IEICE TRANS. COMMUN., VOL.E87–B, NO.7 JULY 2004

PAPER Special Section on Next Generation Networks Software

# Design and Analysis of Resource Management Software for In-Vehicle IPv6 Networks

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**SUMMARY** Various demands for next generation networks can be condensed into always-best-connected, ubiquitous, mobile, all-IP, application-aware, and converged networks. Vehicles have also come to be ubiquitous computing platforms associated with mobile communication functions. IPv6 has been introduced for all-IP ubiquitous communications. This paper proposes application-aware resource management for in-vehicle IPv6 networks, which are adaptive to different hardware configurations. We focus on power and bandwidth, since their management is critical for mobile communications. To manage these two critical resources, we identify the mobility characteristics and hardware configurations of in-vehicle networks. Based on these characteristics, we propose vehicle-aware power saving schemes. Our main idea for power saving is to dynamically adjust the mobile router (MR) advertisement interval and binding update lifetime. In addition, depending on the hardware configuration of the wireless environment, we propose two adaptive bandwidth management schemes using multihoming, which we refer to as *best-connected MR selection* based on location and *high-data-rate MR selection* based on priority. We evaluate the performance of our bandwidth management schemes by performing simulations, and that of our power saving schemes by mathematical analysis. Based on the results, it was found that the performance of each software scheme depends on the hardware configuration, so that an application-aware adaptive scheme is needed to optimize resource consumption.
***key words:*** *network mobility, IPv6, in-vehicle networks, mobile router, multihoming, power saving*

## 1. Introduction

As mobile communications come to play an ever-increasing role in our lives, the need for Internet connectivity at any time, in any place and using any kind of device is growing and presents a significant technological challenge. This next generation ubiquitous communication concept faces many daunting challenges, e.g. the need for application-aware networks, seamless handoff, always best connection (ABC), heterogeneous network operation, power saving, and so on.

Automation is another technological trend which is associated with ubiquitous communication. The different demands for automation lead to the creation of new networking platforms and result in the convergence of digital technologies. Vehicles are coming to represent an important platform for mobile networking [1], [2]. The current demand for ubiquitous Internet connectivity and automation to be provided for passengers' mobile devices and vehicle components is a good example of such progress.

As part of the ongoing efforts towards the development of the next generation all-IP networks, attempts are being made to address all of the issues pertaining to converging technologies that are mentioned above. These efforts include the development of new IP layer protocols, and it is critical that these protocols manage mobility and resources efficiently. Among the many resources which are involved in mobility management, bandwidth and power are the most critical issues for mobile communications, since wireless links suffer from low data rates and mobile devices rely on batteries.

*Network mobility (NEMO)* Basic Support [4] provides the capability for a particular type of network, which is referred to as a mobile network, to maintain its Internet connectivity while it changes its point of attachment to the Internet. *In-vehicle IPv6 networks*, i.e. mobile networks embedded in vehicles, allow the interconnection of devices permanently installed inside the vehicle, as well as those belonging to the passengers or crew. So, fixed devices such as sensors, controllers and local servers, or mobile devices such as personal digital assistants (PDAs), mobile phones, radios and portable computers connected to in-vehicle networks can all communicate with the Internet.

Based upon previous experience gained with the InternetCAR project [5], we are currently conducting NEMO research activities within the WIDE community as part of the Nautilus project [6]. The goal of the nautilus project is to deploy an extensive testbed, which integrates all IPv6 mobility features, such as host mobility, network mobility, seamless handoff and various optimizations. A further aim of this project is to show how multihoming can enhance the overall connectivity of hosts and mobile networks. In addition to cars, we are also investigating the application of NEMO to large public vehicles, small private vehicles, and embedded personal area networks (PANs), in order to demonstrate how IPv6 could be deployed.

In this paper, we emphasize the impact of vehicular network mobility on the management of resources, focusing on mobile networks deployed in public vehicles. We use the mobility characteristics of vehicles for the purpose of implementing resource management for power and bandwidth. To optimize power consumption, we propose an extension to NEMO Basic Support. To optimize bandwidth usage, we propose the use of multihoming and various connection selection schemes.

The remainder of this paper is structured as follows: First, we introduce the basic concepts of network mobility

Manuscript received November 19, 2003.
Manuscript revised January 23, 2004.
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and multihomed mobile networks, and describe the efforts of the Internet Engineering Task Force (IETF) NEMO working group [7]. The characteristics of vehicle mobility are analyzed in Sect. 3. Then, in Sect. 4, the power and bandwidth usage issues in NEMO are described. Based on these characteristics, in Sect. 5, we illustrate our resource management optimization schemes: location management delegation, router advertisement (RA) interleaving of mobile routers (MRs), and load sharing between multiple MRs. In Sect. 6, we present our analysis and simulation results. Finally, we conclude this paper in Sect. 7.

## 2. Background

This section describes the basic concept of network mobility based on Mobile IPv6. Then we explain the concept of multihoming in terms of mobile networks.

### 2.1 Network Mobility

The IETF NEMO working group has defined terms [3] and proposes NEMO Basic Support [4] based on Mobile IPv6 [8]. NEMO Basic Support enables a *mobile network* to maintain Internet connectivity while it changes its location in the Internet topology. A mobile network is composed of one or more mobile routers (MRs) and mobile network nodes (MNNs) connected to the MR. In mobile networks, only the MR physically changes its point of attachment to the Internet, and provides location and mobility management transparency to the MNNs. According to NEMO terminology, MNNs are divided into three classes: local fixed nodes (LFNs), local mobile nodes (LMNs), and visiting mobile nodes (VMNs).

NEMO Basic Support manages network mobility by establishing a bi-directional tunnel (Fig. 1). In Mobile IPv6, mobile nodes are identified by their home addresses (HoAs) and located by their care of addresses (CoAs). When a mobile node moves, it obtains a CoA on foreign links and registers this address in its home agent (HA). In this way, any correspondent node (CN) that wants to communicate with the mobile node only has to send the message to the HoA

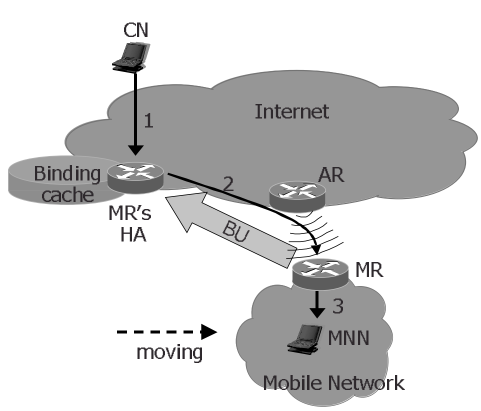



**Fig. 1** NEMO Basic Support protocol behavior.

of the mobile node. Then, the HA intercepts the message and forwards it to the mobile node with encapsulation. The association between the mobile node's HoA and the CoA is called a binding.

If Mobile IPv6 in its pure form is used to manage the mobility of networks, a routing loop problem arises [5]. To solve the routing loop problem, NEMO Basic Support uses the prefix of the mobile network as the netmask of the binding cache (BC). Only the MR obtains a CoA, while the MNNs retain their original addresses. All MNNs share the same prefix (NEMO-prefix). So, the MR sends a binding update (BU) message on behalf of the entire mobile network. This BU contains the association between the NEMO-prefix and the CoA. Even if the MR changes its point of attachment to the Internet, the network topology behind the MR is stable and all traffic destined for the MNNs transits through the HA and the MR.

When a mobile network is embedded, as an in-vehicle network, the MR within the vehicle provides the connection to the Internet. The MR connects the mobile nodes in the vehicle to the Internet via the access router (AR). As the vehicle moves, the MR leaves the coverage area of the current AR and therefore has to find a new AR, in order to provide continuous connection to the Internet. The in-vehicle network itself moves, while the passenger mobile nodes, i.e. VMNS, join/leave the network. For example, people with PDAs get on/off a train. When a mobile node first joins an in-vehicle network, it obtains an IP address with the in-vehicle network's prefix using IPv6 address autoconfiguration. Then, the MR performs mobility management on behalf of the MNNs. In other words, each MNN's connection to any CN is maintained, in spite of the mobility of the in-vehicle network.

Mobile networks can be nested, i.e. a mobile network's MR can connect to the Internet through another mobile network's MR. For example, a PAN in a vehicle network forms a nested mobile network.

### 2.2 Multihoming

Mobile networks can have multiple points of attachment to the Internet, in which case they are said to be multihomed. Multihoming arises when the MR has multiple addresses, multiple egress interfaces on the same link, or multiple egress interfaces on different links. In a mobile network, multihoming can also arise when there are multiple MRs.

Multihoming provides the advantages of session preservation and load sharing [11].

- *Session preservation by redundancy*. Session preservation is an important issue in mobile environments, since a wireless link is not as stable as a wired link.
- *Load balancing by selecting the best available interface or enabling multiple interfaces simultaneously*. Traffic load balancing at the MR is critical since, in a mobile network, all traffic goes through the MR.

Multihoming configurations can be classified according to parameters or practical usage [12], [13]. The multihoming parameters are the number of MRs, the number of HAs, and the number of network prefixes. However, not all of the eight models described in [12] are practical. This paper focuses on configurations with multiple MRs, in order to satisfy the requirements of large in-vehicle networks.

## 3. Characteristics

In this section, we identify the characteristics of public vehicles in terms of mobility and nested mobile networks.

### 3.1 Mobility Characteristics

We identify the mobility characteristics of public vehicles, with a view to optimizing bandwidth usage.

- **Movement limitation**. The movement patterns of vehicles are limited according to the road topology. For example, vehicles such as trains and aircraft can only follow predefined paths, i.e. railroads or established flight paths. Bus routes are more flexible than those of trains or airplanes. In the case of buses operating on the highway, however, this flexibility decreases. So, we can apply a movement limitation characteristic to public vehicles. In comparison, pedestrians also walk along the road, but the road topology of pedestrians is much denser than that of vehicles. So, the road topology of pedestrians does not limit movement, as much as that of vehicles does.
- **Regularity**. The mobility of public vehicles has a tendency to be regular and iterative. They follow the same route and stop at the same places, e.g. train stations or bus stops. In the case of trains or subways, their timing is also strictly regular.

### 3.2 Nested Mobility Characteristics

Public in-vehicle networks can be viewed as nested mobile networks. We identify their characteristics, for the purpose of optimizing power consumption.

- **Converse passenger mobility**. Passengers get on or off only when the vehicle stops. Once they get into the vehicle, they stay there as long as the vehicle is moving. So, the mobility of in-vehicle networks and VMNs are converse.
- **Large scale**. Public vehicles take large numbers of passengers and their own equipments as VMNs. A passenger can again take a Wireless PAN consisting of several mobile devices. So, the number of MNNs inside a public vehicle can be quite large. In addition, some vehicles need multiple MRs. Multiple MRs are needed, for example, when the vehicle is too big to be covered by only one MR, or when the number of passengers is too large to be served by only one MR. In addition, some vehicles such as trains need multiple MRs, one in each railcar, since metal obstructs the reception of the wireless signal.

## 4. Problem

This section analyzes the resource management problem associated with NEMO. In NEMO, the MR constitutes a single point of failure since all traffic passes through it. We also pay attention to the VMNs, since they dynamically join and leave the mobile network. The main problem with MRs and VMNs from the point of view of resources is that they are connected via wireless channels.

Wireless channels have limited bandwidth and high jitter, so the following problems can occur [9]:

- High error rate and bursty errors
- Location-dependent and time-varying wireless link capacity
- Scarce bandwidth
- Power constraint of the mobile nodes

### 4.1 Single Point of Failure and Bandwidth Limitation

The multiple communication nodes belonging to passengers inside the vehicle depend on a single MR for their connection to the Internet, and they have to share the same connection. MRs are connected to the Internet using wireless technologies. Wireless technologies do not support data rates as high as those of wired links. This problem is intensified as the number of passengers who want to exchange multimedia traffic increases. In addition, if the connection is broken, not only a single MR, but all of the passenger devices and sensors inside the vehicle are affected, and can no longer communicate with correspondents outside the vehicle. So, the MR must support a high data rate and be reliable.

To manage limited wireless bandwidth, multihoming can help. Thanks to multihoming, multiple connections to the Internet can be maintained, so that the load can be distributed between these connections [11]. Multihoming in NEMO can be configured with multiple MRs, HAs, prefixes, and multiple interfaces on the MR [12], [13]. Several studies have been conducted, which were dedicated to load distribution between multiple HAs [14]–[16]. Load distribution between multiple MRs is difficult to implement, since it requires awareness of the dynamic creation and expiration of wireless connections.

### 4.2 Scarce Power Resources

For wireless mobile nodes, power saving is an issue. The main factors affecting power consumption in the IP layer are:

- Signaling overhead
- Idle listening

In this section, we divide the power problem associated with signaling into two separate issues: signaling from the in-vehicle network, and signaling bound to the in-vehicle network.

#### 4.2.1 Location Management Signaling Overhead

To allow mobile communications, location management signaling is essential. With more extensive location management signaling, more accurate localization can be achieved. However signaling consumes power resources.

In the NEMO Basic Support protocol, the BU from a mobile node's new CoA to its HoA is provided as a location updating mechanism. Thanks to NEMO Basic Support [4], LFNs inside vehicles do not have to manage their location.

From the VMN's point of view, however, location management is performed as follows: When a VMN moves into a foreign mobile network, the VMN must configure a new CoA and send a BU to its HA. The VMN sends a BU periodically even though it stays in the same vehicle, as the BU's lifetime expires. This BU, from the VMN to the VMN's HA, is performed independently of the BU that is sent from the MR to the MR's HA.

To save power in the IP layer, IP paging has been proposed [10]. The main idea of IP paging is to reduce location update signaling, while mobile nodes are in idle mode. Using IP paging, mobile nodes in dormant mode update their location less frequently than those in active mode. This can be accomplished by constructing a paging area, thus reducing the location update frequency. However, there is a tradeoff between location updating signaling and paging signaling, as described in [17]. If the size of the paging area is small, the amount of location- update signaling increases, while the amount of paging signaling decreases. So, the issue is to find an optimized paging-area size.

The problem is that, for in-vehicle networks, a paging area cannot be constructed by combining neighbor location-management areas. Since the location-management area is moving, it cannot be grouped with other mobile or non-mobile areas.

#### 4.2.2 Movement Detection Signaling Overhead

When a VMN enters an in-vehicle network, it detects its movement by listening to the RA message from the MR. Since the VMN needs to listen to the RA even when it is idle, power is wasted.

## 5. Proposed Resource Management for In-Vehicle Networks

In this section we propose resource management schemes for power and bandwidth, based on the characteristics described above. To solve the problem of there being a single point of failure, we propose the use of multiple MRs. To solve the problem of limited bandwidth on the wireless link between the MR and the HA, we propose to use multihoming and to reduce location management signaling. To optimize the use of power and the limited bandwidth on the wireless link between the VMNs and the MR, we propose to reduce the signaling in the mobile network.

### 5.1 Signaling

This section explains the proposed power management scheme. We focus on the power consumption of the VMNs, and make use of the *public-vehicle characteristics as a nested mobile network*. To reflect the vehicle's characteristics, we introduce a special field in the RA message of the MR. Using this field, our scheme notifies the VMNs of the existence of the vehicle, thus optimizing power consumption.

#### 5.1.1 Binding Update Signaling Reduction

In the case of in-vehicle networks, we can make use of the mobility characteristics of vehicle-passengers. Since passengers (i.e. VMNs) do not move to other foreign links while the vehicle is moving, we can decrease the location updating frequency while the vehicle is moving, by assigning a larger value to the BU lifetime. In this way, devices register their location when the passenger to whom they belong gets into the vehicle, but they do not have to register their location again until he or she gets off the vehicle. Therefore, we can reduce location-update signaling, without changing the cost of paging.

We propose an additional field in the *MR's RA message format* and we prolong *BU lifetime*. To notify the VMN of its entry into the vehicle, we propose to add a new field, V, to the MR's RA message, as shown in Fig. 2. When a VMN receives the RA message with field V set, it assigns a longer lifetime to its BU message (Fig. 3).

#### 5.1.2 Mobile Router Advertisement Signaling Reduction

As mentioned in Sect. 2, there are three kinds of MNNs. Among these, VMNs are the most sensitive to power. Using the mobility characteristics of vehicles and the nodes

| 0 | | | | | 15 | 16 31 |
|---|---|---|---|---|---|---|
| Type | Code | | | | | Checksum |
| Cur Hop Limit | M | O | V | Rsvd | | Router Lifetime |
| Reachable Time | | | | | | |
| Retransmission Timer | | | | | | |
| Options… | | | | | | |

**Fig. 2** Extended RA message of MR for notifying vehicle's existence.

```
If V = 1 then /* in vehicle */
   BU_lifetime = MAX_BU_lifetime
else /* out of vehicle */
  BU_lifetime = normal_BU_lifetime;
```

**Fig. 3** Vehicle existence notification.

inside them, we reduce the MR's RA interval, in order to save power.

The main idea of our scheme is to reduce the MR's RA interval, while the vehicle is moving. The RA interval of Mobile IPv6 [18] is shorter than that of IPv6, since mobile nodes change their association with the AR frequently. No new VMN gets on/off the vehicle, while the vehicle is moving, so there is no need for frequent RA messages to be exchanged between the MR and a VMN during this time.

Our proposed scheme operates as follows: The MR receives sensing information from a sensor that forms an LFN. If the sensing information notifies the MR that the vehicle is moving, the MR sets a long RA interval (Fig. 4), i.e. the RA interval of IPv6. If an MNN wants to associate with a new MR while the vehicle is moving, it sends a router solicitation message.

### 5.2 Multiple Mobile Routers

In this paper, we focus on multihoming with multiple MRs, since the multiple MR configuration is unique in mobile networks. Our contribution to bandwidth management is to propose adaptive MR selection schemes associated with different hardware configurations.

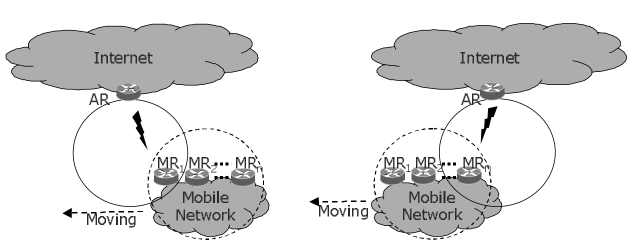
#### 5.2.1 Best-Connected MR Selection Based on Location

Multiple MRs located at regular intervals in a large vehicle such as a train can provide increased connectivity and load sharing. They are located outside the coverage of other MRs (Fig. 5). They connect redundantly to the same access technology or to different access technologies, so that the required bandwidth can be assured.

We propose a *best-connected MR selection* scheme, based on the MR's location. This scheme is based on the characteristics of movement limitation and regularity. Since there is no ping-pong handoff, due to the in-vehicle mobility characteristics, we can build a one-dimensional mobility model, as shown in Fig. 5. Thus, an MR that comes into the coverage area later is expected to have a longer connection lifetime. Therefore, the HA selects the latest binding entry in the BC, and forwards packets to the MR that registered this binding.

```
if vehicle moves
  RA_interval = RA_interval_of_IPv6
else /* while VMNs move */
  RA_interval = RA_interval_of_MIPv6;
```

**Fig. 4** MR's RA interval assignment.




(a) Before moving (b) After moving

**Fig. 5** Location based selection of the best-connected MR.

Figure 5 shows the selection of the best-connected MR among multiple MRs when an in-vehicle network moves. At first, $MR_1$ goes into the coverage of the AR and becomes the best-connected MR (Fig. 5(a)). As the vehicle moves, $MR_1$ leaves the coverage area of this AR and $MR_n$ becomes the best-connected MR (Fig. 5(b)). Then, the HA forwards packets to $MR_n$, so that packet loss can be avoided during handoff.

We assume that the MRs are distributed in an advantageous manner: we control the distance between the MRs, in order to have the always best connection (ABC). For example, in Fig. 5, if we locate one MR at the right end of the vehicle and another MR at the left end, the in-vehicle network connection lifetime increases. If we locate the MRs close together, the in-vehicle network connection lifetime decreases.

#### 5.2.2 High-Data-Rate MR Selection Based on Priority

Our best-connected MR selection scheme described above is based on location and mobile direction, and shows good performance with trains or subways whose mobility is regular. In this section, we extend our scheme, by investigating random global mobility behavior.

A mobile network moves over different access technologies that provide different data rates and coverage. For example, cellular networks provide wider coverage than wireless LANs, but they do not support as high a data rate as wireless LANs. So, we can provide high data rate and con-

| 0 | | | | | | | 16 | 31 |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Sequence number | |
| A | H | L | K | R | **P** | Reserved | Lifetime | |
| Mobility options | | | | | | | | |

(a) Extended BU message for in-vehicle networks

| Type | Length | Reserved | Priority |
|---|---|---|---|

(b) Priority option format

**Fig. 6** NEMO message format extension for bandwidth management.

**Table 1** Extended BU message field description.

| Field | Description |
|---|---|
| Sequence number | Sequence number for this BU |
| A | If this flag is set, the agent should send an acknowledgement. |
| H | This flag is set when this BU is being sent to an HA. |
| R | This flag is set when this BU contains a NEMO prefix. |
| P | Priority of this BU in the BC |
| Lifetime | Lifetime of this BU |

nectivity by supporting heterogeneous access technologies, each with multiple MRs. In this case, we propose a *high-data-rate selection* scheme based on priority. We extend the BU message of [4] to include a priority option, *P*, as shown in Fig. 6 and Table 1.

## 6. Evaluation

This section evaluates the proposed schemes by means of mathematical analysis and simulation. To evaluate our schemes, we first classify the mobility models according to the type of vehicle. We simulate the enhancement schemes with NS-2 prior to their deployment, and we also develop a Linux-based testbed for the purpose of studying various mobile network configurations providing NEMO Basic Support.

### 6.1 Mobility Model for Evaluation

We need a mobility model to evaluate our proposed schemes based on the type of vehicle. The mobility characteristics of in-vehicle networks depend on the type of vehicle. To set up a mobility model for in-vehicle networks, we have to consider the various operational constraints. Table 2 shows the mobility characteristics of public vehicles in comparison to those of pedestrians.

### 6.2 Power Saving Performance Analysis

#### 6.2.1 Paging Location Update Control Packet Saving

The performance of the proposed power saving schemes can be analyzed by mathematical analysis. The power consumed by paging location update can be expressed as follows:

$$E_{BU} = \alpha \cdot \mathrm{N_{BU}} = \beta \cdot \frac{1}{S_{paging}} = \gamma \cdot \frac{1}{t}$$

where $\alpha$, $\beta$, and $\gamma$ represent energy coefficients, $N_{BU}$ the number of BUs, $S_{paging}$ the size of the paging area, and $t$ the BU's lifetime. Since we cannot increase $S_{paging}$ in the case of in-vehicle networks, we can only reduce $E_{BU}$ by increasing $t$. In Mobile IPv6, the BU's lifetime is set to 1–10 sec by default. Since passengers usually stay in a vehicle for more than just a few minutes, we can reduce the power consumption.

**Table 2** Mobility characteristics of public vehicles and pedestrians.

| | Pedestrians | Cars | Trains or Subways | Airplanes |
|---|---|---|---|---|
| Movement limitation | Very Low | Medium | High | High |
| Space regularity | Irregular | Irregular | Regular | Regular |
| Time regularity | Irregular | Irregular | Regular | Regular |
| Regularity variance | High | High | Low | Low |
| Converse passenger mobility | N/A | Yes | Yes | Yes |
| Network Scale | Small | Medium | Large | Large |

#### 6.2.2 MR Advertisement Listening Power Saving

Inside the in-vehicle network, MRs can reduce the number of control packets, and MNNs can increase the time allocated to dormant mode, by reducing the number of RAs sent from the MR. The power consumed by the MR can be expressed as follows:

$$E_{RA} = \upsilon \cdot N_{RA} = \omega \cdot \frac{1}{t_{stay}}$$

where $\upsilon$ and $\omega$ represent energy coefficients.

The power consumed by the dormant MNNs can be expressed as follows:

$$E_{MNN} = \mu \cdot N_{RA} = \lambda \cdot \frac{1}{t_{dormant}}$$

where $\mu$ and $\lambda$ represent energy coefficients.

The RA interval of Mobile IPv6 is 50 ms, whereas that of IPv6 is at least 3 seconds. So, this scheme can reduce the MR advertisement frequency to 1/60.

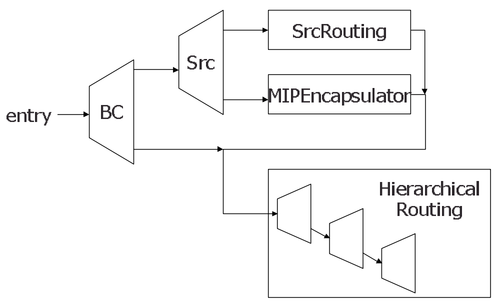
This idea is also applicable to the association of MRs and ARs, in the case of planned ARs for specific public vehicle roads. For example, we can allocate ARs at railroad stations or bus stops and control the ARs' RA frequency in order to save power.

### 6.3 Bandwidth Management Simulation

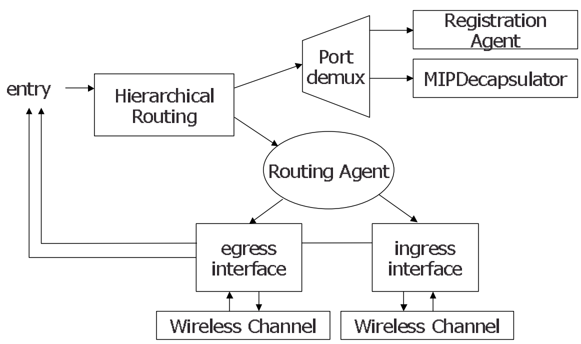
We used NS-2 simulator [18] to evaluate the performance of the bandwidth management schemes. To simulate the NEMO enhanced schemes in NS-2, we added MRs by modifying MobiWan's [19] mobile nodes. The MRs used in the simulation are extended to have the characteristics of base stations and mobile nodes, so these MRs have egress and ingress interfaces.

The extension to NS-2 node's object architecture for NEMO simulation is depicted in Fig. 7. Figure 7(a) shows the NS-2 mobile node architecture. The BC classifies all packets delivered to the entry point. If the destination address of a packet does not exist in the BC, the hierarchical routing module processes the packet and routes it normally. If the BC contains the destination address of a packet, the source classifier (Src) examines the source address of the packet. If the packet came from another node, it is encapsulated by the MIP encapsulator (MIPEncapsulator) and routed through hierarchical routing module. If the packet came from itself, the source routing (SrcRouting) module processes the packets by inserting type II routing header of Mobile IPv6.

We extended the mobile node architecture to the MR architecture as shown in Fig. 7(b). The MR architecture




(a) Mobile node architecture




(b) Extended architecture of MR

**Fig. 7** Ns-2 node architectures.

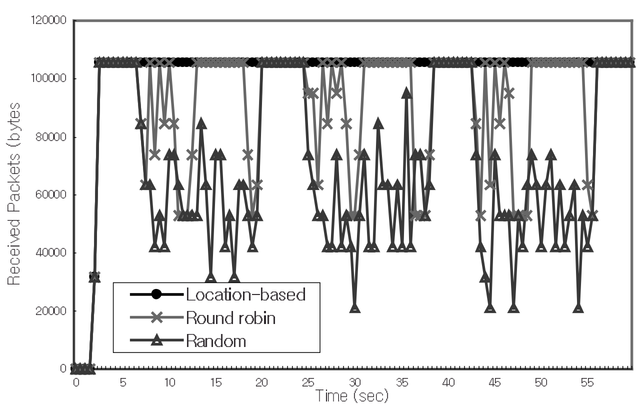



**Fig. 8** Best-connected MR selection for regular mobility.

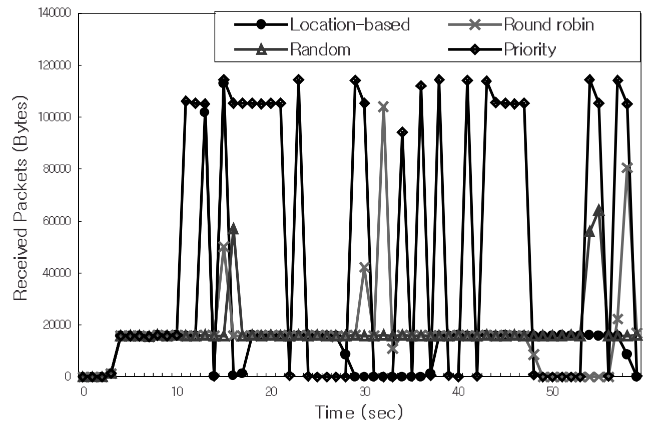



**Fig. 9** High-data-rate MR selection for irregular mobility.

includes two instances of interface, each using a different wireless channel. When the hierarchical routing module delivers a packet to the routing agent, the routing agent module selects one of the interfaces. The egress interface is used to transmit packets from the MR to the ARs, while the ingress interface is used to transmit packets from the MR to the MNNs. If the destination of a packet is the node itself, the port de-multiplexer (Port demux) classifies the packet. The port number of the packet indicates which agent should process the packet. The registration agent module processes the BU message from the MRs or VMNs, and manages the BC. The MIP decapsulator (MIPDecapsulator) module decapsulates packets that are encapsulated by the HA.

Our location based best-connected MR selection simulation is set up for a frequent handoff environment. We simulated trains/subways that follow pre-defined railroads and do not move back-and-forth. The access technology used for our simulation is wireless LAN. The length of the mobile network is 200 m and the mobile speed is set to 25 m/sec. The radius of the access point coverage is 175 m and we assume that each access point installs AR function. In Fig. 8, we show the result of the comparison between our best-connected MR selection scheme and various benchmark schemes. For benchmarking, we use round robin and random distributions. In this simulation, we deploy two MRs at each end of the mobile network. The distance between the MRs is 200 m and the interval between the ARs is 450 m. Even though there are areas where Internet access is impossible for certain mobile routers, at least one of the mobile routers of the mobile network can access the Internet. As shown in Fig. 8, our proposed scheme reduces the amount of packet loss during handoff. In comparison with the proposed scheme, the round robin and random distribution schemes experience more packet loss during handoff. The simulation shows good performance as the size of the mobile network increases and the coverage area decreases.

In the case of irregular mobility, our location-based scheme does not provide much of an advantage. So, we suggest the use of an adaptive resource selection scheme. Our priority-based high-data-rate MR selection scheme selects a tunnel that provides a high data rate.

To simulate the priority-based high-data-rate MR selection scheme, we distributed 4 cellular network base stations and 64 wireless LAN access points in a 2 km × 2 km square area. The radius of the access coverage area of the cellular networks is set to 500 m, while that of the wireless LAN to 62 m. So, the cellular networks can be accessed in almost every area, whereas the wireless LAN is not accessible in some areas. The data rates of the cellular network and wireless LAN are 500 kbps and 11 Mbps, respectively.

Figure 9 shows the throughput of the mobile network with 2 MRs, each incorporating a cellular network interface and a wireless LAN interface. Throughput is defined in terms of the number of received packets. Since wireless LANs provide high data rates but low connectivity, while cellular networks support high connectivity but low data rates, as shown in Fig. 9, we can obtain a high data rate as well as high connectivity, by selecting an MR based on the data rate information that the MRs send to the HA.

## 7. Conclusion

In this article, we described the impact of vehicular network mobility on the management of resources. As mobile communications become increasingly pervasive, with the advent of converging technologies, vehicles are coming to represent an important platform for mobile communications. Herein, we defined the mobility and nested mobility characteristics of public vehicles, namely their movement limitation, regularity, converse mobility and large scale. Based on these characteristics, we optimized power consumption and bandwidth usage for the sake of resource management.

There has been no previous work on power saving in mobile networks, so this paper represents a turning point in the evolution of mobile hosts and networks. There have been many work on multihoming and load sharing between HAs, but load sharing between MRs is more critical in mobile networks: The MR is a single point of failure, and is connected to the Internet through frail wireless links. So, load sharing between MRs requires dynamic notification of association and disconnection between the MRs and the HA. In addition, coordination between MRs is necessary.

By dynamic adjustment of the BU's lifetime and the MR's RA interval, we reduced signaling. By reducing signaling, we saved VMN's power as well as the wireless link's bandwidth between the MR and the HA/MNNs. Our adaptive software configuration of multiple MRs increases Internet connectivity and wireless bandwidth.

In the upcoming converged communication environment, heterogeneous wireless access, diverse mobility behaviors, ubiquitous computing and embedded appliances are the proclaimed goals, and IP layer management forms the cornerstone upon which these advanced technologies can be implemented. As NEMO is based on IPv6 and provides for these new demands, we are currently conducting NEMO research activities under the auspices of the Nautilus6 project. We are developing a Linux-based testbed for the purpose of evaluating NEMO Basic Support with nested and multihoming configurations. As a future work, we will experiment these enhanced schemes on this testbed.

## Acknowledgement

This work was supported in part by the Brain Korea (BK) 21 project of the Ministry of Education and in part by the National Research Laboratory (NRL) project of the Ministry of Science and Technology, 2003, Korea.

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