congestion from a roadside station, the vehicle can send a request to neighboring vehicles to obtain the pertinent information file through an ad-hoc network. Such exchanges of information are not limited to traffic-related information; the exchange of music files, video files, and text files between vehicles may be possible applications.

During a group trip, drivers and passengers will also find it convenient to be able to determine the locations of other vehicles in the group and communicate with each other. In such a case, vehicle-to-vehicle communication will be helpful.

II. EXPERIMENTAL SYSTEM

A. Simulation System

1) System Configuration:

Recognizing the potential usefulness of inter-vehicle peer-to-peer communication, we are developing a practical system. In the first phase of this development, we have designed and tested a media-switching peer-to-peer communication simulation system in which users can apply a wireless-LAN ad-hoc mode, a wireless-LAN infrastructure mode, or PHS depending on the surrounding circumstances [2] [3] [4].

The simulation system consists of an evaluation node, a pseudo-node simulator, a wireless access point, a remote access server for PHS, an intelligent switching hub, and GPS receivers. The configuration of the simulation system is shown in Figure 1. The pseudo-node simulator can conduct traffic simulations with multiple virtual vehicles and can create ad-hoc links, links through access points, and PHS 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. During the simulation, an appropriate communication medium is selected according to a medium-selection algorithm. This algorithm looks up profile information such as the availability of communication media,
the location and speed of nodes, available bandwidth, and transmission delay. We have extended the AODV protocol [5] [6] function so that nodes can exchange profile information with other nodes by using the RREQ (Route Request) and RREP (Route Reply) packets of the AODV protocol.

![Figure 1. Configuration of the simulation system](image)

2) Media Selecting Procedure:

Not all vehicles are necessarily equipped with the hardware needed to use a desired medium. Even if a vehicle is equipped with the required hardware, the medium might not be available because the vehicle is outside of a service area. Thus, the system should be able to use multiple communication media and select the most suitable medium to enable flexible communication. This section explains our method for selecting the most suitable medium based on medium profiles, location profiles, and communication profiles. In this method, the communication initiator selects a medium using the profiles that apply to the initiator and desired responder. The information contained in each profile is as follows.

Medium profile: Installed devices and their availability
Location profile: Actual location (e.g., latitude and longitude), running speed and direction
Communication profile: Available bandwidth and communication transmission delay

![Figure 2. Medium selecting sequence](image)

a) Profile acquisition ((I) in Figure 2):

RREQ packets and RREP packets, which are AODV protocol messages, are also used for profile requests and responses, respectively. This approach reduces the total medium selection processing time because both the route discovery in the ad-hoc network and the profile acquisition are done at the same time. The profile acquisition procedure is as follows.

- The initiator broadcasts an RREQ packet in which an IP address of the responder is included as a destination IP address.
- When a node receives the RREQ packet, it checks the destination IP address to determine whether the RREQ packet is addressed to itself. If not, it rebroadcasts the RREQ packet.
- When the responder receives the RREQ packet, it measures the transmission speed to a wireless LAN access point (AP). It then adds profile information to an RREP packet and sends it back to the initiator via relay nodes.
- When a relay node receives the RREP packet, it adds a location profile to the RREP packet and sends it to the initiator.
- When the initiator receives the RREP packet, it selects an available medium and judges whether the expected duration is sufficient for communication based on the initiator and responder profiles.

b) Measurement of quality ((II) in Figure 2):

In the system, the bandwidth of the wireless LAN (infrastructure mode) is acquired through the “iwconfig” command. This is a Linux OS command that is used to set
configuration parameters and display the communication quality of a wireless LAN medium. In a wireless LAN (in an ad-hoc mode), the “iwspy” command is used to evaluate the bandwidth of each ad-hoc link. For PHS, which is a circuit switching system with a fixed bandwidth (e.g., 32 kbps, 64 kbps), the transmission speed is pre-configured. In transmission delay measurements, the RTT is measured using ICMP echo packets.

c) Media selecting and switching (III) in Figure 2:
The initiator selects the best quality medium based on the results of transmission quality measurement and then switches to the selected medium. This switching is realized by modifying a routing table for the data packets addressed to the responder to be sent via the selected medium. Even if the initiator communicates with several responders simultaneously, this implementation allows us to use a different medium for each responder.

B. Enhancement of the Experimental System

In the second phase of our system development, we upgraded the experimental system. First, we added a function that enabled control of the AODV packet transmission direction by using GPS data. When a relay node receives packets, it compares its own location with the sender’s location. When packets are to be transmitted forward (relative to the direction of travel), the relay node does not relay the packets to other nodes if it judges that it is behind the sender. In this way, the direction of transmission is controlled and unnecessary packet transmission is reduced. That means reducing of unnecessary information to drivers.

Second, we developed an adaptive medium switching procedure to improve the continuity of communication. In our original simulation system, a connection path was maintained until the path was cut, and the route discovery process for a new connection began only after complete interruption of the connection. In the second-phase system, a new route discovery process begins as soon as the quality of the connection deteriorates while the connection is still open. When a new path with better quality is found, the path is quickly switched to the new path so that the path quality is maintained and transmission interruption is minimized.

1) Controlling Direction of Transmission:
Notification of an approaching emergency vehicle and transmission of accident information are two practical applications of vehicle-to-vehicle communication. For the first of these applications, packets must be transmitted from the emergency vehicle to the vehicles ahead of it. In contrast, packets for the second application need to be transmitted backward with respect to the direction of travel. This directional control of packet transmission is achieved by comparing the location information of the nodes. For example, a node which receives an emergency-vehicle-approaching notification packet compares its own location with the location information contained in the packet. If the node is within a specified distance and in front of the emergency vehicle, the node relays the packet; otherwise, the node discards the received packet. In other words, the relay node relays received packets only when the direction of the vector from the location of the emergency vehicle to that of the relay node is within ±90° of the emergency vehicle’s moving-direction-vector – that is, when the inner product of the two vectors is positive.

The criterion formula that determines the relay node area for emergency-vehicle-approaching notification is

\[ (\vec{X}_1 - \vec{X}_2 + \alpha \vec{V}_2) \cdot \vec{V}_2 > 0, \]

where

- the position vector of a relay node \( \vec{X}_1 = (x_1, y_1) \),
- the direction vector of a relay node \( \vec{V}_1 = (\cos(90^\circ - \theta_1), \sin(90^\circ - \theta_1)) \)
- the notified position vector \( \vec{X}_2 = (x_2, y_2) \),
- the notified direction vector \( \vec{V}_2 = (\cos(90^\circ - \theta_2), \sin(90^\circ - \theta_2)) \),

(\( \theta_1 \): the clockwise angle from north), and

\( \alpha \) [m] is a position offset coefficient.

2) Adaptive Media Switching:

Under the ordinary AODV protocol, a transmission path established between vehicles is maintained until the connection is interrupted, and then a new route discovery process starts. In continuous communication where the relative positions of vehicles constantly change, an interruption before a new connection is established is very probable. For the TCP communication, it may greatly down in throughput. For the UDP communication, for example VoIP (Voice over IP), the occurrence of packet loss may adversely affect the quality of applications.

To alleviate this problem, we developed an adaptive medium switching procedure where each node periodically monitors the receiving signal level and switches the route to a better one before the original route is interrupted due to deterioration.

The adaptive medium selection sequence is as follows (Fig. 3).

- Node A, the initiator, sends a request packet to node D, a responder, and an ad-hoc route is established through nodes A, B, C, and D.
- After the route is established, each relay node periodically monitors the communication quality. The following commands are used to monitor quality.
  - the iwconfig command, which measures the quality of the wireless-LAN infrastructure mode between an access point and a node.
  - the iwspy command, which measures the quality of the wireless-LAN ad-hoc mode between nodes.
- When quality deteriorates to below a threshold, node B sends an RERR (route error) message containing quality-deterioration information to nodes A and C. Upon receiving the RERR from node B, node C sends an RERR to node D.
Upon receiving the RERR, node A initiates the route discovery process as in (1). As node C places a higher priority on a route other than the route including node B, for a certain period of time node C neither receives an RREQ from node B nor sends an RREP to node B.

A new route is then established through nodes A, B, B', C, and D. If a new route is not found, the original route is maintained.

The sequence shown above is for the case of ad-hoc mode. For the case of infrastructure mode, the medium re-selection begins when an ether side of node connected via infrastructure mode observes the quality degradation, or when a gateway node, which connect an access point and ad-hoc mode, observes the quality degradation.

Figure 3. Adaptive Medium Selection Sequence

III. EXPERIMENTAL ON-BOARD TERMINAL

We mounted the evaluation nodes on our experimental vehicles as on-board terminals. Figure 4 shows the appearance of the vehicle. We used IEEE802.11b as a wireless-LAN. We attached two wireless-LAN antennas on the roof of the vehicle, one for ad-hoc mode communication, and the other for infrastructure mode communication. A GPS antenna was also put on the roof, and the antenna was connected to a compact flash type GPS receiver. A CCD web-camera was put on the dashboard of the vehicle.

We have conducted an outdoor vehicle-to-vehicle connection experiment using an IEEE802.11b wireless-LAN on the premises of the Yokosuka Research Park (YRP) where our ITS research center is located. We obtained an average receiving signal level of ~73 dBm and an effective transmission rate of over 4 Mbps at a distance of 200 m between stationary vehicles, and ~80 dBm and over 3 Mbps, respectively, at a distance of 400 m. We confirmed that IEEE802.11b wireless-LAN connection with our on-board terminals enabled an adequate transmission distance and an effective transmission rate for inter-vehicle peer-to-peer communication under stationary position of vehicles [7].

Figure 4. An experimental vehicle

Following the connection experiment, we performed an outdoor functional experiment to confirm that the terminals functioned properly. Figure 5 shows the configuration of the experiment. We used three vehicles and conducted the experiment under the multi-hop communication environment.

Figure 5. Configuration of the outdoor trial
Figure 6 shows the display of the experimental terminal. The terminal used Linux OS version 2.4.21, and the display was programmed with JAVA. The map of the experimental course was displayed on the terminal, and an icon of the vehicle was located on the map utilizing GPS data just like a car navigation system. When an emergency-vehicle-approaching message was sent from the back, a cautionary message was flashed on the display and the location of the emergency vehicle was displayed on the map. When an accident notification message was sent from the front, a cautionary message was flashed on the display and the location of the accident was displayed on the map with the accident icon.

Vehicles mounted with cameras that allow drivers to see behind and alongside their vehicles are now on the market, but the obtained images cannot yet be sent outside of each vehicle. The exchange of real-time moving pictures will provide an additional source of information for drivers. For example, a driver stopped behind a bus or large truck who cannot see the traffic conditions in front of him can send a request to the vehicle blocking his view and receive from it a picture of the road ahead. After receiving the picture, the driver can better judge the traffic situation. In the same way, a driver can request pictures of intersections through which he plans to pass.

IV. CONCLUSION

We have developed an inter-vehicle peer-to-peer communication experimental on-board terminal. In the first phase of our project, we developed a simulation system which could select between vehicle-to-vehicle ad-hoc communication, communication through access points, and PHS communication depending on the surrounding circumstances. In the second phase of the project, we refined the system in two ways. First, we enabled control of the AODV packet transmission direction by using GPS data. Second, we enabled the system to begin an adaptive medium switching procedure as soon as it detected communication quality deterioration. Finally, we mounted the system on to the experimental vehicles as on-board terminals and conducted the experiment, and we confirmed their proper functions.

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