A High-Availability Network for Reducing Network Operation Burden and Supporting Human Mobility

Hiroaki HARAI

In this paper, we address our R&D towards a high convenience and reliable networking. From a user's point of view, this network provides heterogeneous, secure communication and low-delay and stable throughput communication. From an operator's point of view, it provides high-speed, reliable, and easy operation management. We address ID/Locator Split Network HIMALIS and Hierarchical and Automatic Number Allocation HANA, and introduce outcome through these researches.

1 Introduction

The present networks have the following problems: (1) the growth of circuit-scale, and processing complexity for prompt destination address search, and route-convergence time, caused by bloated routing tables; (2) the increase of administration cost due to simultaneous management of more than one network layer; (3) the degradation of availability caused by human error during manual operations in address configuration and name resolution; and (4) the increase of delays in mobile communications and inaccessibility between heterogeneous network protocols. For example, in (1), the number of forwarding table entries at the Internet backbone routers reached 500,000 in 2014. The architecture of TCAM (Ternary Content Addressable Memory) for destination address lookup consumes energy proportional to the number of entries in the forwarding table. The increase in the circuit footprint leads to increase in the power consumption. For (2), different networks such as large-scale IP (Internet Protocol), Ethernet, MPLS (Multi-Protocol Label Switching), optical networks, and OpenFlow at the data centers are integrated in operation and management. (3) Approximately 2% of accidents for telecommunication services reported to the Ministry of Internal Affairs and Communication of Japan comes from human errors[1]. (4) Mobility causes increase in the end-to-end delay and a single point of failure because even if a host moves to different network, data is passed by the home agent or the local mobility anchor in Mobile IP and Proxy Mobile IP.

In this paper, we introduce our R&D that solves the above-problems and aims the realization of following features.

- User advantage: This network provides a high convenience and reliable communication environment, namely, heterogeneous, secure communication and low-delay and stable throughput communication based on state-aware automatic route selection.
- Operator advantage: This network provides high-speed, reliable, and easy operation management.

More concretely, our target is effective communication on multiple routes, heterogeneous (i.e., different network protocol) communication support, and management simplicity and automation on a multi-homed network where multiple routes are provided in the two nodes (Fig. 1). We also look at not only usual communication failure such as overload caused by concentrating communication data and equipment failure but also failure recovery from the disasters. Our proposal is to facilitate host mobility, heterogeneous communication, and secure communication by using a new layered architecture HIMALIS (Heterogeneity Inclusion and Mobility Adaptation through Locator Identifier Separation) where information identifier (ID) and location identifier (locator) are separated. Moreover, we provide a reliable, low-cost management network by using HANA (Hierarchical and Automatic Number Allocation) where locator assignment and name server registration are done automatically.

Our basic idea behind in our R&D is to make network structure and management simple and smart. The simplicity and smartness cause improvement of reusability and extendibility of networks. In other words, our developed methods are easily embedded in a new network R&D by other researches and are then widely deployed. We are sure

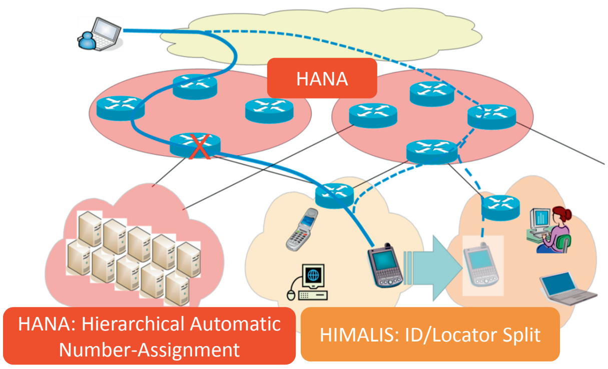

Fig. 1 Network overview for high-convenience, secure, reliable and operation efficient network on a multi-homed network structure

to make designs of HIMALIS and HANA software simple such that application developers and network developers are easily used. Also, we enhance software stability through large-scale verification on the large-scale emulation platform StarBED[3] and wide-area deployment on the new-generation network testbed JGN-X.

2 ID/locator separation and automatic locator assignment

This section addresses ID/locator separation architecture HIMALIS and hierarchical automatic number allocation HANA. These are centered in our R&D. HIMALIS is a user oriented technology for facilitating mobility of hosts and increasing the number of communication objects. HANA is a network operator oriented technology for facilitating network equipment operation and decreasing convergence time of routing information of hosts. The network equipment in HIMALIS and HANA are maintained by registries where name or ID is mapped into locator. Additionally, we have the following features.

- Hierarchical locator structure and ID/locator separation contribute to decrease the routing table size and accelerate routing convergence even if the number of operators and hosts is increased.
- It makes a burden of network operator reduce to automate locator assignment and allocation and locator registration to the name registry and to authenticate access to the network and the registries.

2.1 HIMALIS

HIMALIS is a communication network architecture such that a host in a network can securely move to other network of which protocol and area are different[2]–[4]. Figure 2 shows overview of HIMALIS network. A HIMALIS network consists of a global transit network and multiple edge networks. HIMALIS features in terms of hosts are described as follows.

- Communication is seamlessly continued when a host in an edge network moves to a different edge network.
- The shortest route communication is provided after a host moves to a different edge network (Fig. 3).
- Communication is not interrupted once a host moves to a different edge network when an originally connected edge network fails (Fig. 3).
- A heterogeneous communication is provided between nodes each of which has different network-layer protocol each other.
- Communication is seamlessly continued even when a host in an edge network moves to other edge network of which network protocol is different.
- Multiple connections to two or more different upstream networks, in other words, multi-homing is supported.
- Host authentication function is supported.

More details are explained by using Fig. 2. Each edge network adopts arbitral network protocol such as IPv4 and IPv6. The edge network is connected to the global transit network by using HIMALIS Gateway (HGW) that has a protocol conversion capability. The global transit network uses a common network protocol. Each host is uniquely identified by using globally-unique node identifier (ID). Each HGW includes an authentication agent for a host authentication and local name server for name resolution. The agent and the server are likely to be installed in the edge networks. The transit network has a Domain Name Registry (DNR) and a Host Name Registry (HNR) which are accessible globally. These name registries form hierarchical name resolution architecture like Domain Name System (DNS).

HIMALIS provides each host with a globally unique hostname. The information of the host can be resolved by using name resolution servers. The global hostname is represented by concatenating a locally-unique local hostname and domain name using the concatenation symbol the '#' (e.g., host01#nict.go.jp). When a host connects to an edge network, it is given a local locator (LLoc) and the information for communicating with HGW. Once the access authentication is succeeded, the global locator of HGW (GLoc) is notified to the host. The host can be resolved from outside of the edge network after ID and GLoc of

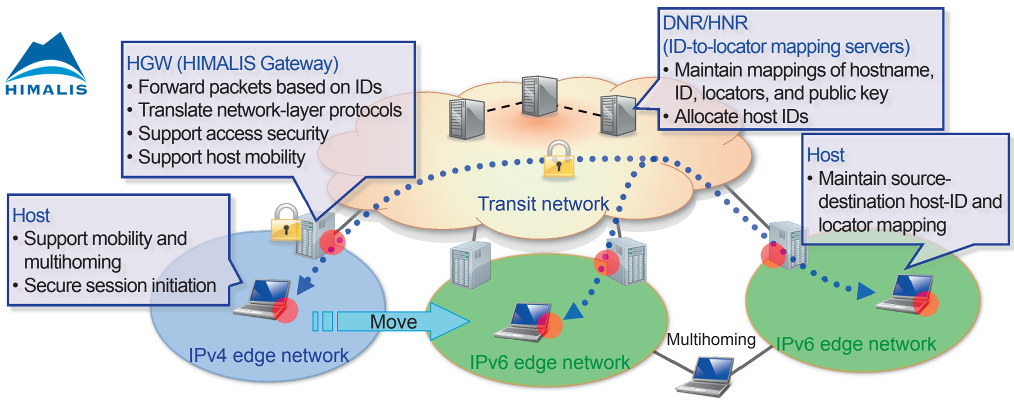

Fig. 2 HIMALIS overview and functions

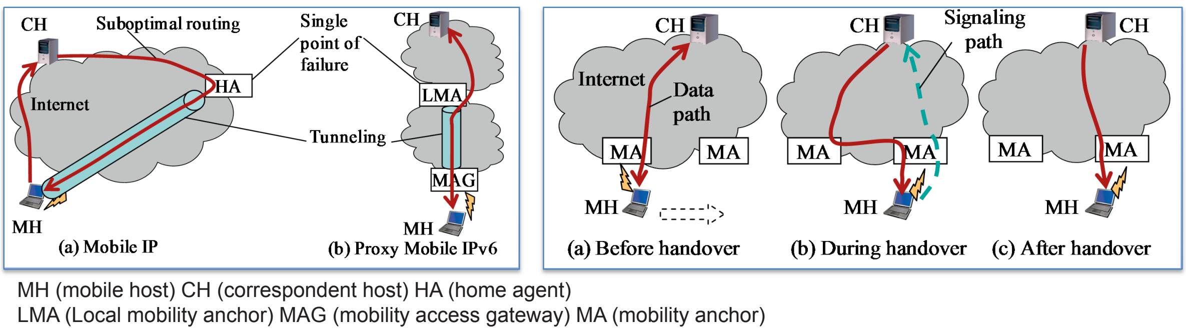

Fig. 3 (Left) Delay increase and single point of failure in the existing mobile communication. (Right) Minimum delay and no single point of failure in the ID/locator split architecture.

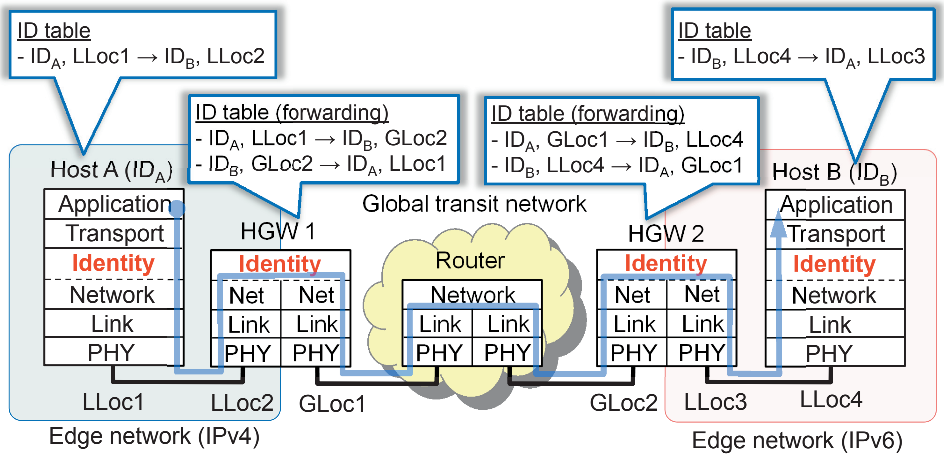

Fig. 4 Communication using the identity layer in HIMALIS

the host are registered to the HNR that maintains the corresponding edge network. When the host communicates with a correspondent host, the host resolves ID and GLoc of the correspondent host by inquiring the global hostname of the correspondent host at HGW. If the HGW cannot resolve the inquiry, the HGW inquires it to DNR and HNR. In more detail, the HGW inquires domain name of the correspondent host to DNR and resolves ID and GLoc of the HNR that maintains ID and GLoc of the correspondent host. The HGW then inquires local hostname to the HNR and finally resolves ID and GLoc of the correspondent host.

HIMALIS has the identity layer between the transport layer and the network layer. Communication procedure using the identity layer is described with an example depicted in Fig. 4. When host A communicates with host B, host A obtains ID (ID_B) and the global locator (GLoc2) according

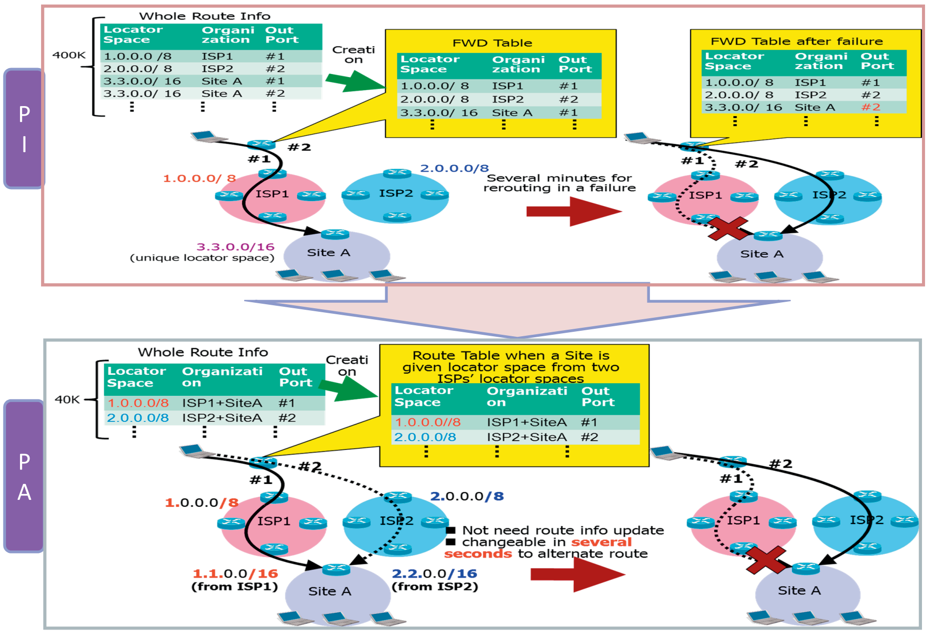

Fig. 5 Advantage of hierarchical multiple locator assignment

to the name resolution procedure. Host A then sends a session initiation request signaling to host B. Host B resolves host A's authentication by using name resolution system and then responds to host A. In the HIMALIS network, for a communication in the transport layer or upper layer, the information of the correspondent hosts has to be registered in the ID tables in the hosts and HGWs. The registration to the ID tables is done only in the case of success of communication initiation procedure for enhancing security in the communication initiation. Thus, HIMALIS uses ID tables in HGWs for communication control between the transit network and edge networks, packet transfer to other HGWs, and mobility. ID tables maintains information of working sessions only. The locator update information resulting from host mobility is notified to HNR and HGW. Thus communication to different hosts is also provided after moving of the hosts.

2.2 HANA

HANA assigns and configures locators to all network equipment such as routers and switches in a network[5][6]. HANA hierarchically and automatically assigns locators to a multi-hierarchical network. Multi-homed networks are given multiple locators to the routers in the network. HANA has the following features. Figure 5 illustrates advantage of assigning multiple locators to a single node hierarchically.

- Automatic number assignment reduces address configuration time and reliefs the network administrator from human-error in configuration. In a network consisting of 1,000 hosts, HANA reduces address-allocation burden down to 1/100 (Fig. 6)[7].

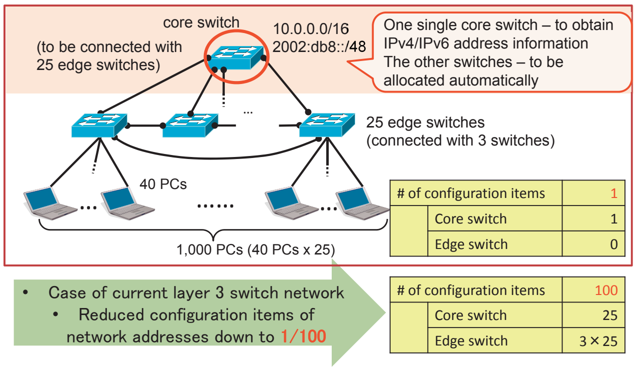

Fig. 6 Efficiency of HANA's automatic locator assignment

- Multi-locator assignment provides redundant routes natively. This makes network reliable and tolerable to failure and congestion of the network.
- Hierarchical locator assignment leads to routing table aggregation. Concretely, if HANA applies to the Internet backbone, the FIB (Forwarding Information Base) size, which is more than 500,000 at the time of 2015, is decreased to several tens of thousands[8]. This is attractive although the required locator space, in other words, the number of required locators, is increased ten times because a node is given multiple locators.

Routers, switches, and hosts are assigned locators from a HANA server. When a network equipment joins the network, it seeks neighbor nodes by using link-local multicast and establishes peer. In the peer network, messages needed to locator assignment are exchanged by using unique names (e.g., string of MAC address and FQDN (Fully Qualified Domain Name)) as identifiers.

HANA servers are likely to be installed hierarchically. The developed set of the HANA servers provides a hierarchical locator assignment. In HANA, a locator is divided into three portions called prefix, midfix, and suffix. A locator of host is determined by concatenating the 3 values. The value of each portion is assigned independently as shown below.

Prefix portion is periodically advertised from network upstream to downstream via PrefixInfo messages and distributed to all equipment in the downstream networks. In the case of Fig. 7, where prefix values are assigned from multiple upstream networks, each host of the network is given multiple prefixes. This means the host has multiple routes natively. Midfix portion is allocated a unique one form the HANA server in the network. Suffix portion is decided by equipment own.

In the example of Fig. 7, a PrefixInfo message including prefix 1.1/16 from upstream ISP1 and that including prefix 2.2/16 from upstream ISP2 are distributed to ISP3. On the other hand, in ISP3, a HANA server periodically advertises MidfixOffer messages. The nodes receiving the MidfixOffer send midfix-value-request (MidfixReq) messages. When the HANA servers receives the MidfixReq massage, it allocates a unique midfix value (among midfix space, i.e., front 17th bit to 24th bit) by using MidfixAck messages. Self-assigned suffix value (i.e., front 25th bit to 32th bit) is sent to HANA servers via MidfixReq messages. In doing so, the HANA servers maintain the latest FQDN and locator mapping of all hosts of which midfix are assigned by the HANA servers. By interworking DNS to the automatic update function of FQDN-locator mapping provided by HANA, DNS records can be updated automatically.

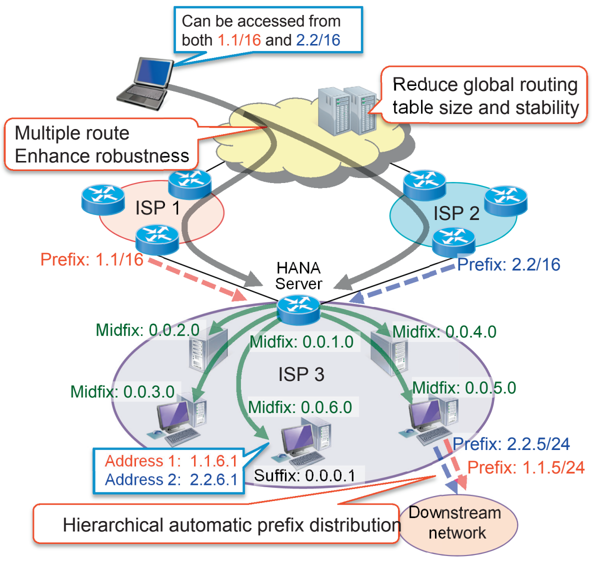

Fig. 7 Overview of automatic locator assignment and multiple route provisioning

3 Outcome

- We developed basic software of HIMALIS[4][9]-[11]. We have implemented the identity layer by extending TCP/IP kernel (see Fig. 8). In spite of overhead caused by identity-layer insertion, we have verified that transmission throughput performance at hosts and latency-performance at the HIMALIS gateway are almost the same as those of existing TCP/IP based communication on a GbE-ink network (see Fig. 9). We developed middleware for communicating existing TCP/IP applications on HIMALIS environment[12].
- Security support. We designed and implemented an integrated security mechanism in HIMALIS, where

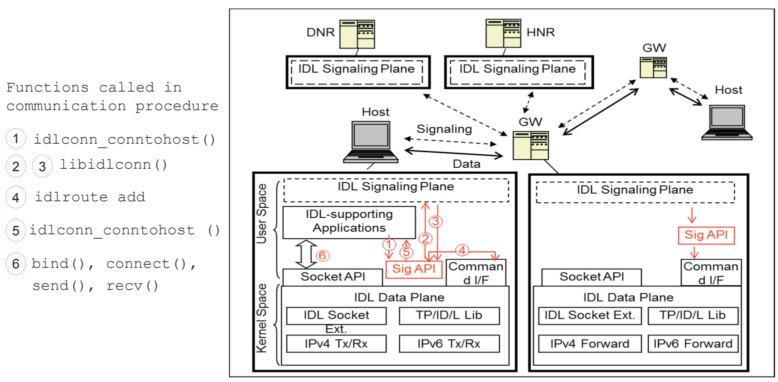

Fig. 8 Overview of software architecture

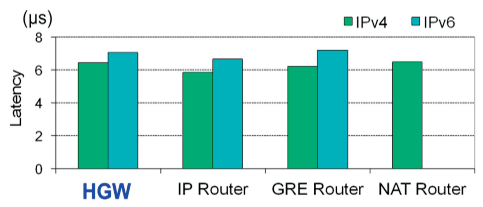

Fig. 9 Forwarding performance at intermediate nodes

mapping between host ID and locator is securely registered in host name registry and host is authenticated at the time of network access[4]. In order to have reliability of the communication in reality, we implemented software for securely registering and deleting information of hosts and securely obtaining information of corresponding hosts via hierarchical trusted authentication mechanism. Here, HNR is the trusted anchor point of the hierarchical trusted authentication for secure registration, communication, and mobility of hosts. The proposed integrated security method enables secure communication in the network where the hosts frequently change their access networks.

- Seamless handover and resiliency. In heterogeneous communications between hosts each of which uses different network protocol each other, we demonstrated periodical changes of networks to which hosts connect. On condition that a host can connect multiple networks simultaneously, we verified the host successfully changes network for access in 4 seconds without data loss (see Figs. 10 and 11)[10].
- Packaging HIMALIS software modules[13]. Our HIMALIS software is configured as a package for dissemination. The package can be installed easily via GUI operation without solid knowledge of the protocol. The HIMALIS gateway in the installed HIMALIS edge network is connected to the Internet. For dissemination, we have installed and operated a set of registries like HNR and DNR in NICT. Thus the researchers outside NICT can use a HIMALIS testbed via Internet by installing the package to their networks (Fig. 12)[14].
- We developed a mobile wireless sensor network where ID-based communication of HIMALIS is used for secure and seamless mobile communication. The sensors in the network are capable of 6LowPAN that has a feature of low-communication overhead. The network has high convenience and operability in the following points. At first, data generated at sensors

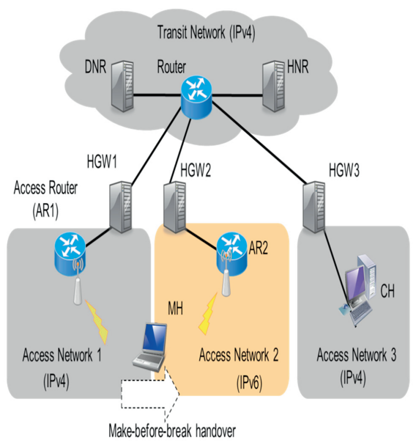

Fig. 10 An experimental network

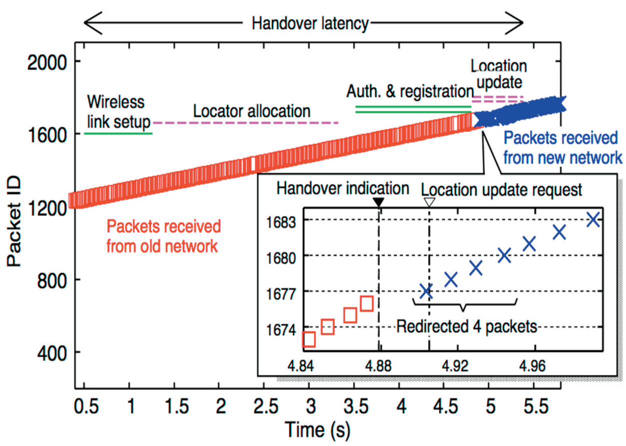

Fig. 11 Host mobility in 4 seconds with no data loss

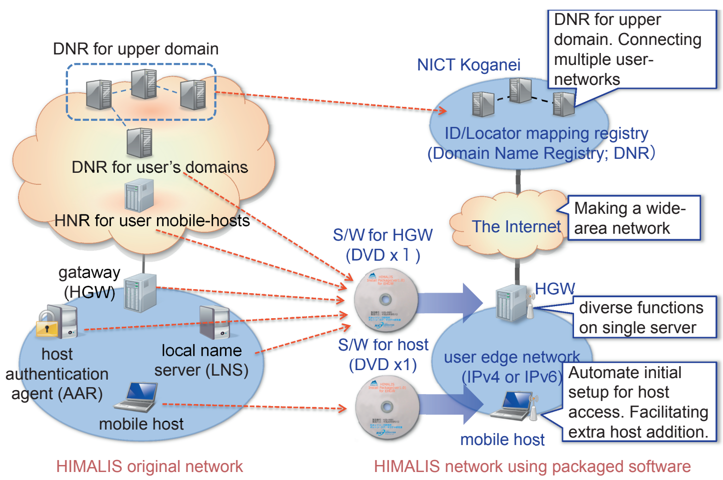

Fig. 12 HIMALIS testbed and use cases

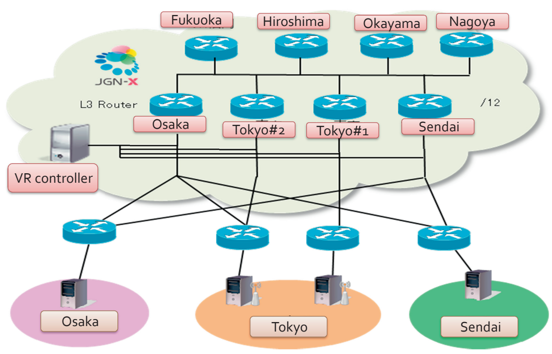

Fig. 13 A multi-homed HANA network built on JGN-X

can be sent to a sensor-data storage server (i.e., a sink server) that can communicate via IPv4 and IPv6 communication. Sensors can move to different 6LowPAN networks from the home network. A remote server in IP networks can configure parameters of sensors[15]–[17]. See **7-6** of this special issue in more detail.

- We proposed Hierarchical Automatic Number Assignment HANA for multi-homed networks that have different access lines to the different provider networks. Using JGN-X, we built a network that provides multiple routes to an end-to-end communication for proper hierarchical address assignment. A pair of two end nodes using a route can communicate in a different route even if a part of communication channels and node equipment fails (Fig. 13)[18]. We also developed a link-state routing protocol HQLIP that is capable of 100 times faster route convergence compared to OSPF in an ideal condition by cooperation of HANA[19]. We developed a network visualization system[20]. By installing the system, we facilitated fault detections that are necessity feature for communication service. The HANA-based network built on JGN-X can allocate address spaces to the access networks where HIMALIS and a wireless mesh network with information sharing system NerveNet[21]–[23].
- We verified large-scale automatic address allocation by building a 10,000-node network (i.e., one-fourth size of the Internet) and applying HANA on large-scale emulation environment StarBED^3 [5]. Figure 14 shows an example of visualization result of address allocation. Figure 15 shows a measured value of control overhead traffic by HANA. We observe that 25 Mbps control message flows among 10,000 networks. This is equivalent to several kbps for each network. Thus we conclude that HANA does not have negative impact the network. Till now, we have succeeded hierarchical and automatic address allocation to a 46,000-node network, namely, we have done the Internet-scale verification.
- We developed a HANA-capable 48 × 10Gbps layer 3 switch. This is a rack-mountable size and the height is 1U (Fig. 16)[7][24]. This switch leads the number of address configurations down to 1/100 for a 1,000 server-scale network. These L3 switches are being installed in the NICT enterprise network and an experimental network. Through the daily operation verification, we are modifying software for solving functional errors and stabilize control and management system of the HANA network.
- We combined HANA into SDN. We developed a unified IP address allocation for LAN switches and terminals for an enterprise network management. The developed system includes auto-generation function of maintenance management table for network administrator[25]. This enterprise network reliefs network administrators from human-error, reduces operational times steeply, and enables existing

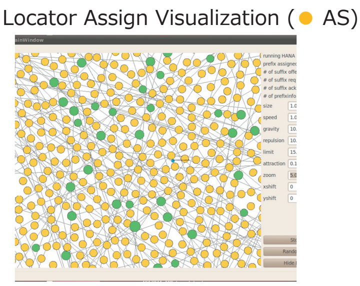

Fig. 14 Visualization of 10,000-AS verification

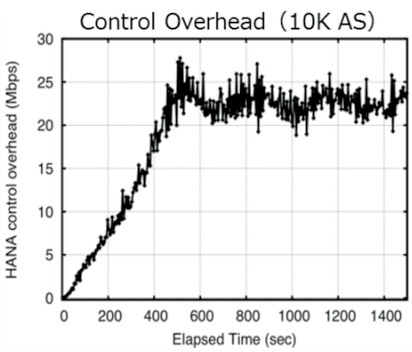

Fig. 15 Control overhead in HANA (25 Mbps control packets flows in 10,000 ASes)

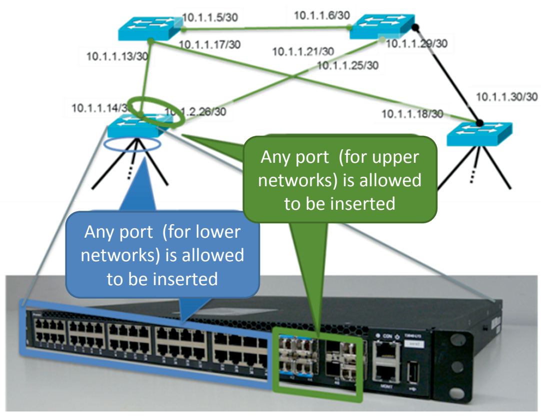

Fig. 16 Developed HANA-capable layer 3 switch and an example of address assignment

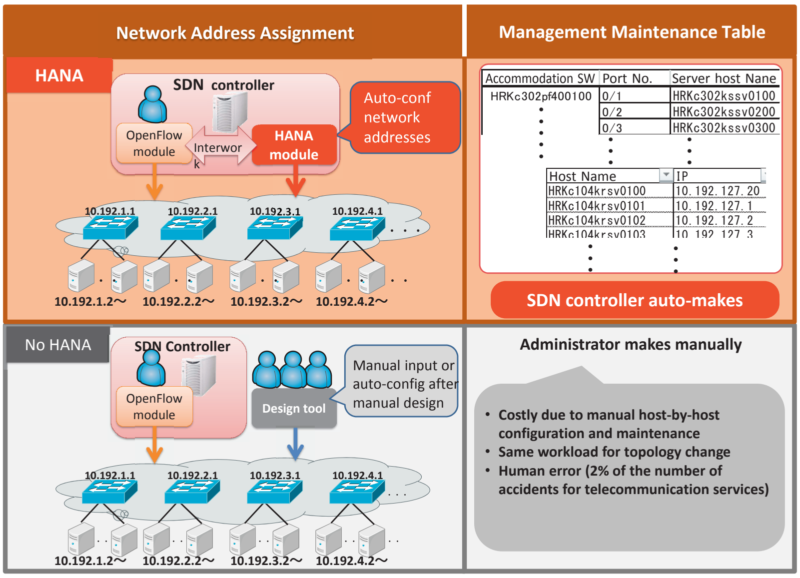

Fig. 17 An enterprise network where HANA and SDN are interworked

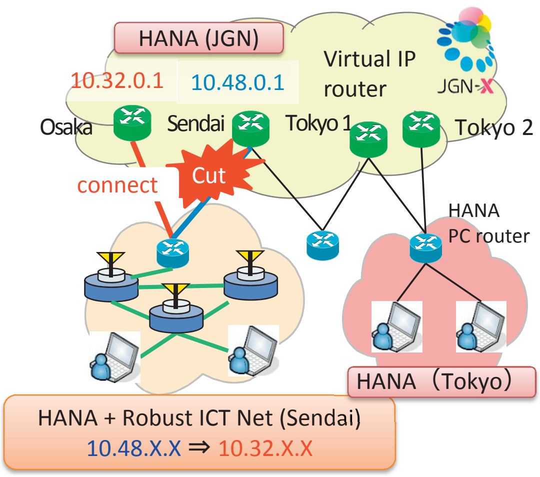

Fig. 18 Experiment of automatic network construction in the disaster by using the resilient ICT testbed and JGN-X

maintenance management (Fig. 17).

- We designed a secure DNS record caching method that is typically powerful in address renumbering of DNS/DNR (Domain Name System/Domain Name Registry) and implemented it in a DNS server[26]. This makes network design flexible, reduces the amount of management traffic for DNS by 20%, and reduces management traffic to the top domains of the Internet (e.g., .com and .jp). Namely, our developed system contributes to stability of the Internet and 20% reduction of equipment cost.
- We designed the ASAP (Address Space Allocation Planning) tool for requesting additional address spaces to the multiple upstream networks. The address spaces are arranged between ASAP processes in the different networks when the downstream network wants to accommodate hosts more than the affordable number of hosts, which number is limited by the given address space[27]. A network can request additional address space on demand, not at the design phase of the network. Thus, ASAP enhances the flexibility of the network design.
- We applied HANA for a simple recovery from failures by using its automatic address allocation to the network equipment even if the network administrator is absent in the large-scale disaster. Combining HANA and a link-state routing distributes a new set of IP addresses and recovers communication once a physical network is recovered after node failures or disconnections of links between backbone network and damaged area. Experimentation on Robust ICT Testbed of NICT shows that it takes about 60 seconds in this testbed scale (Fig. 18).

4 Conclusion

We have addressed our R&D towards a high convenience and reliable networking. The HIMALIS, a new layered structure where identifiers and locators of nodes are separated makes mobility and heterogeneous communication flexible and secure. By expanding communication range and providing secure communication, end users obtain sufficient convenience and reliability. The HANA, an automatic configuration of locators of nodes and an automatic registration to the name server makes network administration and management reliable and easy.

We have designed and implemented them as a form of the software and verified function, performance, and scalability by using JGN-X and StarBED. Currently, we are trying practical use of the software and collaborating application developers who have interest to our software. We pursue dissemination of enabling technologies and applied technology of the HIMALIS and HANA.

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Hiroaki HARAI, Ph.D.

Director of Network Architecture Laboratory, Photonic Network Research Institute/ Research Manager, New Generation Network Laboratory, Network Research Headquarters

Network Architecture, Optical Network