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Research/Development/Deployment of mobility techonologies in IPv6

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第1章 Nautilus6 Project Overview — Deployment of the Mobile Internet

1.1 Motivations and Background

Mobility functions will be essential to achieve the all-IP Internet and to connect all devices to the Internet at all time and any place. To achieve this ubiquitous Internet, we need efficient mobility support mechanisms to maintain ongoing communication flows while on the move. Such mechanism includes host mobility support (displacement of a single host in the IP topology without breaking open sessions), network mobility support (displacement of an entire network in the IP topology without breaking open sessions), ad-hoc networking (routing in an infrastructure-less network), in addition to other core IPv6 technologies such as multihoming, auto-configuration, multicast, security, access control.... The combination of all these technologies will enable on one side cars, trains, airplanes to connect to the Internet and on the other side people carrying IP devices to keep uninterrupted access to the Internet whether they are located at home, office, or commuting between them or shopping. It will also enable new trends, such as PANs (Personal Area Networks, small networks made of a mobile phone, portable music players, PDAs and other devices carried by people) to permanently connect to the Internet via the mobile phone acting as a mobile router.

In mobility specifically, a lot of work has already been done at the IETF in various working groups. The IP Routing for Wireless/Mobile Hosts WG (MobileIP) has been discussing host mobility support for a long time and came up with the Mobile IPv6 protocol which adds mobility functions to IPv6 nodes. The NEtwork MObility WG (NEMO) has been established in November 2003 with the goal to add mobile functions to IPv6 routers to allow mobility of entire networks. The context transfer and seamless mobility WG (Seamoby) has been working on standards to improve handoffs (FMIPv6, CARD) and micro-mobility (cellular mobility and paging)[1]. At last but not least, the Mobile Ad-hoc NETworking WG (MANET) has been discussing routing protocols for mobile and dynamic topologies. However, mobility features have been poorly demonstrated and have not been integrated. The reason which accounts the most is probably because the focus has always been on the mobility management protocols themselves, and not on the architecture needed to deploy them.

There is thus a need to integrate all IPv6 and mobility features, and to demonstrate how the mobility support mechanism could actually be deployed in a live environment, in an operational, efficient, secure, and integrated manner. For doing so, not only mobility management protocols must be implemented, but also most IPv6 features, access control, key exchange mechanisms, and explicit IPv6 applications that can benefit from mobility functions.

1.2 Missions and Objectives

Nautilus6 is a mission-oriented project established within the WIDE organization in spring 2003 to demonstrate how the long awaited mobile Internet could be actually deployed. For doing so, we aim at demonstrating how IPv6 and its mobility features could be implemented, integrated and deployed in an operational, secure, and efficient manner.

1 micro-mobility was later moved to the IRTF, the research side at the IETF

Nautilus6 will seek to select and validate IPv6 mobility-related technologies. The WG will use IETF standards whenever appropriate or develop and standardize new ones when those are lacking within the IETF community. The WG will either be testing existing implementations or implement them when none are available. Also, Nautilus6 will design the operational framework of mobile Internet services to accelerate deployment by the commercial ISPs and carriers and will seek for or develop applications to demonstrate the technology. It will also pursue further research into IPv6 mobility. The missions of the Nautilus6 project are therefore:

- To define the necessary protocol suite for commercial operation.
- To push for and contribute to IETF standardization of newly designed or selected protocols if existing standards are not appropriate.
- To develop reference implementations of the required protocols if existing implementations are not appropriate.
- To produce operational technology and Best Current Practices.
- To develop new paradigms to evaluate the proper operation of developed mobility technologies.
- To demonstrate the technology in field trials with business players.
- To show the business reality of IP mobility in order to convince business players.
- To explore the nation-wide business operation.
- To conduct further research in promising areas.

1.3 Technical Activities

In order to achieve our goals, Nautilus6 must conduct parallel activities in a number of areas. Nautilus6 is thus organized into cooperative subgroups for each of the following activities:

- Host Mobility
  To brush up reference implementations of the IETF Mobile IPv6 specification for BSD and Linux.
- Network Mobility
  To research into and study network mobility, to push standardization at the IETF and develop reference implementations of the IETF NEMO Basic Support specification and related protocols.
- Multihoming
  To research into multihoming issues pertaining to mobility (mobile hosts or routers with multiple interfaces, multiple mobile routers, etc), push for standardization at the IETF and develop the technology which can benefit from it.
- Seamless Mobility
  To study and develop fast handover technologies, such as L2-trigger, and IETF protocols FMIPv6, HMIPv6.
- Security and Access Control for Mobility
  To select key exchange and access control mechanisms adapted to a secure operation of the mobility technologies.
- Services and Applications for Mobility
  To develop demonstrative applications and services that require or benefit from mobility mechanisms.
- Operation and Evaluation of the Mobility Technologies
  To demonstrate the readiness of the technology and evaluate its performance.

1.4 Project Strategy and Time Line

For each protocol needed in the overall system architecture, we need to go through a number of *steps* as depicted below. Those steps will be conducted within *incremental testbeds*. We will go through these steps in *two distinct phases*, first the *technical development* of the protocol suite, and then the *actual deployment* of the technology. The realization of the second phase will depend on the results obtained in the first phase.

1.4.1 Development Steps

- Specification

- Implementation
- Validation
- Demonstration
- Integration within the overall system architecture
- Operational validation and evaluation
- Actual Deployment

1.4.2 Incremental Testbeds

Our testbeds are designed to develop the necessary protocol suite through a number of steps: specification, implementation, validation, demonstration, integration with the overall system architecture, and operational validation and evaluation.

Because each protocol required in our architecture is at various stages of their development process, we cannot demonstrate everything at once right now. Rather, we will go through this process at the pace of each protocol's development. We are therefore developing incremental testbeds to match the level of development of each mobility technology we develop.

At the very early stage of the development of a particular protocol, we will implement and test any given new protocol on our **in-door testbed**. Mature implementations will then be demonstrated on a light-weight **demonstration testbed** to validate and demonstrate the new mobility features. The third stage is an **operational testbed** where we will carry on validation and evaluation of the protocol with the overall system already in place. The forth stage will be a large-scale **real-conditions testbed** we will build to convince business operators once the IPv6 mobile technologies are mature for real deployment.

Each protocol will be moved further up from the in-door testbed to the real-conditions testbed according to our progress in each of the activities highlighted earlier. Not to say, the testbeds will have to be adapted for each new protocol that is brought in.

1.4.3 1st phase: Technical Development (2 years)

The first phase is expected to last two years. During that time frame, we will pursue steps going from protocol design up to the operational validation and evaluation. We will be involved in:

Implementation: We will need to implement, test, validate, demonstrate and evaluate the combination of at least the following protocols:

- Host mobility: Mobile IPv6
- Network mobility: NEMO Basic Support
- Multihoming: interface switching, multiple mobile routers support, etc.
- Seamless mobility: FMIPv6, HMIPv6, CARD, L2-trigger
- Security: IPsec, IKE, etc.
- Access Control: AAA, Radius, etc.

We will use and adapt existing open implementations whenever available, or build our own.

Research: We will pursue research at least in the following areas:

- Routing optimization in mobile networks
- Multihomed and nested mobile networks
- Seamless inter-domain mobility
- Quality of Service in mobile environments
- Multicast in mobile environments

Performance Evaluation: We will conduct a performance evaluation of our new protocols and the overall system architecture by means of:

- Simulation, Emulation
- Data collection under operational use

Applications: We will develop demonstrative applications or adapt existing ones to our needs.

Standardization: We will push for IETF standardization of the technologies we develop or select.

1.4.4 2nd Phase: Actual Deployment (1 to 2 years)

Based on the result of the technical development phase, we will seek to demonstrate the operational deployment of the mobility technologies as needed for commercial use, i.e. taking into consideration security aspects (key management mechanisms, access control and accounting) and performance aspects (fast handoffs, etc). For doing so, we should have a joint experiment with commercial ISPs and carriers under a real situation.

- Designing mobile Internet system for commercial networks.
- Operating mobile Internet services with commercial ISPs and carriers.

1.5 Structure of the Document

All our activities on protocol development, standardization, validation and research are detailed in chapter 2. In chapter 3 we describe the testbeds we use to perform our testings and demonstrations. In 4 we conclude this report with perspectives and the status of our international collaborations.

第 2 章 Protocol Development and Research for Mobility

For each activity, as briefly introduced in section 1.3, we have defined or we are currently defining a roadmap (available on our web site). Some of these activities are at the initial stage of their study (e.g. security and access control) while other are semi-advanced (e.g. network mobility, multihoming) or well advanced (e.g. host mobility). Well-advanced activities are mature enough to be demonstrated in a pre-operational fashion. Semi-advanced activities are in the initial implementation phase and still require validation of the chosen model. In the following sections of this chapter we detail the work done this year in each of the activities already started.

2.1 Mobile IPv6

Participants: Keiichi Shima, Tsuyoshi Momose for KAME Mobile IPv6, Noriaki Takamiya, Masahide Nakamura, Masafumi Aramoto for USAGI Mobile IPv6.

Host mobility support is required to allow IPv6 nodes to move from one IPv6 network to another IPv6 network without terminating on-going connections. Mobile IPv6 is the IETF's standard protocol designed to support host mobility in IPv6. As such, it must be used by Nautilus6.

There are already two activities related to Mobile IPv6 within the WIDE organization. One is the KAME project[2] which aims at developing the IPv6/IPsec reference stack, including Mobile IPv6, for BSD variants. The other is the USAGI project[3] which aims at enhancing the IPv6/IPsec code in Linux. The Nautilus6 activity is based on these implementations.

In this section, we describe Nautilus6 activities related to Mobile IPv6 and KAME Mobile IPv6 activities. KAME activities other than Mobile IPv6 and all USAGI activities are discussed in separate parts of this report.

2.1.1 Implementation Status of KAME Mobile IPv6

Supported Specifications

KAME Mobile IPv6 protocol stack supports the following specifications:

- Mobility Support in IPv6[142]
- Using IPsec to Protect Mobile IPv6 Signaling between Mobile Nodes and Home Agents[7]
- Extension to Sockets API for Mobile IPv6[30]

At this moment, the second specification "Using IPsec to Protect Mobile IPv6 Signaling between Mobile Nodes and Home Agents" is supported only partially. The specification describes an interaction mechanism between Mobile IPv6 and IPsec. There are two ways to establish IPsec

2 http://www.kame.net
3 http://www.linux-ipv6.org

security association between two nodes. One is static keying and the other is dynamic keying. The specification defines interaction scenarios for both keying mechanisms, however, KAME only supports a static keying method for now. A dynamic keying method is planned with the new key exchange daemon “Racoon2”, which is under development in WIDE’s IPsec Working Group.

Supported Platforms

KAME Mobile IPv6 protocol stack supports the following two platforms:

- FreeBSD4.9-RELEASE
- NetBSD1.6.1

The KAME distribution supports OpenBSD3.4 in addition to the above two platforms. However, the Mobile IPv6 stack doesn’t support OpenBSD at this moment, because of the difference of the implementation of IP security stack between OpenBSD and other two platforms. FreeBSD and NetBSD use the IP security protocol stack derived from the KAME stack, while OpenBSD uses its own original IP security stack. KAME project is planning to support correspondent node functions for OpenBSD at least, because correspondent node doesn’t require IP security functions.

Releasing Information

KAME Mobile IPv6 is released with KAME every week as a KAME snapshot release. The last releases in 2003 are as follows:

- kame-20031229-freebsd49-snap.tgz (FreeBSD4.9-RELEASE)
- kame-20031229-netbsd161-snap.tgz (NetBSD1.6.1)

Both snapshots can be retrieved from the KAME FTP server[4].

Regarding to documentation, we published a document which described the instructions for installing and using KAME Mobile IPv6. This document was published as a KAME newsletter and can be retrieved from the KAME web site[5]. Since the Mobile IPv6 stack is enhanced and changed continuously, the document will also be updated regularly.

4 ftp://ftp.kame.net/pub/kame/snap/
5 http://www.kame.net/newsletter/

2.1.2 Standardization

KAME project contributed to the IETF standardization process in a mobility area.

Route Optimization Condition Analysis

The Mobile IPv6 specification defines a method which allows a mobile node and a correspondent node to communicate with each other without bidirectional tunneling via a home agent. This mechanism is called route optimization (RO). We thought that there are cases where RO is not suitable. So, some mechanisms and guidelines are needed to decide when we should use RO. We submitted our idea as an Internet Draft[261]. In the draft, we mention a firewalled network case where RO is not needed and we define a mechanism for distributing information from a home agent to mobile nodes. This information can be used as hints by mobile nodes to decide when they should initiate RO.

This draft was presented during the MIP6 working group meeting at the 58th IETF. At the meeting, many people suggested that the draft should mention an autonomous mechanism which triggers RO by measuring round trip times of HoTI/HoT exchange and CoTI/CoT exchange. It is reasonable not to initiate RO if the round trip time of CoTI/CoT is shorter than HoTI/HoT. We will include this suggestion in the next revision of our draft.

Advanced API

Mobile IPv6 adds one new IPv6 extension header and many options to the IPv6 specification. A new extension header is called “Mobility Header” and is used to carry Mobile IPv6 signaling messages. Mobile IPv6 also defines a new destination option called “Home Address Option” to carry the home address of a mobile node when it is away from home. In addition to these, there are some new ND options. It is useful to define such header and option structures and the manner of header/option manipulation, to keep source level interoperability.

KAME has its own structure definitions and mechanisms to handle header and options, however an Internet Draft which describes those information was published as "Extension to Sockets API for Mobile IPv6[30]."

KAME project sent many recommendations and suggestions regarding the structure names and manipulation mechanisms based on our implementation, since we have a lot of experience in that area. Most of our ideas were merged with that draft. The draft was a personal draft at that time, however it is a working group draft now.

2.1.3 Interoperability

KAME project participated in the following three interoperability test events:

- TAHI test event[6] (January, 2003)
- Connectathon[7] (March, 2003)
- ETSI IPv6 plugtests[8] (September, 2003)

We inter-connected various Mobile IPv6 implementations developed at many research laboratories, companies and universities. As a result, we confirmed that the Mobile IPv6 specification is well specified and works well without any interoperability problems.

2.1.4 Future Work

KAME project is planning the following tasks in 2004:

- Full support of "Using IPsec to Protect Mobile IPv6 Signaling between Mobile Nodes and Home Agents[7]" with Racoon2
  At this time, we don't support exchanging SAD entries which are used for Mobile IPv6 by using a dynamic keying mechanism like IKE. However, when considering a real deployment, it is not feasible to set all IP security parameters by a manual keying mechanism. We need to provide an automatic mechanism to establish Security Associations.
- Kernel API definition and implementation
  We don't have any standard mechanism to get/set Mobile IPv6 related information from/to kernel inside. In some applications, such information is sometimes useful. For instance, a mail application may want to know its connection media type to avoid a large file transfer on a narrow connection. We will research information types which we need to know and design/implement an API set.
- Merging KAME Mobile IPv6 code to BSDs
  KAME Mobile IPv6 is not available easily to average users. The code is distributed as the KAME snap kit. The kit is available to anyone, however most of users do not use the KAME kit. They usually use normal BSD distributions. We need to merge our code to the original BSD trees, so that many users can use our Mobile IPv6 code by retrieving normal BSD distributions.
- Mobile IPv6 bootstrapping mechanism implementation
  KAME project will design and implement a bootstrap mechanism for mobility service. The Nautilus project started an operational experiment in late 2003. There are no such bootstrapping mechanisms (see section 3.3), since the experiment is based on the KAME implementation. In the experiment, all users must install configuration files in their mobile nodes. From an operator and users' point of view, such a complicated operation should be avoided as much as possible. We will develop an easy way to set up terminals of users by using some bootstrap mechanisms

6 http://www.tahi.org/
7 http://www.connectathon.org/
8 http://www.etsi.org/

and operate them in the Nautilus operational testbed, collaborating with Nautilus6 Operation Team.

2.1.5 Publications

- IETF Documents:
  - "Route Optimization hint option[261]"

2.2 Network Mobility

Network mobility arises when entire networks are changing their point of attachment with respect to the Internet topology. Those are thus referred to as *mobile networks* and will soon be found in vehicles (taxi, cars, trains) and embedded on people (Personal Area Networks or PANs). A mobile network is connected to the Internet via one or more mobile routers (MR). Nodes behind the MR are referred to as mobile network nodes (MNNs). MNNs are either *local fixed nodes* (or LFNs, i.e. nodes that belong to the mobile network with no abilities to change their point of attachment), *local mobile nodes* (or LMNs, i.e. nodes that belong to the mobile network with the ability to change their point of attachment), or *visiting mobile nodes* (or VMNs, i.e. nodes which do not belong to the mobile network and which are able to change their point of attachment). If no network mobility support functions are provided, all connections between the MNNs and nodes located in the Internet would break as a result of the MR changing its point of attachment.

The IETF NEMO (NEtwork MObility) working group has been created in fall 2002 to standardize a solution for this problem. The NEMO WG has decided to first specify an easy, straight forward, but not optimal solution for this problem referred to as *NEMO Basic Support*. The solution is to set up a bidirectional tunnel between the home agent (HA) and a mobile router much like it is done in Mobile IPv6[142] (see previous section 2.1). The first version of this solution has been issued in June 2003.

The IETF's NEMO working group is also investigating issues related to specific configurations of mobile networks, such as *nested mobile networks* (mobile networks that attach in a larger mobile network, such as a PAN that is getting Internet access through a mobile network deployed in a train), *multihomed mobile networks* (mobile networks with several point of attachment to the Internet), issues related to prefix-delegation and other IPv6 mechanisms, and compatibility issues with other IPv6 protocols, such as multicast. For the long term, the IETF's NEMO working group intends to investigate how the solution could be optimized, i.e. *NEMO Extended Support*. This includes solutions to improve routing, particularly when there are several levels of mobility (i.e. nested mobile networks).

Network mobility is the key mobility feature to bring all mobility features together. It provides an environment where all IPv6 features must be combined (mobility, multihoming, security and access control, auto-configuration, multicast), particularly mobility activities (host mobility using Mobile IP, network mobility using NEMO, nested mobility using a combination of NEMO and Mobile IP, ad-hoc networking, seamless mobility, micro-mobility). NEMO can thus serve as a glue between all IPv6 features.

The objectives of Nautilus6 in this activity is to develop reference implementations of the standards designed at the IETF, to contribute to the standardization process, to push for the development of additional features which are required for a proper operational use of the protocols, and to investigate potential new solutions for the longer term. This year's activities can thus be split into implementation, testing and research.

2.2.1 Standardization Activities at the IETF and ISO

Participants: Thierry Ernst, Ryuji Wakikawa, Keisuke Uehara.

We are very actively participating into the overall activities conducted in the IETF NEMO working group (we are actually chairing this working group). Particularly, we are authoring the NEMO terminology document[72] and the NEMO requirements and guidelines document[70]. We take part into the specification of the NEMO Basic Support solution[55] and multihoming activities (see section 2.3). We are also serving as a link between ISO's TC204 WG16 and the IETF. ISO TC204 WG16 is defining the communication system architecture as needed in the transportation industry, particularly the automotive industry[74].

2.2.2 Development: IETF NEMO Basic Support

Participants: Koshiro Mitsuya

We are implementing the IETF NEMO Basic Support protocol based on the current version of the specification[55]. Since the protocol is an extension of Mobile IPv6, we have implemented it based on KAME's Mobile IPv6 stack. For the details of the protocol, refer to the IETF draft.

Overview

Our kernel has two different configurations, one is as MR, the other is as HA. The two setups are exclusive events and not configured simultaneously, so a node can either be configured as a HA or as a MR. The protocol has three modes: "Explicit" and "Explicit Prefix Length" modes have been implemented, but "Implicit" mode is not implemented yet. HA has those modes simultaneously, and MR switches the mode according to its configuration.

New Data Structures

We have defined and implemented the following new data structures:

- prefix table:
  This is a list of Mobile Network Prefixes indexed by the Home Address of the MR. The prefix table is managed by the HA and is used by the HA to determine which Mobile Network Prefixes are owned by a particular MR. This is an optional data structure.
- managed_prefix_table:
  In our implementation, HA has a managed prefix table which includes "capable" mobile network prefixes which are statically configured by a manager. Here, "capable" means that the prefix can be routed and managed by the HA. If HA receives any invalid prefix, where "invalid" means not-capable-mobile network prefixes, HA returns a binding acknowledgment containing the error code "141". Then MR may try another HA on its HA list. If a similar entry already exists in the table, MR overwrites the entry by new BU. Otherwise, HA should return a BA with status 141[9].

Changed from MIPv6

The main changed parts on MIPv6 stack are as follows:

- On HA:
  - *ip6_forward*()
    If the destination address in a packet matches a prefix in the prefix table, the packet is tunneled to MR.
- On MR:
  - *ip6_output*()
    If the source address in a packet matches a prefix in the managed prefix table, the packet is tunneled to HA.
  - *mip6_select_coa*()
    It was changed not to choose an address, of which prefix is managed by MR, as a CoA.
  - *mip6_ip6mu_create*()
    This module processes mobility options. In order to process nemo-related mobility option, the module was extended.
- Parts common to HA and MR:

9 This behavior was proposed by Alexandru Petrescu on the NEMO mailing list

– *ip6_input*()

Initialize nemo-related database.

– *mip6_get_mobility_options*()

This module processes mobility options. The module was extended in order to process nemo-related mobility options.

Current Status

The current implementation is based on the IETF draft version 01. We are now implementing the current version 02 and "Implicit" mode. It is due to be finished by March. The validation of this implementation is performed using our indoor testbed (see section 3.1). We have demonstrated that MR and its attached LFNs can move between networks, but nested configurations and multihoming configurations are going to be verified from now on.

2.2.3 Development: Simulation Tools

The implementation of new network protocols in an operating system takes a lot of time. Moreover, it is particularly difficult to verify the behavior of protocols on a wide scale. A simulator for network mobility is also useful for fast prototyping of new protocols or schemes and performance analysis of their operation.

SimulX

Participants: Nicolas Montavont, Julien Charbon, Romain Kuntz

University Louis Pasteur Strasbourg developed a new simulator, called SimulX[10], designed for wireless communications. The aim of this simulator is to validate current and new protocols. This simulator is a stand alone simulator developed in C++ and Gtk. The main features are the support of 802.11 and IP mobility (e.g. Mobile IPv6). Resulting from the collaboration with Nautilus6, SimulX is currently being extended to include the NEMO Basic Support protocol[55] and to test large scale multihoming scenarios.

NS-2

Participants: HoSik Cho

Seoul National University extended Network Simulator (NS-2)[78] to support network mobility based on the Mobiwan extensions for mobility[69]. These extensions are useful to simulate intra-domain mobility of multihomed and nested mobile networks. The simulator can be extended to support multiple CoA and CoA selection for multiple mobile routers.

2.2.4 Research: Route Optimization in Mobile Networks

NEMO Basic Support imposes to transmit packets in both directions through the home agent. This causes unnecessary delay in packet delivery and packet overhead due to tunneling. We are therefore conducting research in route optimization in mobile networks. At the IETF, such optimizations are referred to as NEMO Extended Support.

Network Mobility Support Based on LIN6

Participants: Takuma Oiwa.

Conventional mechanisms for routing optimization need additional signaling and processes which may themselves cause delay and overhead in packet delivery. We are therefore investigating alternative ways to optimize routing in mobile networks. LIN6[164] is such an alternative addressing model and mobility support mechanism in IPv6. We thus research into a more efficient network mobility support protocol using the LIN6 concepts. Our results were published in [222] and are referred to as LIN6-NEMO.

LIN6-NEMO can always accomplish route optimization without tunneling even in nested mobile networks. In LIN6-NEMO, the destination address of the packet destined to a mobile node located in a mobile network (i.e. VMN) must be made of the network prefix of the MR which directly connects the mobile network to the

10 http://clarinet.u-strasbg.fr/SimulX.html

Internet (i.e. root-MR) and VMN's LIN6 ID. To obtain this prefix, the CN must send mapping acquire messages to the *Mapping Agents* (MAs) until the MA returns a network prefix to CN. Packets sent from CN to VMN are intercepted by the MR. MR overwrites the network prefix of the destination address with the actual network prefix of VMN and forwards it down its own mobile network.

When mobile networks are nested, the registered value on "Mapping Agent" is not a network prefix, so CN must send more than two mapping acquire messages:

- When there is one level of nesting, the first reply from MA contains the LIN6-ID of MR; the second reply contains the network prefix of MR as the location of VMN (i.e. 2 mapping acquire messages are needed).
- When there are 2 levels of nesting, the first reply from MA is the LIN6-ID of the root-MR, the second contains the LIN6-ID of the second MR, and the third contains the location of VMN (i.e. 3 mapping acquire messages are needed).

The number of mapping acquire messages is the same as the number of levels in the nested mobile network, but the signaling procedure is needed only before starting communication with VMN. We found that the time for overwriting the destination address at the MR is negligible.

Under this protocol design, a VMN in a mobile network must send Mapping Update to CNs (unnecessary to MAs) whenever the mobile network changes its point of attachment to the Internet. In order to improve this problem, we are redesigning LIN6-NEMO. In the redesigned LIN6-NEMO, we define "domain" in the Internet to reduce sending Mapping Update. While the mobile network moves inside the domain, VMN in the mobile network does not have to send Mapping Updates.

Comparison of RO Mechanisms in Network Mobility Support

Participants: HoShi Cho, Thierry Ernst.

Protocols other than NEMO Basic Support such as LIN6, HMIPv6, and ORC, can also support network mobility and IPv6 mechanisms such as RA (router advertisements) can be extended to improve routing, as suggested in [35]. To find out reasonable RO mechanism for (nested) mobile networks, each mechanism should be compared and analyzed using common metrics. We have thus started a survey of routing optimization mechanisms and we are currently writing a paper. Based on the results of performance analysis, and using the NS-2 extensions developed by SNU (see section 2.2.3), we are describing the characteristics of each network mobility mechanism. Comparison and analysis of RO characteristics in LIN6 and HMIPv6 will be followed to suggest an appropriate RO scheme.

2.2.5 Future Work

Our following activities rely on the completion of NEMO Basic Support and its validation on our indoor testbed. Once this is completed, we will in parallel:

- try to merge our NEMO Basic Support implementation into the KAME stack, depending on the conclusions of the IPR discussion currently held at the IETF.
- implement NEMO Basic Support in Linux based in cooperation with the USAGI team.
- demonstrate the use of mobile networks on our demonstration testbed (see section 3.2).
- deploy NEMO services in home agents and mobile routers (e.g. in WIDE members cars), much like we already do for Mobile IPv6 in our operational testbed (see section 3.3).
- conduct more research on routing optimization in mobile networks and compare different approaches by means of simulation and real testing on your indoor testbed.

2.2.6 Publications

- IETF Documents: [33, 55, 70, 72, 210, 315]
- Master Report: [32]
- Conference Papers: [68, 71, 75, 192, 222, 313, 315]
- Journal Papers: [73, 193, 312]
- Talks: IPv6 Forum (Korea, July), IPCN conference (Paris, Dec)

2.3 Multihoming

Multihoming refers to a situation where a node can choose between several paths to reach a correspondent, either because the node has several interfaces to choose from, or because the network where it is located in is connected to the Internet by several routers, or by routers with several interfaces. Such a configuration is particularly useful in mobility contexts because it ensures mobile entities remain permanently connected to the Internet upon loss of connectivity (as a result of moving out of a coverage area or because wireless technologies are more subject to interferences), lack of connectivity (a given technology cannot cover all geographic areas) or lack of bandwidth (technologies with high bandwidth are generally not available for mobile users). Besides enhanced session continuity, it also allows to choose and balance the traffic between the available connections.

The question of mobile hosts with multiple interfaces has been discussed at the IETF in the Mobile IP working group. Many solutions have been proposed, but none has ever been adopted as a working group solution. As a matter of fact, the working group doesn't have much interest in including this topic in its deliverables, although several people have pushed for it. What is indeed missing is a comprehensive problem statement. Meanwhile, the NEMO working group has been entertaining discussion turning about multihomed mobile networks since almost the first day it was setup. We are leading and actively contributing to this discussion since the beginning.

The objective of our investigation of multihoming in mobile environments (mobile hosts and routers with multiple interfaces; and mobile networks with multiple mobile routers) is to push forward the standardization process at the IETF (many solutions exists, but they do not share a common understanding of the problem) by understanding and defining the problem for host mobility and network mobility. We also intend to demonstrate the benefit of multihoming for mobile hosts and networks; for doing so we need to implement protocols and design demonstrative applications.

During the course of this year, our in-depth investigation of this issue resulted into a few internet drafts submitted to both the NEMO and Mobile IP working groups in parallel to conference papers. We carried on standardization activities at the IETF for both multihomed mobile hosts and multihomed mobile networks. We also carried out some testing on our in-door testbed, we developed protocols and performance evaluation tools, and we conducted more academic research activities.

2.3.1 Standardization Activities at the IETF Problem Statement for Multihomed Mobile Hosts

Participants: Nicolas Montavont, Ryuji Wakikawa, Thierry Ernst, Thomas Noel.

Motivations New mobile nodes often integrate several wireless technologies. The main purpose of this integration is to federate all means of communications in order to have an ubiquitous mobile node which can be used to access to the Internet everywhere and at any time. For example, it is desirable to maintain the Internet connectivity while an automobile running on a freeway receives voice or video streaming data from different access networks.

Each network interface has different cost, performance, bandwidth, access range, and reliability. Users should thus be able to select the most appropriate set of network interface(s) depending on a visiting network environment, since wireless networks are mutable and less reliable than wired networks. Users should also be able to select the most appropriate interface per communication type.

Mobile IPv6 is being designed to allow a mobile node to maintain its IPv6 communications while moving between IPv6 subnets. However, the current specification does not give any hint nor requirement how to deal with multihomed mobile nodes. In front of this observation, several IETF drafts were proposed to manage multihoming in Mobile IPv6, such as [199, 214, 314]. The main drawback of each of these contributions is that each identifies a problem and proposes a solution to this particular problem instead of looking multihoming issues in general.

Taxonomy In order to define an accurate problem statement, we proposed in [200] a new taxonomy based on the number of home addresses, the number of care-of addresses and the number of active interfaces a mobile node has. This taxonomy will be useful to define the different scenarios of multihoming. From the evaluation of the scenarios, we identified different issues, some related to Mobile IPv6 and others not related to Mobile IPv6:

- The main issues related to Mobile IPv6 are:
  - How to define a relation between Home addresses and Care-of addresses?
  - How to identify an entry in the Binding Cache if several CoAs are simultaneously bound to the same home address?
  - How to manage multiple Care-of addresses bound to a single HoA?
- The issues not related to Mobile IPv6 are:
  - How to allow a mobile node to simultaneously use several interfaces?
  - How to manage multiple home addresses (with the same IPv6 prefix or not)?

Problem Statement for Multihomed Mobile Networks

Participants: Julien Charbon, Thierry Ernst, EunKyoung Paik, Koshiro Mitsuya.

The NEMO working group has been discussing multihoming almost since it was setup and agreed that multihomed configurations shouldn't be prevented. However, network mobility gives raise to new multihoming issues. Since we believe that multihoming configurations are necessary to ensure that we always remain connected to the Internet, we have pushed for a problem statement document at the IETF. Our standardization activities at the IETF can be summarized as follows:

- we defined the terminology related to multihomed mobile networks[72],
- we contributed to the definition of a taxonomy to classify the potential multihomed configurations in [210],
- we explained the motivations for multihoming and we defined the prerequisites in [226],
- we evaluated the ability of NEMO Basic Support to allow all potential multihomed configurations and we documented configuration issues related to specific scenarios of network mobility[33, 71],

Terminology New terms necessary to discuss multihomed configurations of mobile networks were added to the NEMO terminology draft which we are authoring[72]. This includes definitions for multihomed mobile routers and networks, and terms for nested multihomed mobile networks.

Motivations and Prerequisites In [226], we made a case for why multihoming is needed for NEMO and we discussed what prerequisite issues for developing multihomed mobile networks. In multihomed configurations, multiple connections can be used simultaneously or one at a time. The issues were thus examined with respect to connection availability, and selection mechanisms. In both cases, connection selection mechanisms are required: which connection to use, or, which connection for each flow. The selection of a connection can be done either by the home agent (HA), the MR, and/or the MNN. A hybrid mechanism should be also available, e.g. one in which the HA, the MR, and/or the MNN coordinate to select a connection. Once the selection mechanism is decided, potential problems can occur:

- when there are multiple HAs and the HA selects a connection: coordination between HAs is needed.
- when there are multiple MRs and the MR selects a connection: coordination between MRs is needed.

Taxonomy A taxonomy is necessary to study the issues peculiar to each potential multihoming configuration. We have thus worked on the definition of such a taxonomy in collaboration with other IETF members. This resulted into the following taxonomy described in [210] and proposed to the IETF NEMO working group. Three discriminant factors, arbitrary named x, y, z, are used to differentiate these configurations:

x: Indicates the number of MRs (presumably with multiple egress interfaces).
y: Indicates the number of HAs associated with the mobile network.
z: Indicates the number of MNPs announced to MNNs.

Eight cases have been identified using the tuple (x, y, z). A value of *1* implies there is single instance whereas a value of n indicates several instances.

Evaluation of NEMO Basic Support for Multihoming Based on the taxonomy summarized in the above section, we have evaluated the behavior of NEMO Basic Support with multihomed configurations of mobile networks and we reported the results in an internet-draft[33]. For each multihomed configuration depicted with the above taxonomy, the draft describes prerequisites and existing mechanisms which can be used to allow redundancy, load-sharing, and policy-routing, and points out what are the remaining issues in NEMO Basic Support. For instance, we emphasized the need for a mechanism to record in the HA several entries for each MR. Some of our results of this study were also published in a conference paper[71].

Current Status In the 58th IETF meeting, the working group decided to issue a working group's problem statement based on the three individual problem statement drafts on which we are involved[33, 210, 226]. We are now working on a common draft with all the co-authors of these three drafts.

2.3.2 Testing

Participants: Julien Charbon, Koshiro Mitsuya, Manabu Tsukada

Our NEMO Basic Support implementation is not ready yet to test multihoming, however, many interesting tests can be conducted without mobility support. So, we only conducted tests on fixed multihomed networks to learn more about multihoming mechanisms. We were particularly interested by the configuration with multiple routers. We tested the behavior of fixed multihomed networks as defined in [210] and the behavior of multihomed mobile networks as defined in [210] and [33]. Some of our results can be found in [32, 299].

Multihoming has no formal definition and covers many scenarios. We can see three cases: the first is with a single network interface, which has been assigned multiple IP addresses (see Fig. 2.1), the second one is multiple network interfaces on the same network node (see Fig. 2.2). We add a third case at a higher scale to test site multihoming: when a network site has more then one connection to the public Internet (see Fig. 2.3).

We tested the three cases using our indoor-testbed detailed in section 3.1 with KAME's NetBSD snapshot 20030505 and no mobility support protocols. We kept the acronym MR on the figures to comply with the description of our

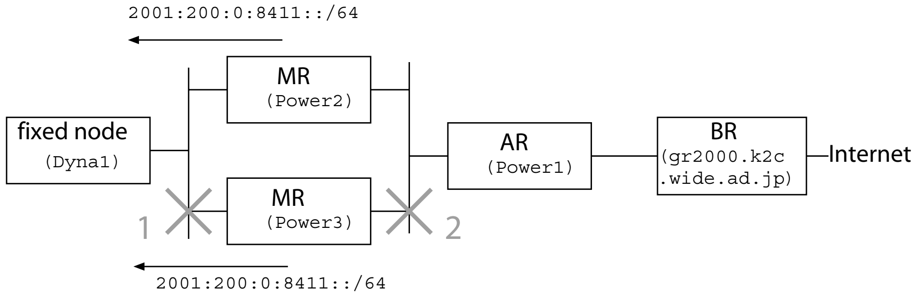

Fig. 2.1. Case 1: Single Network Interface with Multiple IP Addresses

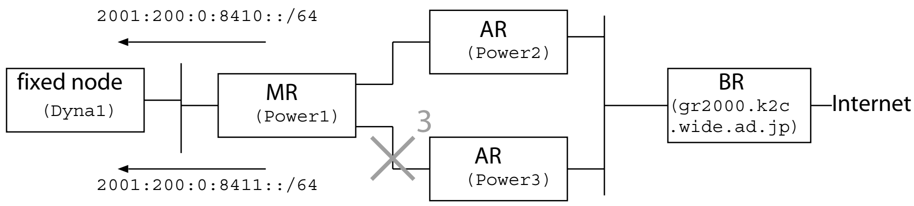

Fig. 2.2. Case 2: Multiple Network Interfaces with Single IP addresses

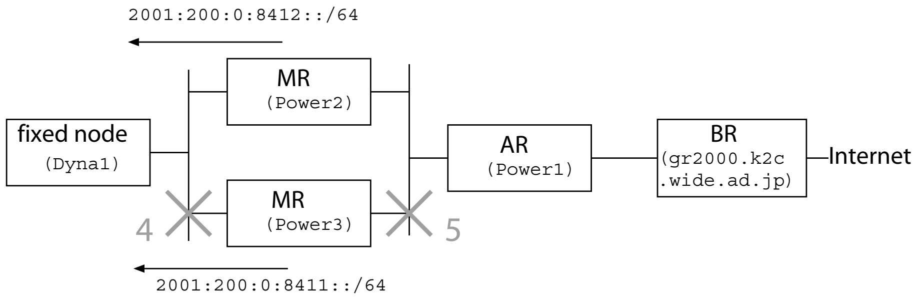

Fig. 2.3. Case 3: Multiple Network Interfaces with Multiple IP Addresses

testbed. We checked the behavior of routing protocols when an interface goes down. In total, we performed five experiments: 2 with the first configuration, one on the second configuration, and 2 on the third, as indicated by numbers on the figures which show which interface was stopped.

In the remaining parts of this section, we only describe experiment 3 (Fig. 2.2) and experiment 5 (Fig. 2.3) for which we obtained the most interesting results.

In the second case, illustrated on Fig. 2.2, Power2 and Power3 use Reverse Path Filtering like ISPs. Power2 transmits packets which source address or destination address is generated from prefix 2001:200:0:8410::/64. Power3 transmits packets which source address or destination address is generated from prefix 2001:200:0:8411::/64. Power2, Power3 and gr2000 run RIPng. Power1, Power2 and Power3 run OSPF. As Power1 receives two routes, it sends two kinds of Router Advertisements (RAs). As a result, Dyna1 is configured with two IP addresses. Power1 chooses its default router by random and Dyna1 chooses its source address by random. We started the “ping6” command from Dyna1 to BR. After that, we stopped Power1’s interface connected to Power3.

Two possibilities can happen during the initialization stage of this experiment as a result of the random choice of the default router and the source address. First is that the source address Dyna1 has picked up can NOT pass Power1’s default router. Second is that source address Dyna1 uses CAN pass Power1’s default router. The problem is that Dyna1 cannot choose its source address before it knows Power1’s default router.

In case Dyna1 succeeds to ping6 BR, another problem occurred when we stopped the interface. The problem is that Power1 cannot teach when its own route has changed.

Those two problems can not be solved by existing implementations. From our experiment, it became clear that a mechanism is required for Dyna1 to know the default router of Power1.

In the fifth experiment (third case, as illustrated on Fig. 2.3), Dyna1 has two default routers and two global addresses. Power1, Power2 and Power3 run OSPF. We perform the "ping6" command from Dyna1 to BR. At first Dyna1 sent packet through Power3. When we stopped the interface of Power3 connected to Power1, Dyna1 didn't change the route, and kept sending packets to Power3. After routing table update, ping6 packets still went to Power3 and Power3 sends ICMP redirect messages to Dyna1 to use Power2 instead. However, Dyna1 uses an address generated from the prefix advertised in the RA from Power3 which is not allowed to pass through Power2 (ISP Ingress Filtering).

From our experiment, it became clear that it is important to care about the source address when the route is redirected.

2.3.3 Development: Automatic Interface Configuration for Mobile Nodes

Participants: Masafumi Watari[11]

Automatic Interface Configuration In an ubiquitous computing environment, mobile terminals will have not one but multiple wired and wireless interfaces, and will be connected to the Internet using one or several network interfaces simultaneously. As the mobile terminal moves between different access networks, the terminal will automatically reconfigure the current interface or switch to another interface to maintain continuous Internet connectivity, all based on an algorithm which selects the most preferred interface. When realizing such environment, a function which automatically configures the selected interface is needed.

As an output, a design and a prototype implementation of API for automatic interface configuration was made for Linux. Ethernet was used for the wired interface, and 802.11b, bluetooth, and GPRS were used for the wireless interfaces and a static preference in the same order was configured for each interface to describe the most preferred interface.

On the testbed provided by ENST Bretagne, horizontal and vertical handoff tests were conducted using a Mobile IPv6 implementation and the prototype implementation. The results of the test showed the effectiveness of the API and also verified the need for an "Interface Adaptive Handoff."

Interface Adaptive handoff Multiple interfaces allow the mobile node to move a communication flow to another interface, known as vertical handoff or interface switching. However, moving all traffic from one interface to another, due to a device going down or whatever, may not always be a wise idea.

For example, in a scenario where a mobile node with 802.11b interface receiving video and audio streams from a correspondent node and a GPRS interface for backup connectivity, the mobile node can switch to the GPRS network and continue to receive the streaming from the correspondent node, due to the mobile node moving out from the 802.11b cell range. However, devices like GPRS are not capable of handling video streaming data due to its narrow bandwidth, and high cost. In such case, vertical handoff should only be performed for Mobile IPv6 signaling to and from the Home Agent, but not for the video streaming from the correspondent node.

An extension to Mobile IPv6 implementation was made to check for available interfaces the mobile node has before any vertical handoff, and if in case GPRS is the only available interface,

11 internship at ENST Bretagne for 70 days, under the supervision of Bruno Stevant and Jean-Marie Bonnin

Binding Update messages are not sent to the correspondent node, and the corresponding binding is deleted from the Binding Update list. This allows the mobile node to keep connectivity, without having to receive video streaming on GPRS.

Future Work Experiments of Interface Adaptive Handoff using 802.11b and Bluetooth showed that the correspondent node soon received a destination unreachable message for the mobile node, deleted the binding entry from the Binding Cache, which ended up resuming communication to the Home Address. For the future work, filtering specific packets at the Home Agent maybe required, such as the one stated in [198] is considered.

2.3.4 Research

Multihomed and Nested Mobile Networks

Participants: Nicolas Montavont, Thierry Ernst, Thomas Noel

A mobile network is said nested when one of the egress interfaces of a mobile network is connected to another mobile network. When a mobile network is getting attached to another mobile network, the aggregated hierarchy of mobile network becomes a single nested mobile network. In a nested mobile network, the hierarchy of mobile routers increases the overhead introduced by the NEMO basic support. Each level of a mobile network implies the usage of a new tunnel between the mobile router and its home agent. Thus if a mobile network node connects to a sub-mobile network which is also a sub-mobile network, packets from the mobile network node will be encapsulated three times. When the nested mobile network is multihomed, several interfaces of the mobile network are giving internet connectivity. Our goal is to propose a new mechanism to allow either mobile network node or mobile router to choose the most appropriate egress interface to route packets of mobile network nodes in multihomed nested mobile networks. This work was presented in [197].

Reference [62] introduces new options in Router Advertisement to allow any node on a link to choose between several routers. This option indicates the preference of the router (or the preference of a specific route). However this preference is only useful in a flat topology; It gives a way to the node to choose between different access routers advertising prefixes on the node link. But if the node is inside a hierarchical topology (some access routers are not at the same level) the node can not be aware about the level of each access router.

We propose to add a new option in Router Advertisement to distribute the knowledge of the MR hierarchy inside a nested mobile network. This option indicates the level of hierarchy of the sending mobile router and allows any receiving mobile network node to deduce the level of nesting. So this option can be used by mobile network nodes to determine the hierarchy of mobile routers and thus to choose the best default router. Also, this option can help mobile router to configure their preference in their Router Advertisement. Mobile network nodes that are not able to interpret the new option, can use the preference field to mobile routers to choose their best default router.

The management of multihomed nested mobile networks is still a research topic. On one hand, other parameters such as the available bandwidth or the cost of a link can also help to choose the best default router. On another hand, other optimizations in multihomed nested mobile networks need to be investigate to reduce the overhead introduced by the aggregation of mobile routers.

Load Sharing and Session Preservation with Multiple Mobile Routers

Participants: EunKyoung Paik, Thierry Ernst.

Using NEMO Basic Support, the mobile router provides the connectivity to the Internet and mobility transparency for the rest of the mobile nodes in the mobile network. So, it is important for the mobile router to assure reliable communications and a high data rate for the group of nodes behind it. We have thus investigated how multiple mobile routers would allow the transfer of large volumes of data to a group of mobile nodes. We studied the protocol issues in such a multihomed configuration, and we analyzed the influences of mobility on load sharing and session preservation of multiple mobile routers. For doing so, we performed some simulations using NS-2 extensions developed by Seoul National University. Different configurations were investigated. The simulation results showed that session preservation and load sharing schemes are influenced by application mobility behaviors and wireless access technologies. Some of our results were published in [227], other papers have also been submitted. Our future plan is to evaluate the performance of our ideas using the Nautilus demonstration testbed with applications such as multicast over e-bike or e-wheelchair. To achieve such an evaluation, NEMO prefix delegation and other implementation issues will also be explored.

2.3.5 Future Work

Our plans in this activity are:

- to push for a NEMO working group's multihoming problem statement for network mobility support,
- to document the use and configuration of IPv6 in a multihomed and mobile network environment,
- to continue the tests summarized in section 2.3.2 once our implementation of NEMO Basic Support is completed
- to select and/or implement interface switching, fault-tolerance, load-balancing, and policy-routing mechanisms,
- to demonstrate the benefit of multihoming in mobile environments on your demonstration testbed (see section 3.2)
- to study multihoming issues in nested mobile network configurations.

2.3.6 Publications

- IETF Documents: [33, 198, 200, 210, 226, 314]
- Master Report: [32]
- Conference Papers: [71, 197, 227]
- Internal Reports: [299]

2.4 Seamless Mobility

The activities turning around host mobility, network mobility and multihoming concentrate on the pre-requisites features which will allow ubiquitous mobility. However, performance is also necessary to reach deployment of the technology, and that's why efficient handoffs mechanisms are required. The purpose of this activity is to investigate and implement fast handoffs mechanisms for mobile hosts and routers. We will have to care both about horizontal and vertical handoffs since mobile nodes will switch between access networks. For the longer term, we also need to consider fast handoff mechanisms when mobile nodes cross domain boundaries.

This activity is in its infancy. Our objective is to implement standards currently being defined at the IETF, and to validate them in combination with other mobility features. So far, we haven't determined if any functionality is missing or if there are issues with those protocols specified by the IETF. For the actual validation, we need to develop tools as it is extremely difficult to test such kind of protocols under a real situation. The roadmap we have defined for the seamless mobility activity is a follows:

Task1. Setup Test-Bed.
Task2. Implement FMIPv6 on SFC-MIP.
Task3. Test Implementation.
Task4. Build a Wireless Environment Emulator.
Task5. Test vertical handoffs with FMIPv6.
Task6. Implement CARD.
Task7. Test CARD.
Task8. Integrate everything with KAME.
Task9. Implement HMIP.

We have completed task one (see details in section 3.1), and we are currently working in parallel on task 2 and 4.

2.4.1 FMIPv6

Participants: Susumu Koshiba

FMIPv6 will be used as one of the seamless mobility support protocols. The implementation itself is the output of SFCMIPv6 and Nautilus6 will be using this implementation to test the performances in various configurations. FMIPv6 on SFCMIPv6 is currently under development and no tests have been conducted at this point. Tests of FMIPv6 will be conducted on our in-door testbed (see section 3.1) using the Wireless Environment Emulator currently under development (see below).

2.4.2 L2 Trigger

Participants: Koki Mitani

To achieve seamless mobility, we have developed the Inter-Layer System (ILS) which provides a way to exchange information between different layers, and the Abstracted Entity (AE) which abstracts layer dependent information in order to transport it to another layer. L2 Trigger is a subset of this architecture, and implemented on FreeBSD4.7 and NetBSD1.6 as MITAC[190]. In MITAC, Link Layer Abstracted Entity (L2AE) abstracts the network device dependent information into generic information, then ILS transports it to another layer.

MITAC provides link layer information to arbitrary kernel modules, daemons and applications dynamically. At the network layer, L2 Triggers can help detecting network attachment and candidate access point/router discovery. At the transport layer, it can provide hints for wireless-TCP. Also, it is useful for some mobile applications.

For the future work, improvement of existing protocols by L2 Trigger will be concretely explored and implemented.

2.4.3 Wireless Environment Emulator

Participants: Koki Mitani

The Wireless Environment Emulator is equipment required to test handovers. The emulator can generate many kinds of link layer events which occur on the links between access routers and a mobile node (e.g., link up/down, packet loss) according to a given scenario. It also can notify those events to a mobile node as if wireless devices of a mobile node sense them directly. Those notifications can make a mobile node generate L2 triggers for a seamless mobility protocol located in the network layer.

The emulator is placed between access routers and a mobile node, and connected by cable. It defines one or more virtual access points for each access router internally, and provides virtual links between some of virtual access points and a mobile node. Also, it can make characteristic frame loss and frame delay for each virtual link, and provide various types of horizontal and vertical handover scenarios in response to the request of an experimenter.

The specifications of Wireless Environment Emulator[191] are mostly fixed. However, its implementation is currently under development. Also, the mobile node side implementation is being developed. In Nautilus project, Wireless Environment Emulator will be used for development and evaluation of seamless mobility protocols such as FMIPv6.

For the future work, development of the L3-driven fast handover protocol will be important for realizing seamless mobility. Currently, Wireless Environment Emulator is also designed to have the flexibility for testing L3-driven handover.

2.4.4 Future Work

Our plan on testing seamless mobility is not fully determined and will depend on the results obtained during the FMIPv6 testing. However, the project believes that the implementation of Candidate Access Router Discovery (CARD) will be important for realizing seamless mobility. Currently, there is no specific design nor plan for implementing the CARD protocol, but this will be planned once the test with Wireless Environment Emulator is completed and the required functionalities are clarified.

2.4.5 Publications

- Bachelor Report: [190]
- Internal-Memo (Specifications): [191]

2.5 Security and AAA

Participants: Francis Dupont, Jean-Michel Combes, Keiichi Shima

2.5.1 Objectives

When we consider a real operation of any services for business, we cannot avoid security and AAA mechanisms for those services.

When we operate layer 3 mobility services such as Mobile IPv6 or NEMO, we must protect mobility signaling packets by IPsec. IPsec requires preconfigured associations between nodes. The association can be created even by manual configuration, however, from an operator's point of view, some kind of automatic mechanism must be developed to reduce maintenance cost.

Accounting is another important topic in business. Recently, most of ISPs provide a roaming service to their subscribers so that they can access ISP services via another ISP's access points. In addition to those basic roaming services, a mobility service requires other authorization and accounting mechanisms to permit layer 3 roaming.

The objectives of this subgroup are:

- Develop an interaction mechanism between mobility protocol stacks and a dynamic keying processing stack
- Observe requirements for AAA mechanisms which are needed for mobility services in real operation/services
- Develop an AAA mechanism which covers our requirements

2.5.2 Future work

We had meetings with ENSTB and INT regarding to AAA mechanisms. As described in section 3.3, we started a layer 3 experimental operation. In the operation, we don't provide nor operate any AAA mechanisms at this moment. The reason we don't operate them are just we don't have any operatable implementation for them. In the meetings with ENSTB and INT, we discussed what a realistic AAA infrastructure is, and the way to deploy it in our experimental operation.

We decided to write a requirement document of AAA infrastructure which satisfies our experimental operation network, which will be a good example for wider area deployment in a real business.

The document will be published in 2004 and we will modify our experimental operation network to support those requirements.

第3章　Phase-1 Testbeds

In this chapter, we detail the various testbeds that were outlined in section 1.4.2. So far, only host mobility has reached the necessary maturity to move on to an operational testbed while other protocols such as network mobility are only at the earliest stage of development. Our indoor testbed detailed in section 3.1 is thus designed to test the implementations of NEMO Basic Support and FMIPv6 under several configurations. Our **E-Bike** and **E-Wheelchair** demonstration testbeds detailed in section 3.2 are designed to demonstrate and validate NEMO Basic Support and multihoming mechanisms, while the **Zaurus** operational testbed detailed in section 3.3 is designed to validate and evaluate the operation of Mobile IPv6.

3.1 Stage 1: In-door Testbed

Participants: Koshiro Mitsuya, Julien Charbon, Manabu Tsukada, Susumu Koshiba, Koki Mitani.

In the process of developing new protocols, finding the problems in existing solutions is one of the most important processes. Even though developed protocols should be tested in real situations, many problems can be discovered and addressed using a small in-door testbed. Our indoor testbed is designed to validate our protocol implementations during the course of their development. It is currently configured to test a wide range of configurations. For network mobility, possible configurations include "multihomed mobile networks" (mobile network connected to the Internet via several mobile routers), and "nested mobile networks" (ability to bring a mobile node or a mobile network into another mobile network without breaking open connections by performing a combination of Mobile IPv6 and NEMO) and a combination of both. It has recently been extended to test seamless mobility protocols.

In the following sections, we describe our testbed, the tests conducted so far, and the extensions that will shortly be brought to test other protocols. The acronyms used in this section strictly comply with the terminology we defined in [72].

3.1.1 Current Network Topology of the Testbed

The network topology of the in-door testbed is illustrated in figure 3.1. The node labeled "Router" is connected to the Internet and three routers labeled "NEMO-HA1", "NEMO-HA2", and "MIP-HA" are connected to the same subnet. They are usual routers and also provide a Home Agent service. NEMO-HA1 is a Home Agent for Mobile Router1 (labeled MR1), and NEMO-HA2 is a Home Agent for Mobile Router2 (labeled

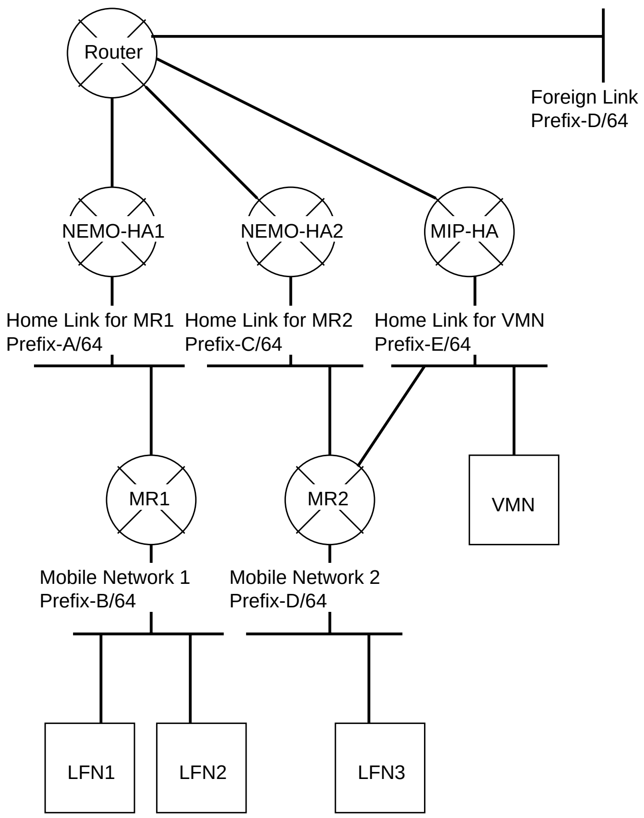

Fig. 3.1. In-door Testbed Topology as of Year 2003

MR2). MIP-HA is a regular Mobile IPv6 Home Agent and serves as a Home Agent for Visiting Mobile Node (labeled VMN). VMN is a wireless node and can move between the home network and each mobile network. Nodes labeled LFNs (Local Fixed Nodes) are wired nodes connected to the subnetwork served by mobile routers. LFNs do not have any mobility support functions.

3.1.2 Possible Configurations

The current architecture of the testbed can be configured to test host mobility (MIPv6), network mobility (NEMO Basic Support), the combination of network mobility with network mobility (MIPv6 and NEMO), nested mobility and all the multihoming configuration of mobile networks are highlighted previously (see section 2.3.1)[210]. For network mobility, MRs and their attached LFNs can move to other subnetworks while LFNs are communicating with CNs. A MN (i.e. VMN) can be moved into the mobile network. MRs could use multiple interfaces simultaneously so that the use of vertical handoff can be tested. We can configure the testbed so that LFNs have more than one MR to choose from (multihoming). In addition, MNs could move between normal IPv6 network and mobile network. In this situation, MNs which belong to mobile network are called VMNs.

3.1.3 Public Demonstration

Our testbed is also used for demonstrations. Using this testbed, we have demonstrated the NEMO implementation to the public during the public open-day of our campus. The testbed needs to be improved so that we can show the advantages of using mobility protocols to anyone who is interested.

3.1.4 Further Improvements of the Testbed

The testbed is currently being improved to test seamless mobility mechanisms including L2 triggers, and FMIPv6. The intent is to test such mechanisms for both horizontal and vertical handoffs. An example of topology required for testing seamless mobility is shown in figure 3.2.

FMIPv6 For FMIPv6, no big changes to current topology will be made. However, in order to test the advantages of FMIPv6, MN should be able to switch between networks as quickly as possible. This would allow to test FMIPv6 under situations where the network is switched with short delay and where the network is switched with long delay. The development of an auto-network switcher is therefore necessary. Auto-network switcher is a device which switches the networks automatically without actually changing the network switch or HUB where Ethernet cable is connected.

L2 trigger To explore the possibilities for improvement of existing mobility protocols by L2 Trigger, a Wireless Environment Emulator is due to be introduced into the testbed. The Wireless Environment Emulator will be connected to several access routers and a mobile node. Particularly, a mobile node and the emulator will be connected by more than one cable for testing vertical handovers. With this tool, we will be able to perform both horizontal and vertical handover scenarios.

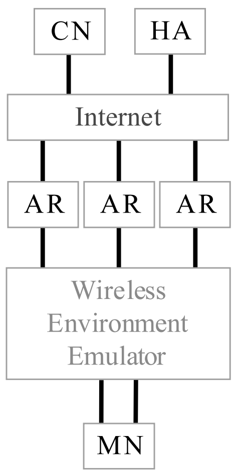

Fig. 3.2. An Example of In-door Testbed Topology for Seamless Mobility

3.2 Stage 2: Demonstration Testbeds

Participants: Thierry Ernst, Francois Leiber, Thomas Noel, Jean-Marie Bonnin.

Light-weight demonstration testbeds are necessary to validate the new protocols developed by Nautilus under more complex situations, to demonstrate the new protocols, to demonstrate their combination with other existing IPv6 features, and to evaluate their efficiency.

As for today, only host mobility protocol implementations would be available for such a testbed, however, we don't need to repeat demonstrations already done in the past. We need something new, and for this we must wait for the completion of the protocols currently implemented in the indoor testbed, i.e. mainly NEMO Basic Support. Since the implementation should be available very soon, we have started to develop the *E-Bike* testbed and we are investigating ways to achieve an *E-Wheelchair* testbed targeted to handicapped persons.

3.2.1 E-Bike

The E-bike testbed will be used to demonstrate the benefit of network mobility for all types of configurations (i.e. nested mobile networks and multihomed mobile network). The testbed is currently under development. We are waiting for the completion of the implementation of the NEMO Basic Support protocol currently tested in the indoor testbed to start the actual demonstration.

Testbed Description

A portable IPv6 Personal Area Network (PAN) made of several IPv6 devices with several access technologies.

- PDA (e.g. Zaurus)
- IPv6 sensors (temperature/humidity sensor, 2-axis acceleration sensor, direction sensor) which can be accessed by using SNMPv1/UDP/IPv6.
- Microphone, video-camera
- GPS
- Internet access: 802.11b, Ethernet, cellular (e.g. AirH, mobile phone)
- Bicycle

Demonstration Scenarios

While readers may wonder what is the usefulness of Internet access on a bicycle, it's also easy to notice that such a testbed is easy to move around and thus ideal for demonstrations at remote sites. It is also ideal to demonstrate energy constraints. The usefulness is not an issue either when we think about all the demonstrations that can be demonstrated using such a tiny, funny, convenient and inexpensive testbed: video streaming while on the move, real-time monitoring while on the move, adaptive applications (access networks and quality changes over time). It will be enough to convince many people about the usefulness of the underlying technology. In addition, this technology can easily be brought to a motor-cycle, an automobile (as already demonstrated by the InternetCAR project[73]), or even a wheelchair (see section 3.2.2).

We have thus defined several scenarios. All scenarios require network mobility support. One is targeted to people that need permanent medical monitoring, one is targeted to tourists in a city that would rent E-Bike for sightseeing, and one for live-news reporters or live video-games (treasure quest in the city). All would obey to the following succession of events:

- IPv6 sensors, a microphone, a video-camera and a PDA are carried by a person and are components of a mobile network. The PDA acts as a mobile router.
- At first, the person is located at home or at office, with 802.11 Internet access.
- Data sent by IPv6 sensors, voice and video is transmitted permanently and receivers by one or more receivers located anywhere in the Internet.
- The person is leaving the house or office, and takes his bicycle.

The PDA is put on the bicycle. Other sensors on the bicycle are activated and start to transmit the speed and the acceleration through the mobile router (nested mobility). Live voice and video keep transmitting through the PDA.

- The mobile router detects the other access networks, i.e. cellular (l2 trigger, multihoming)
- The cyclist moves around. The GPS provides the location to the PDA, and the rider receives suggestions (which road he should take, places to visit).
- When the cyclist leaves the coverage area of 802.11, the mobile router automatically switches to the other available access network.
- The cellular network is low bandwidth. The flow of the video streaming is automatically adapted to the available bandwidth. The transmission is not interrupted (adaptive applications), voice and data collected by sensors are always transmitted.

Adaptive Applications

As expected in such mobility context — intensively using network mobility and multihoming-network conditions can change frequently in quality and bandwidth.

Therefore we decided to demonstrate the interest of IPv6 mobility technologies by using a multimedia streaming application, since it can adapt itself to any available bandwidth; the problem is that changes in the network state must be quickly detected, to take the best advantage of the bandwidth and to avoid network congestion.

We need an open-source client-server streaming application, developed under Linux, standards-oriented and MPEG4-compliant; our investigation showed that two applications are usable: VideoLan[12] and MPEG4IP[13]. The goal is to prove that applications after only little modification can take advantage of the Mobile IPv6 functionalities.

12 http://www.videolan.org
13 http://mpeg4ip.sf.net

Here, the streaming client will regularly check what MR and what mobile interfaces are presently available in the network; when a change occurs that modifies the available bandwidth, the client will send a Real-Time Streaming Protocol (RTSP) message to the distant server to tell him to adapt the bit-rate of the multimedia stream.

L2TP

An ubique terminal (or mobile router) should use mobile phone network to access to the Internet when cheaper technologies are not available. Unfortunately, mobile phone operators (either in France or in Japan) do not provide native IPv6 access. It is therefore necessary to use a tunneling mechanism to gain IPv6 access. The tunneling mechanism currently in used is IPv6/IPv4 encapsulation, but assumes a static configuration at both sides. ENTSB has developed an automatic tunneling configuration based on L2TP. This mechanism allows us to automatically configure an IPv6 interface (ppp) on the mobile node. This interface is connected to a server (L2TP LNS) in ENSTB IPv6 testbed through the IPv4 Internet. The tool will be ported to the Zaurus PDA.

This mechanism also allows us to pass through the NAT. We are currently evaluating different way to manage the (vertical) handover to and from the GPRS network. The goal is to reduce the latency but also to avoid the extra cost due to the signaling traffic necessary for the tunnel maintenance. We will define metrology tools to evaluate the performance of the network access provided by mobile phone operator. We will work on a header compression and/or a compression mechanism in the L2TP tunnel, to reduce the overhead due to the L2TP tunneling (IPv4/UDP/L2TP encapsulation).

3.2.2 E-Wheelchair

This is a new plan for next year. The objective would be to demonstrate the benefit of network mobility protocols, particularly NEMO, for health-care applications. Various IPv6 devices could be embedded in a wheelchair in a PAN-fashion. We expect to work in collaboration with a team of people working in relation with hospitals and doctors. This seems to be feasible with both Keio University (there already exists an E-Care project in IPv6, which doesn't deal with the necessary mobility protocols) and University Louis Pasteur.

3.3 Stage 3: Operational Testbed: Zaurus

Participants: Tsuyoshi Momose, Keiichi Shima for testbed network, Masafumi Aramoto, Noriaki Takamiya for Zaurus implementation, Koichi Kunitake, Koshiro Mitsuya, Masafumi Watari for applications.

The Nautilus project has began an experimental operation service of layer 3 mobility since December 2003. In the experiment, our project provides mobile nodes to the participants of the experiment and operates home agents for those mobile nodes so that users can use Mobile IPv6. In this section, we describe the objectives and the status of the experiment.

3.3.1 Introduction

The concept of Layer 3 mobility protocols were established long time ago. There were a great effort for researching and developing such technologies. Especially, Mobile IPv6 is the oldest of such technologies and we have almost completed its standardization procedure after a long lasting discussion at the IETF. There are many well tested implementations of Mobile IPv6 already. However it is hard to say that layer 3 mobility technologies are deployed widely. We think that one of the reasons why mobility protocols aren't deployed widely is that most people don't know their usefulness.

The most efficient way to know how a technology is useful is to use the technology in a real environment. In the past few WIDE meetings, some efforts to try to make attendees of the meeting use the mobility technology were made. However such efforts were not so effective as a method to convince the attendees, since there were many restrictions. For example, attendees must install additional software extension modules to their computers, which is not acceptable for some people who are doing serious daily works on their computers. Another reason is that the network services for mobility are terminated when the meeting finishes. The attendees can use such advanced network features only during the meetings. Thus, we have concluded that it is necessary to provide mobility service as a general service to users so that they can use mobility features in their own networks everyday, to accelerate the deployment of mobility service.

In general, the word 'Mobility' doesn't mean only host mobility such as Mobile IPv6. 'Network mobility' is another important technology in the Nautilus project. However, compared to the host mobility technology, it is difficult to show the usefulness of network mobility in user's regular network because network mobility is useful for like vehicles with wireless networks installed on wide area. Of course, there are good applications for network mobility such as PAN (Personal Area Network), however, considering the current technical restrictions, it is hard to operate PAN. Thus, we decided to start our experiment by providing host mobility functions as a first stage.

The objectives of this experiment are

- To demonstrate that Mobile IPv6 is mature
  - Mobile IPv6 implementations work well with current specifications
- To let people who are not familiar with layer 3 mobility know its usefulness
- To encourage application area people to develop mobile aware applications

The goals of the first stage are:

- Provide a stable Mobile IPv6 service to the participants who already have IPv6 connectivity in their office or home, so that many IPv6 users can know that Mobile IPv6 is operatable and useful

- To discover problems in operating layer 3 mobility service
- Provide attractive applications those make use of Mobile IPv6
  - for instance, requiring IP address unchanged permanently

3.3.2 Equipments and Implementation of Mobile IPv6

We use both PC and PDA as a mobile node for this operational experiment. In most cases, PC doesn't have any problems regarding to implementation, however PDA sometimes have serious restrictions. When we select a PDA which we use in this experiment, we consider following conditions.

- The PDA must be able to support Mobile IPv6
- The PDA must be usable for daily use, such as their schedule management or reading/writing mails
- The PDA must be provide easy way for us to add new applications

Regarding these requirements, the selections are very limited because most of PDAs don't have mobile node capability nor allow modification to their network protocol stack. At the final stage of selection, two Linux based PDAs, Zaurus and iPAQ (the original iPAQ is shipped with Windows CE, but we can install Familiar Linux on it) were left.

After some discussions and consideration, we had decided to adopt the Linux Zaurus as a participant's PDA because of following reasons.

- We knew Zaurus would be able to support Mobile IPv6 through the experience at the last Networld + Interop held on June 2003
- We have some experts of Zaurus in Nautilus Project
- Zaurus is shipped with Linux by default. We can replace its kernel with Mobile IPv6 capable one, keeping installed applications unchanged.

However, this decision doesn't mean we avoid other implementations in the future.

Table 3.1 is the list of the set what we delivered to participants.

We installed USAGI Mobile IPv6 implementation, which is derived from HUT works, on each Zaurus. It supports most of mobile node specifications.

On a home agent side and all other mobile nodes, KAME Mobile IPv6 implementation is used.

The members who implemented Mobile IPv6 in USAGI and KAME project had attended interoperability test events several times in 2003. And we confirmed these implementations are almost fully interoperable each other.

3.3.3 Applications

We provided Linphone which is a VoIP application as an attractive Mobile IPv6 application. VoIP application requires stable IP address because it has to keep sessions while talking to another person even if a node has moved to another network and requires an unchanged IP address to call a node on networks unless other registration systems such as a SIP server are available.

Porting Linphone wasn't easy because Linphone required GTK libraries but Zaurus had only embedded Qt for handling its screen. Because of this restriction, Linphone works as a command line based application in a terminal window at this moment.

Table 3.1. The contents of the PDA delivery set

PDA	SHARP Zaurus SLC-760
Memory Card	MELCO 512MB SD Card
Wireless Network Card	MELCO WLI2-CF-S11
misc	SHARP voice recorder kit CE-VK1

3.3.4 Network Configurations

Topology and server placement

Network topology which we are using in this experiment is shown in figure 3.3.

Home agents are located at both Keio University at K2 campus in Japan and Strasbourg in France. Which home agent would be used for a participant dependent on the home position he or she is. The figure shows two home agents and a server are set at the Japan side network, however, the 2nd home agent and the server are not configured yet at this time. Participants use their mobile node on their own IPv6 networks.

IP security configuration

The most difficult thing to set up Mobile IPv6 network is configuring IP security association between mobile nodes and home agents. In our experiment, we used static key configuration method. That is, we prepared all IP security configuration files for all mobile nodes and installed to all mobile nodes by hand. This procedure is too complex and takes too much time. So we must implement a dynamic configuration mechanism as described in [7]. However, [7] only describes an interaction mechanism between Mobile IPv6 and IP security, and it doesn't solve an initial setup for IP security, for instance, how do we share pre-shared keys between two nodes or how to get a certification information of the communicating peer safely. Such a bootstrap mechanism must be researched and developed also.

Access technology

We assume all PDA users have a 802.11 wireless access point at their home or office to connect PDAs to the IPv6 Internet. We didn't provide any other wireless communication method, for instance, PDC cell phone or PHS cell phone. This is a big restriction, because PDA users cannot perform a vertical handover without more than two different access methods. Unfortunately, Japanese data communication networks, like cell phone networks, don't provide IPv6 connectivity at this moment. We must use IPv6 over IPv4 tunneling mechanism to use IPv6 over such telecommunication networks. However, because of restriction of implementation, our Mobile IPv6 stack of Zaurus cannot be used over such a tunnel interface.

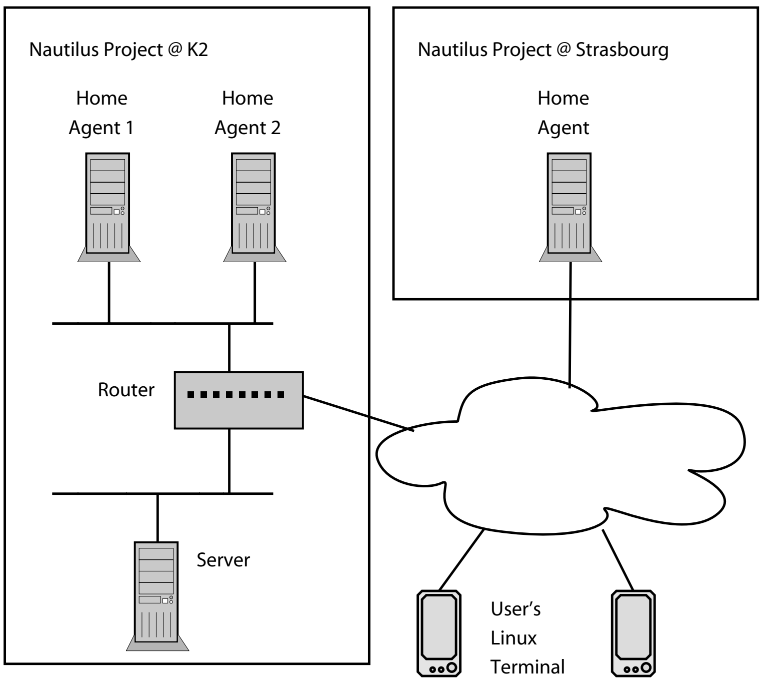

Fig. 3.3. Zaurus testbed network configuration

We are now investigating the way to use IPv6 over tunnel interfaces. It is definitely needed for users to use other access methods than a 802.11 wireless access. With those methods, users, who connect their PDA at their home by 802.11, can move outside keeping their on-going connection by roaming to cell phone networks. A vertical handover will extend the usability of PDA significantly.

Regarding to PC users, there are no restrictions for them. They can handover from a 802.11 network to a cell phone network, which is used as a IPv6 over IPv4 tunnel interface.

3.3.5 Future Work

As described above, the experiment has been just started since December 2003. Therefore we have no meaning results about this yet.

We have a lot of things to enhance mobility environment.

- Implement and operate a dynamic key exchange mechanism
- A bootstrap mechanism for mobility services
- Develop new attractive applications
- A presence management service for VoIP-like applications that notify someone is on line or not
- Introduce network mobility environment

第 4 章 Conclusions and Perspectives

During the course of this year, we have successfully set up the Nautilus6 project which is still at its early infancy since the idea to create a new project with such an objective was born at the end of year 2002 only. Setting up a project means building a team of researchers around common objectives. Sharing the objectives is a difficult task and we went through it successfully during the course of the past year. Now that the objectives are shared and understood, that we were able to issue this activity report, our tasks should be performed at a much higher pace.

Although the project is its infancy, we have been able to push and influence IETF standardization forward for many specifications as this report shows. We also published in various places. The testbeds we have designed are taking shape and our operational experimentation of Mobile IPv6 has effectively started. The operation of the protocol will have to be evaluated based on the collected data.

Important to note, we have also been successful in bringing together researchers from three countries in the world, all of them with different views, working style, and skills.

4.1 International Collaboration

In order to achieve the integration and deployment of IPv6, the simultaneous efforts conducted in countries that favor IPv6 must be brought together. Particularly, Japanese researchers (mainly WIDE) are the IPv6 leaders in the world, while French account for some of the pioneer researchers in IPv6 and as the leaders in Europe. Korea is also one of the countries that have most significantly demonstrated its commitment to IPv6. In addition, the need for more cross-relationships between those countries is generally emphasized by their governments. Complementary efforts conducted in the world in IPv6 can easily be put together based on the already established relationships between WIDE and foreign researchers and organizations. Nautilus6 is spreading its memberships based on existing foreign relationships particularly with French and Korean researchers:

- University Louis Pasteur Strasbourg (ULP), France.
- ENST Bretagne (ENSTB), engineering school in France.
- INRIA, research institute in France.
- INT, engineering school in France.
- France Telecom Research and Development (FT R&D) France.

- Seoul National University (SNU), Korea.
- Samsung, Korea.

A MOU (Memorandum of Understanding) has already been signed with ULP, ENSTB, SNU, and FT R&D; the signature of a similar document is pending with INRIA, INT, France Telecom and Samsung. Besides links with French and Korean institutions, individual Nautilus6 members already maintain cross-relationships with individual from other countries, particularly on IETF activities. Following the signature of the MOU, we were able to exchange students in both directions for a few months:

- Master student from ULP visiting Japan for a 6-months internship, working on multihoming in NEMO.
- PhD student from ULP, visiting us for a few weeks to work on multihoming in nested mobile networks and multihoming activities at the IETF (MIPv6, NEMO).
- Master student from Keio University sent to ENSTB for 2 months, working on automatic interface configuration and interface adaptive handoff (see section 2.3.3).
- PhD student from SNU, visiting us for 4 months, working on multihoming in NEMO.
- Master student from SNU, visiting us for 2 months, working on routing optimization in NEMO.

In the next few months to come, we should also be hosting another student from ENSTB and one from ULP, and send two Japanese students to ULP while the Korean PhD student while be still staying with us.

4.2 Output and Results

All publications of our project during 2003 are listed bellow.

- IETF Documents: [33, 55, 70, 72, 198, 200, 210, 226, 261]
- Master Report: [32]
- Bachelor Report: [190]
- Conference Papers: [68, 71, 75, 197, 222, 227]
- Journal Paper: [73]
- Talks: IPv6 Forum (Korea, July), IPCN conference (Paris, Dec)
- Internal Report: [299]
- Internal Memo: [191]

4.3 Perspectives for Next Year

As the testbed showed, we are in the process to realize effective demonstrations. The operational testbed is particularly important as this is the first-ever such an effort conducted in the world. As the development of the protocols involved goes, we will be able to enrich the operational testbeds and to demonstrate tremendous applications and usages of the mobility technology. The current operational testbed will serve as a base.

Particularly, network mobility features will allow us to bring the technology to new areas where Internet technologies were not yet envisioned, such as bicycles or wheelchairs. While the E-Bike testbed may seem at first sight funny or useless, the E-Wheelchair testbed is likely closer to the real usages expected from the Internet technologies. Once this is demonstrated, it won't take long before we can equip buses, taxis, trains, robots, people which will allow to communicate from everywhere at anytime with anybody in any form, voice and video.

Of course, we will need to evaluate the performance of the protocols and of the overall system if we want to be successful to demonstrate its readiness for deployment. We will also need to bring the knowledge of the technology to the users, i.e. by writing documentation to teach how to use and configure the protocols.

第 5 章 Participants

- Masafumi Aramoto
  - Mobile IPv6 and Operational experiment
- Jean Marie Bonnin
  - Multihoming: Automatic network inter-

faces selection and configurations
  - NEMO: Information mechanism for adaptive applications
  - E-Bike Testbed
- Julien Charbon
  - NEMO, Multihoming
  - In-door testbed
  - Evaluating Multi-homing Support in NEMO Basic Solution[33], "Multihoming in IPv6 Mobile Networks[32]", "Multihoming with NEMO Basic Support[71]", "Multi-Homing Issues in Bi-Directional Tunneling[210]", "Test of multihoming with KAME implementation[299]", "Enhanced Mobile Network Protocol for its Robustness and Policy Based Routing[312]"
- HohSik Cho
  - Extended MobiWan to simulate network mobility in NS-2
  - Simulation about multi-homed and nested network mobility
  - Survey on route optimization schemes in (nested) mobile network
- Jean-Michel Combes
  - Security
- Francis Dupont
  - Security
- Thierry Ernst
  - NEMO, Multihoming
  - E-Bike Testbed
  - "Problem Statement for multihomed Mobile Nodes[200]", "Multiple careof Address Registration on Mobile IPv6[314]", "SAINT 2004: The 2004 International Symposium on Applications and the Internet[197]", "Connecting Automobiles to the Internet[74]", "Network Mobility from the InternetCAR Perspective[73, 75]", "Network Mobility Support Requirements[70]", "Network Mobility Support Terminology citenautilus6-Ernst03d", "Le Support des Réseaux Mobiles dans IPv6[68]", "Multihoming with NEMO Basic Support[71]", "Load Sharing and Session Preservation with Multiple Mobile Routers for Large Scale Network Mobility[227]", "Multihomed Mobile Networks Problem Statements[226]", "Basic Network Mobility Support[315]", "Demonstration System supporting Host and Network Mobility[313]", "Enhanced Mobile Network Protocol for its Robustness and Policy Based Routing[312]"
- Susumu Koshiba
  - Seamless Mobility (FMIPv6)
  - Indoor Testbed
  - "Enhanced Mobile Network Protocol for its Robustness and Policy Based Routing[312]"
- Koichi Kunitake
  - Operational experiment
- Francois Leiber
  - E-Bike Testbed (Adaptive Applications for NEMO)
- Koki Mitani
  - Seamless Mobility
  - Indoor Testbed
  - "Specifications of Wireless Environment Emulator[191]", "Design and Implementation of Fast Handover Support Mechanism using L2 Trigger[190]"
- Koshiro Mitsuya
  - NEMO, Multihoming and Operational experiment
  - Indoor Testbed
  - "Network Mobility from the InternetCAR Perspective[73, 75]", "Test of multihoming with KAME implementation[299]", "The In-vehicle Router System to support Network Mobility[192, 193]", "Basic Network Mobility Support[315]", "Demonstration System supporting Host and Network Mobility[313]"
- Tsuyoshi Momose
  - Mobile IPv6 and Operational experiment
- Nicolas Montavont
  - Multihoming, Mobile IPv6, Nested Mobile

Networks
- "Problem Statement for multihomed Mobile Nodes[200]", "Multihoming in Nested Mobile Networking[197]"

- Masahide Nakamura
  - Mobile IPv6 and Operational experiment
- Thomas Noel
  - Multihoming, Mobile IPv6, Nested Mobile Networks
  - E-Bike Testbed
  - "Problem Statement for multihomed Mobile Nodes[200]", "Multihoming in Nested Mobile Networking"
- Takuma Oiwa
  - NEMO
  - "A Network Mobility Protocol based on LIN6[222]"
- EunKyoung Paik
  - NEMO, Multihoming
  - "Load Sharing and Session Preservation with Multiple Mobile Routers for Large Scale Network Mobility[227]", "Multihomed Mobile Networks Problem Statements[226]"
- Keiichi Shima
  - Mobile IPv6, Security and Operational experiment
  - "Route Optimization Hint Option[261]"
- Noriaki Takamiya
  - Mobile IPv6 and Operational experiment
- Fumio Teraoka
  - Mobility technology, Seamless mobility
  - "A Network Mobility Protocol based on LIN6[222]", "Specifications of Wireless Environment Emulator[191]"
- Laurent Toutain
  - Autoconfiguration, Transition IPv4-IPv6
- Manabu Tsukada
  - NEMO, Multihoming
  - Indoor Testbed
  - "Test of multihoming with KAME implementation[299]"
- Keisuke Uehara
  - Mobility technology, Internet Car
  - "Network Mobility from the Internet-CAR Perspective[73, 75]", "The In-vehicle Router System to support Network Mobility[192, 193]", "Multiple careof Address Registration on Mobile IPv6[314]", "Basic Network Mobility Support[315]", "Demonstration System supporting Host and Network Mobility[313]", "Enhanced Mobile Network Protocol for its Robustness and Policy Based Routing[312]"
- Ryuji Wakikawa
  - Mobile IPv6 and NEMO
  - "Problem Statement for multihomed Mobile Nodes[200]", "NEMO Basic Support Protocol[55]", "Multiple careof Address Registration on Mobile IPv6[314]", "Basic Network Mobility Support[315]", "Demonstration System supporting Host and Network Mobility[313]", "Enhanced Mobile Network Protocol for its Robustness and Policy Based Routing[312]"
- Masafumi Watari
  - Automatic Interface Configuration for Mobile Nodes
  - "Demonstration System supporting Host and Network Mobility[313]"