R&D and Societal Activities at the NICT Resilient ICT Research Center

— *Focusing on wireless infrastructure technologies* —

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1. Introduction

Information and Communications Technology (ICT) is the foundation of daily activity in society. If we think of the electricity grid and distribution networks playing the same role as blood in the human body, ICT plays the role of the nervous system and brain. With the arrival of the age of the Internet of Things (IoT) and cyber-physical systems, this role will expand and increase in importance.

However, with the Great East Japan Earthquake in 2011, there was extensive damage to communication networks, causing life-threatening delays in obtaining information regarding the damage, as well as causing major difficulty conveying information such as the well-being of survivors and obtaining daily necessities. Learning from this experience, research and development to improve resilience of data communication networks was started, with a third revision to the 2011 MIC budget. Then, in April, 2012, the National Institute of Information and Communications Technology (NICT), Resilient ICT Research Center was established in Sendai City. It was organized for collaboration among industry, academia and government, to promote initiatives in resilient ICT R&D and their implementation in society. In 2014, a building for the center was completed on the Katahira Campus of Tohoku University. Tohoku University has the Research Institute of Electrical Communication, which was established in 1935, the Graduate School of Engineering and the Graduate School of Information Sciences, so there is much active research related to ICT. After the earthquake, it also established the Research Organization of Electrical Communication, gathering faculty with a desire for resilient ICT research.

Initiatives at the Resilient ICT Research Center promote fundamental and applied research on resilient ICT and its implementation in society, to maximize the contribution of the results of such R&D to society. The Planning and Collaboration Promotion Office collaborates with laboratories within and outside of the Center, promotes collaboration with external research organizations, including those in Tohoku University, and works to establish a network among industry, academia and government. It also promotes demonstration and use during real disasters, of resilient ICT research results arising through related collaboration among industry, academia and government, including disaster preparedness exercises, and implementation of research results in society through symposia and exhibitions.

This article gives an overview of recent R&D results, focusing on resilient ICT infrastructure technologies, and demonstrations and other initiatives to implement them in society.

2. Resilient ICT research at the Resilient ICT Research Center

The Center has two laboratories in which it conducts resilient ICT R&D: The Infrastructure Laboratory has the Optical Networks project, and the Applications Laboratory has the Wireless Communication Applications project and the Real-Time Social Knowledge Analysis project.

2.1 Infrastructure Laboratory

Optical networks use low-loss optical fiber to realize long-distance, high-capacity communication, so they are used for wide-area core networks. Before, during and after large-scale disasters, optical networks should be able to switch smoothly among redundant optical network resources to mitigate major congestion, and to quickly establish emergency optical networks to satisfy various communication requirements in disaster areas. We are conducting R&D on the technologies for an elastic optical switching platform and emergency recovery of optical networks.

When a large-scale disaster occurs, due to the increased communication requirements into and out of the affected regions, congestion will happen in wide-area networks. The goal of elastic optical switching technology is to establish fundamental technologies enabling dynamic reconfiguration, in the spectral domain and the time domain, to avoid congestion when a disaster occurs, making the optical network infrastructure more resilient. We have optimized the processing in an optical power equalization system for acousto-optic devices, making it possible to maintain transmission quality with stable response times when the power changes due to optical switching. To realize interconnection with heterogeneous traffic, we have also worked on the data plane of integrated optical networks: we have conducted R&D on interconnection between integrated optical networks and different transport networks such as MPLS, Ether, OpenFlow, and IP. For the control/management plane, we have focused R&D on orchestration technology for interconnection. These technologies enable services delivering traffic crossing over the integrated optical networks and different transport networks during normal times. In addition, during disasters and emergencies, the integrated optical networks (as the core networks) can be employed to relay different types of traffic for the disconnected MPLS, Ether, OpenFlow and IP networks, resulting in quick restoration of communications.

In R&D on emergency recovery of optical networks, we are developing a self-healing control-system technology using multi-function recovery support tools to facilitate rapid emergency recovery of optical networks near a disaster area when optical fiber communications is interrupted. We are also collaborating with enterprise to develop technology for creating and utilizing a temporary shared packet transport network between carriers, implementing automated control without leaking confidential carrier information. Based on this research, we are conducting R&D on carrier-collaboration platform technology that will enable carriers to cooperate during disaster, sharing surviving communication-facility resources with each other. We implement third-party mediation that incentivizes collaboration between carriers (mutual provision of optical path support, balancing of repair tasks), promoting R&D and collaboration that will advance disaster recovery. During a disaster, this platform will make it possible to set a concrete collaboration plan between carriers, including sharing of optical path resources and allocating repair tasks among each other by matching supply and demand for resources.

Since FY2018, we have also been conducting R&D on disaster-resiliency strategies for next-generation metro optical networks under the Joint Japan-US Network Opportunity 2 (JUNO2) project. In this research, we are conducting R&D on a robust telemetry technology that can quickly rebuild lost optical network functions of monitoring and telemetry during disaster, using a temporary control and management planes established with various access methods, such as private mesh networks, 4G, satellite and the Internet. We are conducting trials of telemetry functions that gather monitoring data using open APIs and protocols, and verifying that network management systems can be notified and quickly gain a global view of network conditions, even with limited and unstable bandwidth, prioritizing important information appropriately.

2.2 Applications Laboratory

This laboratory promotes the Wireless Communication Applications Project, which conducts R&D on network utilization technology to guarantee information-flow requirements in environments where network resources are limited, and the Real-time Social Knowledge Analysis Project, which conducts R&D on technology to obtain necessary disaster information by analyzing disaster-related social knowledge on Social Network Services (SNS) and to present it in a user-friendly form.

The next section introduces R&D on a network system technology that the Wireless Communication Applications Project has been actively working on recently, which can be used continuously even when public communication has been interrupted, and how this technology is being deployed in society. A detailed report of work by the Real-time Social Knowledge Analysis Project is also given in another article in this issue, titled "Disaster-prevention Initiatives using AI and Related Information on SNS."

3. R&D on network system technologies that maintain availability when public networks are interrupted and promotion of results

We are conducting R&D on distributed network system technologies that are resistant to interruption through self-management, enabling both internal communication and application services to be maintained, and also facilitating construction and expansion of networks. Municipalities such as cities and towns are being required to respond quickly and with flexibility to various natural disasters that have been occurring more frequently of late. In such conditions, the role of information is extremely important for understanding conditions of the entire disaster as they change from minute-to-minute, and for making timely and appropriate decisions. However, as experienced with large-scale disasters such as the Great East Japan Earthquake, public telecommunications may not always be available due to congestion or damage, so how to maintain the flow of information even under such conditions is an important key to facilitating support efforts on the ground. One network system technology being developed to maintaining information flow, introduced below, is called "Die-hard Networks"[1]. Its objective is to enable continuous disaster-response work, even between distant locations, by collecting information on servers distributed among vehicles and facilities, and synchronizing that information between the servers using various communication channels that have different characteristics.

3.1 Overview of Die-hard networks

3.1.1 Targeted functional elements

Die-hard networks were proposed and developed as a network system technology that will enable workers to continue using systems, even during disasters and under other conditions where public communications are interrupted, and enable sharing of information between various remote locations and organizations, maximizing utilization of limited means of communication. Features of the technology are described below.

(1) Links between distributed on-premises systems

To enable on-site workers to continue their work under any conditions, an autonomous distributed architecture was adopted. Thus, there are no nodes that provide centralized system management and control, or provide services. Each node provides application services and network control on-premises, and detects and connects with other nodes with the same functionality. This enables nodes to autonomously share and synchronize data (document files, images, etc.) and other information with each other, sharing it between distributed systems at different locations.

(2) Proactive use of mobile resources

Sharing of data as described above is performed in an event-driven manner, when there are updates, or when connecting to a new node. The system is designed using a database to manage data, synchronizing data between nodes so that inconsistencies do not occur. This enables each node to add and update data independently, without assuming a constant connection with other nodes, sharing and synchronizing data between devices only when mobile devices are nearby, and using them as a means of storing and transporting information.

(3) Utilization of heterogeneous communication systems

The system implements functions that enable various communication technologies for connections between nodes, combining available means of communication and using them according to their various characteristics from the application level. For example, wireless local area networks (wireless LAN, or "Wi-Fi") are capable of relatively high capacity data exchange when a mobile station is nearby, but the range is limited, and it can be difficult to predict when a connection to which mobile station will be possible, or when it will be disconnected. Conversely, communication with Low-Power Wide-Area (LPWA) or Convenience Radio is capable of broadcast and communication over relatively longer distances, but has very low speed and is more subject to data loss, so it is not suitable for image transmission or other high-volume data exchange. Long Term Evolution (LTE) connections are capable of very stable, high-speed Internet connections, but contracting mobile service providers only provide private Internet Protocol version 4 (IPv4) addresses, so IP address resolution and direct communication is not possible between nodes behind the NAT gateways, and data synchronization must be done through a cloud service with a global address. The system implements Application Programming Interfaces (APIs) that enable proactive and efficient use of various means of communication, according to their differing characteristics as in the examples above (such as priority, real-time or not, data transmission capacity, broadcast, and single or full-duplex communication) so that distributed, on-premises systems running on nodes can maintain resilient links between each other.

(4) Authentication and access control in distributed environments

Information handled by local governments includes personal information so free access by anyone cannot be permitted. As such, connection to distributed on-premises systems on each node and access to data stored and managed within them must be limited to users and through terminals that have been authenticated. Similar restrictions are also required between nodes for communication between devices and connections through LTE or the Internet. Die-hard Networks do not assume constant connections between nodes or with the Internet, so authorization to connect and access to information is also authenticated between distributed nodes.

3.1.2 Die-hard Network node prototype

We have prototyped a Die-hard Network node. The prototype node specifications are shown in the Table[1]. Under normal circumstances the prototype node uses the mobile phone network (LTE data communication) and implements a mechanism that automatically synchronizes data between each node and a node on the cloud. Besides LTE, each node also has two Wi-Fi interfaces, with one operating as an access point using hostapd[2], and the other operating as a station using wpa_supplicant[3]. The Wi-Fi access points can connect to other nodes and synchronize data, but they are also used to accommodate smartphones, tablets and PCs used by disaster responders, and provide application services to them.

The prototype node implements Fast Initial Link Setup (FILS) on wireless LAN based on the IEEE802.1ai standard[4], providing authentication server, Dynamic Host Configuration Protocol (DHCP) server and Wi-Fi access point functions, so that they are operating on all nodes of the network. This enables high-speed wireless LAN connections with user authentication equivalent to Wi-Fi Protected Access 2 (WPA2) Enterprise. This also allows for more data to be transferred between nodes during the limited time available in scenarios when mobile nodes pass each other, or when mobile nodes pass near nodes in fixed stations.

Each node is also equipped with digital convenience radio

Table: Prototype node specifications

	Specifications
Single Board Computer	Gateworks GW6300 OS: Ubuntu 16.04.05 (Linux 4.14.4) CPU: Cavium Octeon TX Dual Core ARM CPU @ 800 MHz RAM: DDR3 1 GB Storage: SSD 250 GB
Wireless LAN Interface (device driver)	Qualcomm AR9300 (ath9k)×2
Digital Convenience Radio	waveCSR U7000UJC181 351.2 - 351.38125 MHz (30 CH) 4-value FSK 4.8 Kbps RS-232C connection
LTE module	PIX-MT100

equipment, for long distance communication. This is used mainly for transmitting control information between nodes, but when the regular LTE connection is interrupted, it can also be used to transmit high priority application data (low volume text data). The system is also designed so that Long Range (LoRa) and other IoT radio communication devices can be added.

3.1.3 Application software

Application software running on the Die-hard network system is implemented as Web server based applications[1]. Users are able to enter and view information on the system using a Web browser on a PC or smartphone connected to the system by Wi-Fi. The system also implements APIs so that dedicated applications can be developed to facilitate entry of information on a smartphone. Thus, applications can be developed to use the system as required by users, such as: enabling registered users and devices to simplify login to the system, updating information with photos attached, sharing location information for on-site workers, or distributing audio information within groups like a transceiver.

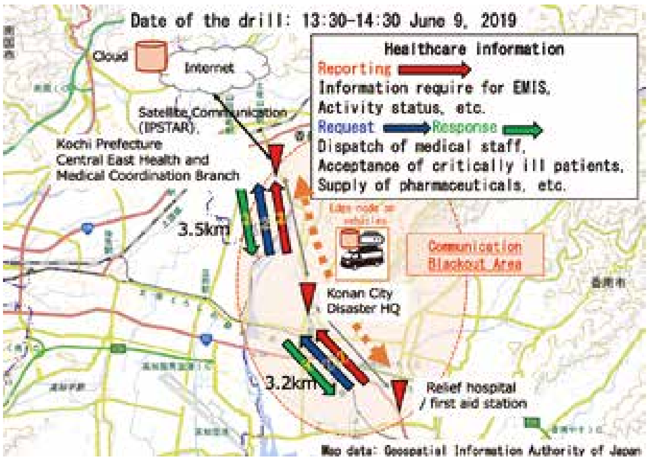
3.2 Use of prototype node in disaster medical drills

The prototype was used in the comprehensive disaster preparedness drill held in Kochi Prefecture on June 9, 2019. The drill supposed conditions in which public communications were completely lost due to an earthquake in the Nankai Trough. As in earlier drills, training was done using conventional means of communication, such as administrative disaster prevention radio systems. Specifically, this involved writing messages on paper based on prefectural forms (e.g., reports from first-aid stations to municipal disaster-response centers, status reports from disaster response centers to prefectural medical coordination office, requests to admit serious patients, and responses), and then transmitting them by FAX. In parallel with this, prototype nodes were installed at the Kochi Prefecture Medical Coordination office (Kochi Prefecture Central-East Health and Welfare Office), the Konan City Disaster Response Office (the Fureai Center), and the emergency medical aid station (Konan City, Akaoka Insurance Center). Drills were then conducted transmitting the same information digitally, without paper, using the prototype nodes with the LTE function disabled[5]. An information transmission application developed for the drills was installed on the prototype nodes, and a Die-hard Network system was configured using several nodes. Figure 1 shows the locations of each of the stations using the system in the drill, and the information transmitted.

With the system, text information entered in reports and requests is automatically synchronized and shared by Digital Convenience Radio with the municipal disaster response center or the prefectural medical coordination center. At each location, a mechanism is implemented to automatically share such status or authorization information by simply performing the approval and authorization processes on the system. City and prefecture staffs participating in the drills were requested to use the system and were able to perform the drill according to the prescribed scenarios. Screen shots of the applications used are shown in Figures 2 and 3.

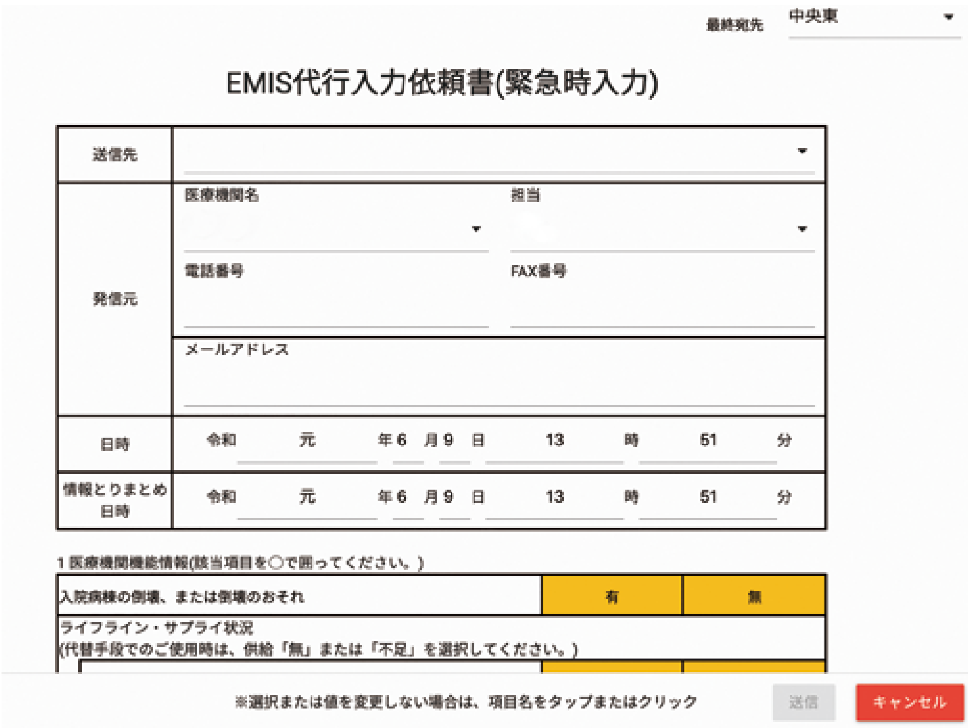
Beyond the scenarios of the drill, we also demonstrated storage and transmission of information that cannot be transmitted using prefecture forms, such as the status of critical patients in care at the first-aid centers, and photographs of triage tags. Prototype nodes on moving vehicles automatically synchronized information through Wi-Fi, so photographic data stored on nodes at first-aid stations was automatically transmitted to the vehicle node, and when the vehicle arrived at the parking lot of the medical coordination center, the photographic data was automatically transmitted to nodes there. We confirmed that photos could be displayed on PCs in the center. In this way, we verified that even high-volume data that is difficult to transmit by Digital Convenience Radio can be shared automatically, transported by vehicle, when public telecommunications are interrupted.

■ **Figure 1: Locations and information transmitted for each location in drills**



■ **Figure 2: Data transmission application screen (Status display screen for Requests/Approvals/Reports)**

Figure 3: Data input screen matching prefecture forms



These efforts have shown that this network system technology is effective, providing continuous availability even when public telecommunication systems are interrupted.

3.3 Future prospects

The Die-hard Network system described here is being developed as a technology to provide a continuous means of communication, to share information among aid workers active on-site during disasters, and is being verified in disaster prevention drills.

In the future, we will continue development of individual technical elements necessary for Die-hard Networks, and build them into the Disaster Prevention Information, Communication and Management System in Konan City, Kochi Prefecture. We will also link with the Shared Information Platform for Disaster Management (SIP4D) system[6], create platform functionality that can be shared for various uses, improve extensibility, and expand laterally so that it can also be used by other local governments and disaster-response agencies.

4. Conclusion

Having learned lessons from the Great East Japan Earthquake, the Resilient ICT Research Center is engaged in R&D on ICT that is resilient in the face of earthquakes and other large-scale disasters and is working to implement it in society. In recent years, we have also frequently seen meteorological disasters such as wind and water damage from typhoons, and sudden and heavy "guerilla" rainstorms. Moreover, we have learned that pandemics such as that resulting from COVID-19 have a strong impact to society, similar to large-scale disasters. ICT must function properly in order to minimize damage to life and economy and to support repair and recovery. With development of ICT and in a society where every citizen is connected to the network, we have entered an age that requires construction of cyber-physical ICT social infrastructure that can support everyday social systems and services, and is continuously maintained and operating right through into times of disaster. To realize this vision will require further R&D on technical systems that are, as the word "resilient" indicates, both tougher and more flexible.

References
[1] Y. Owada et al.: "Information Sharing System for Disaster Response Using Asynchronous Opportunistic Communications Among Distributed Servers," IEICE Tech. Rep., Vol. 120, No. 73, SeMI2020-2, pp. 7-12, June 2020.
[2] J. Malinen: "hostapd: IEEE 802.11 AP, IEEE 802.1X/WPA/WPA2/EAP/ RADIUS Authenticator," https://w1.fi/hostapd/, 2013.
[3] J. Malinen: "hostapd: Linux WPA/WPA2/IEEE 802.1XSupplicant," https://w1.fi/wpa_supplicant/, 2013.
[4] "IEEE Standard for Information technology-Telecommunications and information exchange between systems Local and metropolitan area networks-Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," IEEE Std 802.11-2016, pp. 1-3534, doi: 10.1109/IEEESTD. 2016.7786995, Dec. 2016.
[5] "Trials conducted transmitting health and welfare information during disaster, without using public telecommunications, in Kochi Prefecture Comprehensive Disaster Preparedness Drills," https://www.nict.go.jp/info/topics/2019/06/20-1.html, June 2019.
[6] "Shared Information Platform for Disaster Management (SI P4D)," https://www.sip4d.jp/