E-Wheelchair: A Communication System Based on IPv6 and NEMO

Thierry Ernst
Keio University, Jun Murai Lab
5322 Endo, Fujisawa-shi, Kanagawa 252-8520, Japan
ernst@sfc.wide.ad.jp
http://www.nautilus6.org

Abstract. The development of Internet technologies based on the IPv6 protocol will allow real-time monitoring of people with health deficiencies and improve the independence of elderly or disabled people. We have designed a communication system based on IPv6 protocols, and we are presently developing an electronic wheelchair to demonstrate the benefit of IPv6 and mobility technologies for health-care usages.

1 Introduction

With the rapid raise of mobile telecommunication technologies, it becomes easier for the active people to keep in touch with peers even while on the move. Most people often traveling generally have a mobile phone, a laptop computer with Internet access and an email address. So, they can exchange text, voice, pictures and videos in a very easy and fashion way. However, although Internet access at office, at home and in hotels is now common, Internet access in the streets and when commuting is still somewhat lacking. With the advent of mobile technologies in IPv6, and particularly network mobility support and multihoming, the time has come to realize the awaited ubiquitous Internet. In order to achieve the ubiquitous Internet, connection to the network must be available everywhere, at anytime, without disruption of service. Thanks to NEtwork MObility (NEMO) support which allows an entire network, referred to as a *mobile network*, to migrate in the Internet topology, anything will soon be connected to the Internet, particularly PANs (Personal Area Networks, i.e. small networks attached to people and composed of Internet appliances like PDAs, mobile phones, digital cameras, etc.), networks of sensors deployed in vehicles (aircrafts, boats, buses, trains), and access networks deployed in public transportation (taxis, trains, aircrafts, trucks and personal cars) to provide Internet access to devices carried by their passengers (laptop, camera, mobile phone, and even PANs).

We think that such mobile telecommunication technologies could highly help the disabled and elderly people to keep in touch and even to improve their independence. Permanent communication between these people with deficiencies and all their peers including family, doctor, nurse, is indeed very important. However, because of the health deficiencies, they have limited means to keep in touch with the people most likely to take care of them. Fashion devices such as mobile phones and laptops connected to the Internet would be useful for them, but these are usually difficult to either understand or manipulate for people with deficiencies. We are therefore defining a communication system based on IPv6 and adapted to the needs of such people. We think that this communication system will be highly beneficial for health-care usages. For the purpose of demonstrating the communication system, we focus on an electronic wheelchair which would allow disabled persons to be monitored and would at the meantime increase their independence. The communication system is relevant to other usages. This system is being defined within the Nautilus Working Group [2] of the WIDE Project community [15]. This Working Group has been set up to demonstrate and deploy IPv6 mobility technologies.

The present paper is structured as follows: we first briefly describe the Internet and the TCP/IP reference model, then we discuss in section 3 the functional needs of the system. In section 4 we then define a communication system based on IPv6 [3] and NEMO [12, **?**] that meets those functional needs. In section 5, we highlight the validation of the communication system in our indoor testbed and the E-wheelchair demonstration testbed currently under development.

2 Internet and TCP/IP

2.1 The Internet

The *Internet* is a collection of heterogeneous networks hierarchically organized and running under distinct administrative policies. Typically, the Internet is partitioned into different administrative *domains*. A domain shall usually correspond to a large organization operating an internal corporate network or an *Internet Service Provider (ISP)* (e.g. *UUNET*, *MCI*, *Wanadoo*, *AOL*). A domain is simply speaking a *network* made of *nodes* and *links*. The Internet terminology distinguishes two kinds of nodes: a *router* is a node that forwards packets not explicitly addressed to itself, whereas a *host* is any node that is not a router. Nodes connected on the same communication link form a *subnetwork* (typically, an *Ethernet* link, or a *802.11b WLAN*). Subnetworks are interconnected by means of routers. The node that initiates or terminates the transmission of a packet is referred to as the *end-node*, i.e. the source or the destination of the packet.

2.2 The TCP/IP reference model

Internetworking is performed by the *TCP/IP* reference model which defines the protocol suite used for data exchange between nodes in the Internet. TCP/IP is a *packet-switched* technology. Unlike *circuit-switched* technologies like telephone networks, TCP/IP relies on the *connectionless* concept: routers cooperate to determine the path toward the destination and carry packets between the two end-nodes. The forwarding decision called *routing* is made on a per-packet basis. The intelligence is put at the edge of the network (i.e. end-nodes), whereas the purpose of the network infrastructure is only to provide internetworking. This allows an easy deployment of new functionalities without need to upgrade the network infrastructure. As a result from this, the Internet is not specific network-technology-dependent, allowing a global network of unlimited scope and reach. This has largely accounted for its success.

TCP/IP is very similar to the *OSI reference model*, but does not map well into the seven layers as defined by *ISO*. It has fewer layers than its OSI counterpart as the use of intermediate abstraction layers between the *transport layer* and the *application layer* was not perceived. As its name stands for, it is named after its two main protocols, *Transport Control Protocol*

(TCP) [14] and *Internet Protocol (IP)* [3, 13]. IP corresponds to OSI's network layer. Its role is to interconnect all the subnetworks so that any two nodes can communicate with each other. It defines a number of rules, a packet header format, and an addressing scheme which aims at identifying nodes and determining their position in the network hierarchy. It is assisted by a number of other protocols like routing protocols that determine the path a packet has to take between the source and the destination. There presently exists two versions of IP, the getting old IPv4, and the new generation IPv6 [3]. IPv6 is meant to replace IPv4 and to address its shortcomings. IPv6 has built-in features that allow to support the new services requested by recent applications. This includes embedded security and support for mobility, extension headers to specify additional information, native multicast, provisions for traffic reservation, etc. IPv6 also offers a generous number of addresses compared to IPv4. IPv6 addresses are 128-bits large. In theory, this would allow to allocate an address to billions of nodes on every square meter on Earth. In practice, it is much less due to allocation rules but still enough to embed an IPv6 stack in every computer, camera, phone, watch, sensor, etc, ever produced on Earth. For the novice reader, we advice [7, 10].

2.3 Mobility in the Internet

Mobility in the Internet arises when a portion of the network changes its point of attachment to the overall topology. However, the Internet is hardly tuned to allow mobility in the midst of data transfers because protocols have not been conceived for devices that change their point of attachment in the topology. Each device is identified by a unique IPv6 address with a prefix which shows the location of the devices in the Internet topology. There is typically a change of this physical IPv6 address each time a *mobile node* (*MN)* changes its point of attachment and thus its reachability in the Internet topology. Support mechanisms are then necessary to maintain open connections. In some cases, the mobile node may indeed be a *mobile router* with a number of nodes (*MNNs*) attached behind it. This forms what we refer to as a *mobile network*. Only the MR changes its physical point of attachment and thus its address. However, this changes of address has an impact on routing to the entire mobile network. This results in losing packets in transit and breaking transport protocols connections if mobility is not handled by specific services.

3 Functional Needs

In this section, we elaborate the requirements for the communication system from a functional point of view. Basically, the system must allow permanent communication between the patient and the peers, real-time monitoring, and improve the dependence of disabled and elderly people.

- Ubiquity: to ensure the system is reachable at any time, any place, with anyone.
- Permanent Connectivity: to maintain connectivity between the patient and its peers while moving.
- Reliability: to guarantee against loss of access coverage of a particular wireless technology and against failure of equipments
- Scalability: to guarantee an expanding number of equipments and users

- Safety: to ensure a proper operation of the system with no risk for the user and to prevent intruders from breaking or disrupting the data communication flows.
- Privacy/Confidentiality: mechanism to prevent intruders from accessing personal information of individuals
- Multimedia Applications: given his deficiencies in using all his senses, the user needs enhanced means to communicate with peers. The overall system must be able to combine data originated or intended to different kinds of senses: vision (images and video, through digital camera, camera, web camera, displays), voice (through microphone and amplifier), touch (through movement detector, blood pressure) and environmental data (humidity, temperature, air pressure, location).
- Real-Time Monitoring: to perform a permanent health check and to guarantee that proper action would be taken in a timely manner and the most effective way in case of health troubles.
- Ease of Use: users of the system may not have knowledge in the underlying technologies and may have limited physical and intellectual abilities. The usage of the system must be as simple as turning the light on.

4 The Communication System

In this section, we elaborate the networking features required to meet the functional needs.

4.1 IPv6

IP is the de-facto protocol to unify the different technologies. A number of reasons drive us to favor IPv6 over IPv4. First, IPv6 has built-in features that allow to support more effectively the new services requested by new demanding applications. This includes support for mobility, multicast, traffic reservation, security, etc. A second reason is that IPv6 offers a generous number of addresses compared to IPv4. As the number of devices connected to the Internet is grooving to millions, it is necessary to have a sufficiently large number of addresses. Not to say, it is also necessary to ensure that the system under development will be compatible with future devices. Basically, any kind of device, like a mobile phone or a watch will ultimately be connected to the Internet, and this will be IPv6, not IPv4. Lastly, deploying IPv6 devices should make application development costs cheaper since these applications and devices wouldn't only be developed for telematics.

4.2 Network Mobility Support

In order to achieve the ubiquitous Internet, connection to the network must be available everywhere, at anytime, without disruption of service, even when a device moves. A mechanism is required to manage the mobility of the equipment within the Internet topology. Mobile IPv6 [9] is usually sought to manage mobility of a single IPv6 device. The disadvantage of this approach is that all embedded devices must be designed to operate this protocol. The IETF NEMO working group [12, **?**] has thus been set up recently in an effort to address issues related to network mobility, i.e. entire IPv6 networks that change their point of attachment to the Internet topology. Such work allow to set up network of sensors and exchange data between those sensors and remote computers, while on the move, and transparently to the sensors. The protocol to manage the mobility of entire networks, i.e. NEMO Basic Support [4] is surely a better approach than Mobile IPv6 because it allows to bring an unlimited number of usual IPv6 devices behind a mobile router.

The first task of the working group was to define a terminology [**?**] which we use in this paper. A MR has at least two interfaces, the *egress interface* is first attached to the home link, and later to a visited link. The *ingress interface* is attached to an *internal link* in the mobile network. All nodes (MR and *MNNs*) attached to a given internal link have their addresses taken from the same mobile network prefixes advertised on this link. *MNNs* are either *fixed nodes* or *mobile nodes*. Fixed nodes are unable to change their point of attachment while keeping their connections open, whereas mobile nodes have this ability, presumably using Mobile IPv6. If such a mobile node is indeed a MR with a number of nodes behind it, a sub-NEMO is getting attached to a root-NEMO. In this former case, the aggregated network is said to be *nested*.

The working group is working on a solution termed *NEMO Basic Support* [4]. The primary objective is to preserve session continuity between CNs and all MNNs behind the MR while the MR changes its point of attachment. This protocol associates each egress interface of a MR with two distinct addresses, much like what is done in Mobile IPv6. The *home address* (HoA) serves as a permanent location invariant identifier whereas the *care-of address* (CoA) serves as a routing directive to the current point of attachment. The permanent HoA is obtained in the home network and has the same prefix as the home link. The temporary CoA is obtained in the visited network and formed based on the prefix advertised on the visited link. The purpose of the protocol is to establish bi-directional tunnels between the home links and the mobile network for each couple HoA/CoA.

4.3 Multihoming

To ensure safety and reliability, a continuous connectivity to the Internet must be provided, at anytime, any place. For doing so, the mobile network is preferably best connected via several interfaces, several access technologies and to distinct access networks [**?**], which we refer to as *multihomed mobile network*. Distinct interfaces may indeed be active simultaneously. As a result, the system must be able to deal with both *horizontal handovers* (between access points using the same communication medium) and *vertical handovers* (between distinct communication medium). As a wide coverage nor a lack of failure cannot be ensured by a single *Internet Service Provider* (ISP), handovers may need to be performed between distinct administrative domains and thus topologically distant parts of the Internet (*global mobility*). This may occur, for instance, when access is offered by different ISPs. The latter is effective to keep communication costs low from a user's point of view. Having multiple points of attachment is also effective to avoid disruption of service when either a particular technology is not available in the geographic area or when one is experiencing some sort of failure. Besides this, provided simultaneous access are available, data must be sent on the most efficient available media according to the type of flow. A number of issues must still be solved first to multihomed mobile networks. Such issues are presently discussed at the IETF within the NEMO working group [**?**].

4.4 Seamless Mobility and Adaptive Applications

Smooth handoffs from one access point to another are necessary to avoid abrupt degradation of the connectivity. This could be provided by FMIPv6, HMIPv6, CARD and other protocols. On the other hand, vertical handoffs between distinct access technologies will necessary result into changes of network conditions. Applications must thus be able to dynamically adapt to the available bandwidth. For instance, transmitting video over a GSM link is not possible, so the application has to switch to a less bandwidth-consuming mode (e.g. refreshing a picture every ten seconds).

4.5 Security and Other Features

IPSec and AAA are protocols that can provide for the necessary security, authentication, and confidentiality. Auto-configuration mechanisms allow the system to set up by itself without human intervention.

5 The E-Wheelchair Testbed

We are setting up various IPv6 equipments on an electrical wheelchair. The intend is not to develop an effective prototype at the time being, but to demonstrate and validate the underlying IPv6 technologies. We are currently validating our protocol implementations and communication system on our indoor validation testbed and we are purchasing equipment for our outdoor demonstration testbed.

5.1 The E-Wheelchair Communication System

We are relying on NEMO Basic Support (see section 4.2) to manage the mobility of the mobile network and provide permanent monitoring. A permanent connectivity and reliability is ensured from multihoming abilities of the system. We will use several wireless technologies to connect to the Internet. Applications sit on other CPUs in the mobile network; a protocol is being designed to exchange preference settings and network quality between demanding applications and the mobile router. The mobile router connecting the mobile network to the Internet will thus be able to choose the most effective available link, according to the need of the application. Demanding applications will thus be able to adapt their flow according to the network conditions. Security between the mobile router and the home agent is provided by IPSec, while authentication and confidentiality will be ensured by proper AAA and encryption mechanisms.

5.2 The Indoor Validation Testbed

The current testbed allows multiple configurations of mobile networks, including nested and multihomed mobile networks. It is composed of two mobile routers and two home agents, each running NetBSD 1.6.1 and NEMO Basic Support. The mobile router is actually connected to a PC which emulates interface switching. Network conditions are thus changing periodically. This allows to performed our tests automatically, as if the mobile router was switching its egress interface between the mobile router's home network and four foreign networks.

Several IPv6 nodes are located behind the mobile router. This includes an IPv6 sensor, and an IPv6 camera. The IPv6 sensor is a prototype designed by the WIDE for the InternetCAR project [8]. It is queried by SNMP-v2 and provides the temperature and the humidity (values are indeed estimated by a number of measures taken over a short period of time). Power can be provided by a power-over-Ethernet hub. The IPv6 camera is a commercial product, and can be manipulated remotely. One can presently monitor the current temperature and manipulate the camera from the web (see http://www.nautilus6.org/show.html, but access to the IPv6 camera is of course restricted for obvious reasons).

Our implementation of NEMO Basic Support [11] is based on the second version of the NEMO Basic Support specification and is presented as an extension of KAME MIPv6 [1] for NetBSD 1.6.1. It supports MR and HA functionalities and both explicit and implicit modes. The HA supports both modes whereas MR can switch from one mode to the other. The implementation also supports DHAAD and IPSec protection between HA and MR. The MR can have multiple interfaces, each with a specific preference. The NEMO Basic Support implementation works fine on a regular basis as it can be seen by monitoring the temperature and humidity provided by the IPv6 sensor located behind the MR and the emulator. We are currently testing multihoming configurations, following the classification provided in [**?**] and [6]. The results of tests already performed are published in [**?**].

5.3 The Outdoor Demonstration Testbed

For the demonstration, we have investigated several equipments as for the mobile router, including a PDA running linux, a Soekris mother card, and a laptop. After a few tests and purchases, we end up nowhere with the PDA (hardware limitations), while we are faced with battery issues with the Soekris mother card. We have thus finally selected a new tiny laptop from SONY (VAIO type U50/U70), for its convenience of use (compact size, the display can be shut down, and the keyboard can be removed, battery life time), the numerous potential interfaces, and the possibility to use it under linux or BSD. It can thus easily be used as a mobile router. The heartbeat sensor remains to be designed, whereas the other are already available.

The mobile router will be connected to the Internet via WLAN 802.11 series (native IPv6), cellular phone (using PPP) and AirH (using L2TP because this technology doesn't yet support IPv6). Others communication medium such like a satellite (possibly one-way only, using UDLR) could be envisioned.

We are investigating the purchase of an electric wheelchair. The electrical power of the wheelchair will in essence give power to some of the various IPv6 equipments, though most of them could actually rely on their own batteries, as far the demonstration of the sole communication technologies is concerned. The wheelchair will be equipped with various IPv6 sensors: an IPv6 GPS sensor to determine the location of the wheelchair, an IPv6 sensor to monitor the health of the person (heart-beat sensor) and an IPv6 environmental sensor (temperature and humidity sensor). An IPv6 camera, with remote movement control facilities restricted to a limited number of peers will transmit video of the surrounding scene or of the disabled person. The flow of video will depend on the available wireless technology and may be limited to a single picture refreshed from time to time.

6 Related Projects

The E-Care Town Project [5] aims at creating a town in which people of all ages: young and old, healthy and disabled, can feel comfortable, safe and enjoy living in. Six types of monitoring programs have been defined (e-Health Up Program, e-Family Care Program, e-Nursing Care Program, e-Professional Skill Up Course Program, e-Resident Health Course Program and e-Care Information Security Program). IPv6 equipments and data communication methods are being used, but the project currently doesn't consider IPv6 mobility support mechanisms such as Mobile IP, NEMO, FMIP, etc.

7 Conclusion

The purpose of this paper is to demonstrate how cutting-edge Internet technologies based on IPv6 and network mobility will allow to improve mobility and independence of people with health deficiencies. We have defined the necessary communication system, based on IPv6 and NEMO and we are actively involved at the IETF in the specification of the required protocols. E-Wheelchair is only one of the potential usages of the proposed system. Our E-Wheelchair demonstration testbed is under development while IPv6 implementations are being validated. More in-depth performance evaluation of the system will be performed once the complete system is fully set-up.

Acknowledgments

We are thankful to the members of the Nautilus6 team for all the fruitful discussion that led to set up this demonstration testbed and to the members of the InternetCAR team for providing equipments and advices. As for the current realization of the experiment, we are particularly indebted to Koshiro Mitsuya (testbed set up, NEMO implementation), Romain Kuntz (tests of the equipment), and Francois Leiber (applications).

References

[1] The IPv6 KAME Project, As of 2004. http://www.kame.net.

[2] WIDE Nautilus6 Working Group Web Page, As of September 2004. http://www.nautilus6.org.

[3] S. Deering and R. Hinden. Internet Protocol Version 6 (IPv6) Specification. Request For Comments 2460, December 1998.

[4] Vijay Devarapalli, Ryuji Wakikawa, Alexandru Petrescu, and Pascal Thubert. NEMO Basic Support Protocol. Internet Draft draft-ietf-nemo-basic-support-03.txt, IETF, June 2004. Work in progress.

[5] E-Care. e-Care Town Fujisawa Project Consortium, As of 2004. http://www.e-care-project.jp/english/index.html.

[6] Thierry Ernst and Julien Charbon. Multihoming with NEMO Basic Support. In *First International Conference on Mobile Computing and Ubiquitous Computing (ICMU)*, Yokosuka, Japan, January 2004.

[7] Christian Huitema. *IPv6 The New Internet Protocol*. Prentice Hall, 2nd edition, 1998.

[8] InternetCAR. WIDE InternetCAR Working Group Web Page, May 2002. http://www.sfc.wide.ad.jp/InternetCAR.

[9] David B. Johnson, C. Perkins, and Jari Arkko. Mobility Support in IPv6. Request For Comments 3775, IETF, June 2004.

[10] David C. Lee, Daniel L. Lough, Scott F. Midkiff, Nathaniel J. Davis, and Phillip E. Benchoff. The Next Generation of the Internet: Aspects of the Internet Protocol Version 6. *IEEE Network*, January 1998. Virginia Polytechnic and State University.

[11] Koshiro Mitsuya. Nautilus6 NEMO Basic Support Implementation. Technical Report ir-nemo-bs-20040712-MitsuyaK.pdf, WIDE at Keio University, April 2004. http://www.nautilus6.org/doc/ir-nemo-bs-20040712-MitsuyaK.pdf.

[12] NEMO, As of September 2004. http://www.ietf.org/html.charters/nemo-charter.html.

[13] Postel. Internet Protocol DARPA Internet Program Protocol Specification. Request For Comments 791, IETF, September 1981.

[14] Postel. Transmission Control Protocol DARPA Internet Program Protocol Specification. Request For Comments 793, IETF, September 1981.

[15] WIDE. WIDE Project: Widely Integrated Distributed Environment, June 2002. http://www.wide.ad.jp.