The In-vehicle Router System to support Network Mobility

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Abstract. This paper proposes a communication system which ensures Internet connectivity and network transparency to a group of nodes with several network interface devices. We also implement this system as In-vehicle Router System. A vehicle consists of a group of nodes such as sensor nodes and devices held by passengers, is connected to the Internet through several network interface devices. It is typical for buses, trains, and airplanes to have such Mobile Internet environment, and the nodes in such vehicles have to change the attachment point of the Internet frequently. But the nodes would then not be able to maintain transport and higher-layer connections if it changes the attachment point. Thus, it is important to provide mobility support like Mobile IP. These nodes include low cost network appliances with only limited space for extra functions. It is preferred that a solution has no impact on these low cost nodes. Therefore, existing Host Mobility Protocol is not suitable for this situation. In this article, we propose the In-vehicle Router System as a solution to this situation by combining network mobility protocol with Interface switching system. We also implement and evaluate our system on the InternetITS testbed. We have confirmed that our system provides enough functionality to satisfy the requirements of Mobile Internet vehicles.

1 INTRODUCTION

Automobiles contain a group of nodes, consist of sensor nodes and devices held by passengers. Passengers can also be considered as a group of nodes with PDA's and cellular phones. These groups of nodes are connected to the Internet using several communication devices such as cellular phones and Wireless LANs.

This paper proposes a communication system which ensures Internet connectivity and network transparency to a group of nodes with several network interface devices. Based on the suggested model, we have designed and implemented the In-vehicle Router System for automobiles connecting to the Internet.

The InternetITS Project [1] aims at building the ITS infrastructure, and ultimately promoting ITS-related industries and businesses. ITS (Intelligent Transport Systems) is a system which is designed to promote the advance of car navigation technology, to ensure that the Electronic Toll Collection System (ETC) is effective for tolling and to support safe driving. With this system, people, roads, and vehicles mesh using the latest information communications technology.

The InternetITS Project carries on three pilot programs, Nagoya Pilot Program: services for use by taxi companies, drivers and passengers; Tokyo Pilot Program: services for general car drivers; High Function Prototype Car Program: future services assumed. This paper is a part of High Function Prototype Car program. A High Function Prototype Car is equipped with functions we expect for future InternetITS, safe driving assistance, management of drivers' physical conditions, group multi-media communications, vehicle status monitoring and so on.

This paper explores the requirements of the prototype car, and proposes the design of the In-vehicle Router System which satisfies the requirements. In order to verify the validity of this system, we also evaluate this system.

2 ASSUMED ENVIRONMENT FOR OUR SYSTEM

The purpose of this study is to propose a communication system for the High Function Prototype Car. In order to arrange the requirements for the In-vehicle Router System, we explain the assumed environment, some applications and features of the prototype car in this section. The applications include a probe information service, a group multi-media communication, vehicle monitoring service.

As we mentioned in section 1, we assume that automobiles contain a group of nodes and these groups of nodes are connected to the Internet using several communication devices such as cellular phones and Wireless LANs. Figure 1 shows the Mobile Internet environment currently assumed.

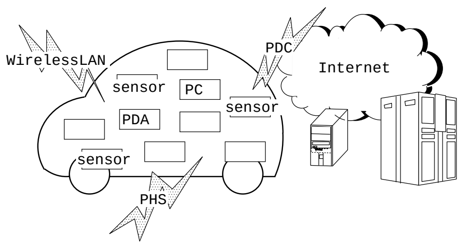

Fig. 1. Mobile Internet environment assumed

A probe information service is an application of the High Function Prototype Car. The probe information service utilizes automobiles as roving sensors scattered all over. The center system collects desired informations from each automobiles. New information is produced by processing collected data. The information will be used for operation management of vehicles, public service and etc. Many different types of computers are carried in the present cars, and those computers are processing more than 100 different types of information. However, these data collected by a car are currently used only by the car itself and not exported. In the probe information service, data are collected and processed by the information center of vehicles, and then, the processed information is sent back to the vehicles. This model could be applied to traffic congestion information service, road information service, weather information service, parking lot usage information service, etc. efficiently.

The prototype car has touch-sensitive displays, video cameras, and microphones on each seat. We can perform a group multi-media communication with movies and audios with those devices using the existing applications and products. The video stream, VIC/RAT [2] over IP, are delivered by Explicit Multicast [3] to the Correspondent Nodes. VIC and RAT are widely deployed video conference applications.

We can also monitor the current status of the car at anytime by using custom-made applications. The status includes the current location, speed, wiper and lights status and so on. These status information are collected through SNMP using the InternetITS Management Information Base (MIB). The specification of the MIB is available from [1].

Other featured services include portal web sites, individual authentication by IC card, access by center-type voice recognition, electric money reconciliation settlement, push-type content delivery service.

3 REQUIREMENTS FOR OUR SYSTEM

In this section, we summarize the requirements to design the communication system in the environment described in section 2.

End-to-End communication, **Permanent connectivity**, **Reaching via fixed IP address**: As a car moves around, the attachment point of the Internet could change frequently. For example, within a few seconds, a car communicating by IEEE802.11b could be out of the cell range for the cell size of IEEE802.11b is about 300 meters. To keep stable connectivity, we have to switch the network devices in time, because there are no network devices which covers all over the world. When a node changes its attachment point to the Internet, the IP address changes. Thus nodes inside the car can not have fixed identity on the Internet. It is not preferable to have an extra naming mechanism on the session layer or more upper layer such as TCP migration [4] or I-TCP [5], because it has an impact to the existing applications. Thus we assume End-to-End communication and fixed IP address for each in-vehicle node.

Migration transparency, **Transparency from Application**: The changes of IP address also trigger disconnection of the session between Corresponding Nodes and nodes inside a car. To keep the session connected with the existing applications, we need to introduce migration transparency into our system. The solution dose not affect the existing applications and products.

No impact to nodes inside a car: We have Low Cost Network Appliance(LCNA) such as sensor nodes inside a vehicle. We can not extend LCNA, thus the solution should support those nodes and have no impact to nodes inside the vehicle. This allows us to use existing products without any changes to nodes inside a car.

Desirable bandwidth: Our applications, the probe information service and vehicle monitoring service, should be in operation at all times. To collect information which are used by those applications, we use SNMP. The MIB of InternetITS is 788 bytes in total. To obtain the information every 1 second, we need at least 6,304 bps. Additionally, the group communication application requires the following bandwidth with h263 codec (320 x 240 size); if the object is moving and the frame rate is 1.3 fps, it requires 25 Kbps, if the object stays still and the frame rate is 15 fps, it requires 14 Kbps. Therefore, about 20-31 Kbps is desirable in total.

Small Round Trip Time: We have the video conference application which requires real-time communication. According to [6], we need less than 200 ms to get good performance with this applications. Thus, it is preferable to keep the latency within 200 ms, between Correspondent Node and node inside a car. Of course, the round trip time depends on the topology and Layer 2 technologies.

4 RELATED WORKS

We use Mobile IPv6, Interface Switching and Prefix Scope Binding Update as components of the proposed communication system.

Mobile IPv6 [7] provides host mobility on the network layer. Each mobile node is always identified by its home address, regardless of its current point of attachment to the Internet. In this case, a mobile node has a *fixed IP address as Home Address*. While situated away from its home, a mobile node is also associated with a care-of address, which provides information about the mobile node's current location. IPv6 packets addressed to a mobile node's Home Address are transparently routed to its care-of address. The protocol enables IPv6 nodes to cache the binding of a mobile node's Home Address with its care-of address, and then send any packets destined for the mobile node directly to this care-of address. Thus Mobile IPv6 can provide *End-to-End communication* between Mobile Node and Correspondent Node as well as *Migration Transparency*.

Interface Switching using Care-of Address provide a *permanent connectivity*, a mobile node has to optimize the data-link media according to the situation. "Multiple Network Interface Support by Policy-Based Routing on Mobile IPv6" [8] is a framework for optimum interface selection with respect to each network connection. It provides persistent Internet connectivity, better throughput and efficient utilization of multiple network interfaces.

Prefix Scope Binding Update (PSBU) [9] is one of the solution of the network mobility. In contrast with host mobility, the network mobility support is considered where an entire network changes its point of attachment to the Internet and thus its topology changes. PSBU is an enhanced Mobile IPv6 Binding Update which associates a care-of address with a network prefix instead of a single IP address to provide network mobility. Network mobility can provide *the mobility for nodes inside a car* even if we can not extend the nodes.

5 DESIGN OF OUR SYSTEM

We choose the combination of those three technologies, Mobile IPv6, Interface Switching and Prefix Scope Binding Update, which are mentioned in section 4 to satisfy the requirements. Each function alone can not satisfy all the requirements. However by integrating these functions in to a system, we can satisfy the requirements. In this section, we show how those three technologies work as one system. Refer to [7], [9] and [8] about the detailed actions.

We describe the entire picture of the In-vehicle Router System in Figure 2. There are Mobile Router(MR), Home Agent(HA) and Correspondent Node(CN). MR is a router which provides mobility support for a group of nodes. We assume that the group of nodes is addressed on a subnet behind the HA. HA is a router which knows the current care-of address of MR. The care-of address is the current IP address of the external interface of MR. CN is a node which communicates with the group of nodes.

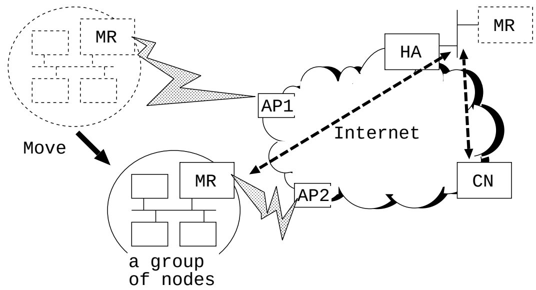

Fig. 2. System image of In-vehicle Router System

When the CN sends packets to the group of nodes, the packets are forwarded toward the HA according to the routing of the Internet. Assuming that the MR is not behind HA, the packets will become unreachable. However, the HA knows the current IP address of MR enabling HA to re-route the packet which destined to the group of nodes to the current location.

The In-vehicle Router System is designed as an extension to SFC-MIP6[10], which is our own implementation of Mobile IPv6. Our Mobile IPv6 stack is comprised of Header processing part, care-of address management part and home address selection. The packets sent from Mobile Node are destined to the CN by using care-of address as source IP address. CN can know that the packets are sent from the Mobile Node, because the packets also include the home address as an IPv6 destination header. Thus the header processing part can provide Transparency to the upper layer. CN has to manage the binding between home address and care-of address as Binding Cache. Mobile IPv6 also defines the management of Binding. For details, refer to [10].

The distinctions between Mobile IPv6 and PSBU are the entity of Binding Cache and signaling messages of Binding Update. CN has to hold the network prefix corresponding to the network behind MR, in this case the network inside a car, in the Binding Cache. In order to transmit the information of the network prefix, we also have to extend the signaling between CN and MR. Thus PSBU is designed by extending the header processing part. To perform interface switching, we have to decide the care-of address depending on the situation. In our design, each network interface has a priority. The interface is switched depending on the priority and link status of the interface. For example, assume having two interfaces, A and B; A has priority 1 and B has priority 2. When interface A is down and interface B is up, the system uses interface B. However the system switches to the interface A if interface A comes up. This function works as an extension of the care-of address management parts. In this way, these functions are carried out.

CN and MR in the vehicle are based on this design, but CN have only Header Processing Part and Binding Cache. Nodes inside a car keep the normal specification of IPv6.

6 IMPLEMENTATION

This implementation is an extension of SFC-MIP. We implemented this system on NetBSD 1.5.2 and on FreeBSD 4.4. In this section, we explain about basic data structures, the interface switching module and the extension of signaling for Binding.

The implementation has data structures shown in Figure 3. Structure mobileip_data includes the pointer of all data for this implementation. Structure mobileip_softc includes the information only related to the function of Mobile Router. When the system works as CN or HA, this structure isn't referred. Structure mip_if includes the information of pseudo device, virtual device, which has a home address. In this implementation, each home address is held on each pseudo device. Thereby, it becomes possible to have multiple home addresses and switch the home address for the purpose of use. Structure coa_list includes the list of care-of addressees(CoA) which is managed by CoA selection parts. The care-of addresses are stored with a priority, the care-of address which have the highest priority is used as the primary care-of address. Structure home_agent_list includes a list of HAs. Structure binding_update_list includes a list of CNs to which Biding Update should be sent. All nodes have the Binding Cache as structure binding_cache and the corresponding network prefix as Structure mobile_network_cache . We divided the mobile network cache from the binding cache, because it is less cost to implement. When CN sends a packet to the nodes inside a car, CN looks up the Binding which corresponds to the destination of the packet from the mobile network cache. If it matches, the corresponding care-of address is searched from Binding Cache. Thereby, nodes can know the corresponding care-of address of nodes inside the car.

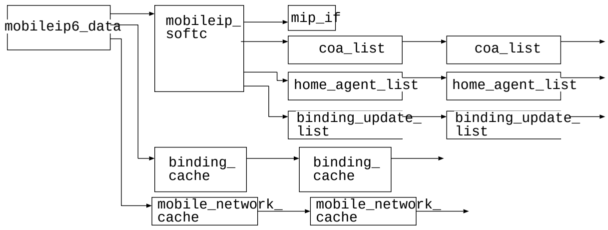

Fig. 3. The Basic Data Structures of our implementation

When nodes inside the car communicate with CN for the first time or when the timer of an entry in Binding Cache has expired, MR send the Binding Update to the CN. The Binding Update includes the network prefix inside the router as an optional header defined in the specification of Mobile IPv6.

All functions except interface switching daemon are implemented in the kernel. Such a native implementation is needed, because many functions are processed by IPv6 option header. Meanwhile, we have to select the best network interface by using the link status and the priority. It's easy to collect those information from the user space, because various APIs are available. We used these APIs to collect the link status and the priority, and implemented a API to advertise the care-of address from the user space to the kernel.

The interface switching daemon selects the primary care-of address from the priority and link status of the network interfaces. We set the priorities in a configuration file. The daemon monitors the status of all the interfaces, and tries to enable the network interfaces as long as possible. For example, if a Wireless LAN is down, the daemon sets the new ESS-ID and the WEP Keys registered beforehand to search for a new access point. If PPP link is down, the daemon carries out the negotiation of PPP once again. The daemon compares the priority of the network interface with other interfaces, and selects the care-of Address for the current situation.

This implementation was performed to support the environment among illustrated in Figure 4. The nodes in the vehicle behind the MR, 5 are FreeBSD, 4 are Mircosoft Windows 2000, and 1 is Linux. They are connected to the MR via Fast Ethernet. The MR has 5 access links. 2 are Personal Digital Cellular(PDC) (PDC-P 9.6Kbps, PacketOne 28.8Kpbs), 2 are Personal Handy-Phone System(PHS) (AirH" 32Kbps, P-in 64Kbps) and 1 is IEEE802.11b. PDC and PHS currently only provide IPv4 connectivity. Thus, we use *IPv6 over IPv4 tunneling* and *Dynamic Tunnel Configuration Protocol*. A Dedicated Short Range Communication (DSRC) is provided from another router which is running Linux under IPv4. The DSRC connection is not performed by the same MR because there is no DSRC driver available in NetBSD. The CN is running a SNMP client under FreeBSD 4.4 or NetBSD 1.5.2. The MR, CN and HA are running our implementation.

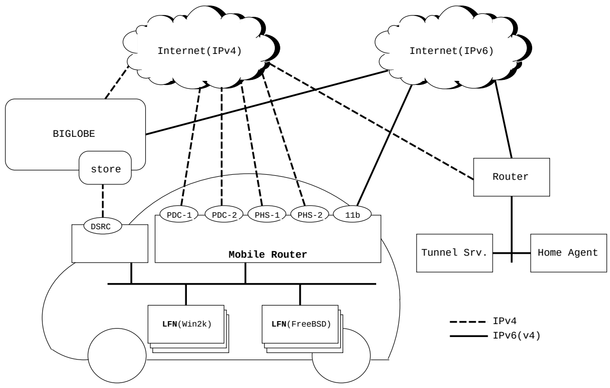

Fig. 4. The testbed of the High Function Prototype Car: This network is deployed in one of the pilot program. A Correspondent Node, the HA and a tunnel server are located on the Shonan Fujisawa Campus Keio University, Japan. The vehicle establishes Internet access via distinct access technologies.

7 EVALUATION

We verify the validity of the In-vehicle Router System. There are functional requirements and the performance requirements describe in section 3.

We used the ping program to verify that the operations of this system satisfy the functional requirements. We check that CN and nodes inside the car are still communicating even when the router changes the network interface. Fixed IP addresses are assigned to nodes inside a car, so that there is no impact for the nodes. Therefore this system was verified to meet the requirements: End to End communication, Reaching via fixed IP address, Migration transparency, No impact for nodes inside a car, Permanent connectivity.

The results of this performance evaluation of the performance issue are shown in Table 1. To evaluate the throughput, we transfered a file with size of 10M bytes from CN to nodes inside a car via Wireless LAN, and a file whose size is 1M bytes via PHS. We repeated this 100 times. Wireless LAN is 11M bps mode of IEEE 802.l11b, PHS is 9600 bps.

We obtained enough throughput mentioned in section 3 when using Wireless LAN, which means that all applications can work fine. We can not obtain enough bandwidth to perform the group communication application when using PHS. However, it's enough for other applications if we do not use the Group Communication Application described in section 2. Thus, we may need an approach which gives a priority to the traffic, such as Quality of Service.

Table 1. The throughput and RTT with Wireless LAN and PHS

Throughput(bps)		RTT(ms)			
		min	avg	max	std-dev
Wireless LAN	228,572	4.009	4.631	43.104	1.704
PHS	41,734	125.923	168.188	323.396	29.423

We also evaluated the Round Trip Time (RTT) from CN to nodes inside the car by using the ping program. The results are described in Table 1. The result shows that we obtained the desired value of RTT mentioned in section 3 when using Wireless LAN, which means that all applications can work fine. We can not obtain the desired value to perform the group communication application when using PHS. However, it will be difficult to improve this, because the RTT strongly depend on the topology and layer 2 technologies.

Additionally, we investigated the relation between the condition and the packet size in this testbed. Figure 5 shows the changes of RTT when the router changes the network interface between Wireless LAN and PHS. We pinged from CN to nodes inside the car at a rate of one packet per 0.15 ms with 56 bytes in packet size. Figure 6 shows the change when the packet size is 768 bytes and sent every 1 second.

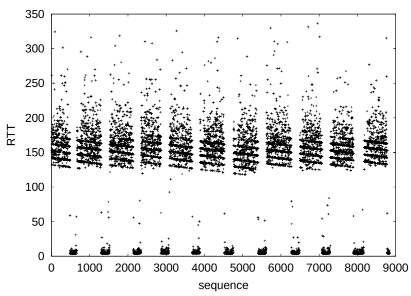

Fig. 5. The change of RTT during MR changes its interface Wireless LAN and PHS, packet size is 56 (40 + 8 + 8) bytes, per 0.15 second

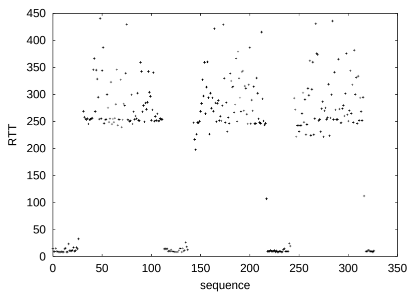

Fig. 6. the change of RTT, packet size is 816 (40+8+768) bytes, every 1 second

When the packet size is 56 bytes, there is no packet loss when we performed vertical handoff. At vertical handoff, the packet loss can not occur easily, because two or more interfaces can be used at the same time. In contrast, it could not communicate at all when the packet size is more then 816 bytes. We may have to consider about the maximum transfer unit to obtain better condition while communicating.

8 CONCLUSION

We proposed a communication system which ensures Internet connectivity and network transparency to a group of nodes with several network interface devices. We also implemented it as In-vehicle Router System.

We summarized the requirements for the communication system of the prototype car from the applications running on the prototype car. We proposed the combination of Mobile IPv6, Network Mobility and Interface Switching to satisfy those requirements. The PSBU is one of the solutions to provide Network Mobility, the Interface Switching using Care-of Address provides strong Internet connectivity. Those are designed as an extension of Mobile IPv6. Therefore, We proposed the design of this system based on Mobile IPv6.

We implemented In-vehicle router system based on the design, and evaluated the system using the InternetITS testbed. We verified that our system satisfies the functional requirements. We also verified that this system can not satisfy the performance requirements with the current cellular phone. This problem will be solved if better Layer 2 technologies appear.

In conclusion, we have confirmed that our system provides enough functionality to satisfy the requirements of Mobile Internet vehicles. We believe that this research will bring the further possibility to the Mobile Internet.

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