https://doi.org/10.20965/jdr.2019.p0348

Paper:

Development of Resilient Information and Communications Technology for Relief Against Natural Disasters

Hiroshi Kumagai[*1,†], **Hiroshi Sakurauchi**[*2], **Shinsuke Koitabashi**[*2], **Takeaki Uchiyama**[*2], **Shinichi Sasaki**[*3], **Kazuhide Noda**[*3], **Makoto Ishizaki**[*3], **Satoshi Kotabe**[*4], **Atsushi Yamamoto**[*4], **Yoshitaka Shimizu**[*4], **Yasuo Suzuki**[*4], **Yasunori Owada**[*1], **Katsuhiro Temma**[*1], **Goshi Sato**[*1], **Toshiaki Miyazaki**[*5], **Peng Li**[*5], **Yuichi Kawamoto**[*6], **Nei Kato**[*6], **and Hiroki Nishiyama**[*6]

[*1]National Institute of Information and Communications Technology (NICT)
4-2-1 Nukui-kita, Koganei, Tokyo 184-8795, Japan
[†]Corresponding author, E-mail: kumagai@nict.go.jp
[*2]NTT DATA Corporation, Tokyo, Japan
[*3]NTT DOCOMO INC., Tokyo, Japan
[*4]NTT Network Innovation Laboratories, NTT Corporation, Kanagawa, Japan
[*5]The University of Aizu, Fukushima, Japan
[*6]Graduate School of Information Sciences, Tohoku University, Miyagi, Japan

[Received September 3, 2018; accepted December 7, 2018]

The study focused on the research and development of ICT for disaster preparedness and response with respect to two categories, namely, the delivery of alert messages to a wider group of residents and providing quick relief communications in affected areas. In the former category, the development focused on two targets, one involving the delivery of alert messages to indoor residents with a V-Low broadcasting service and the other involving the delivery of an alert message to individuals with disabilities and difficulties in understanding Japanese. In the latter category, a portable ICT unit was developed for rapid relief communications and mesh network technology enabling robust information sharing among base stations in the affected area was developed. Furthermore, a related development focused on a resilient information management system to collect information in areas that do not have access to the Internet. Furthermore, device relay technology was developed to expand access network cover areas. After the development of individual technology, activities for the societal implementation of the development results were conducted through field experiments and disaster drills in which the developed technologies were integrated and utilized.

Keywords: message distribution with V-Low broadcasting, multilingual early warning mail, portable ICT unit, NerveNet mesh network, expand access network areas

1. Introduction

Problems in communicating disaster information constitute a big challenge. Thus, in the study, technology development is conducted in two categories, namely an alert message delivery problem "delivery technology" and rapid relief of communication network "connection technology" in areas where the existing communications network fails. In the "delivery technology," it is difficult for a particular delivery method to reach all residents in the target areas depending on the disaster and recipient situation. The objective involves developing new methods to fill the present gap areas wherein the message does not reach sufficiently via existing methods. Two of the aforementioned areas of our target with gaps include message delivery to indoor residents and to individuals who do not recognize Japanese messages. The first attempt is implemented by using a new broadcasting medium termed as the V(VHF)-Low multimedia service in which the broadcast signal reaches inside houses and alert messages are delivered through fire alarm devices whose installment is mandatory in every house. The other attempt involves developing a function wherein the early warning mail is conveyed via a multi-linguistic message and read-out in Japanese.

In the field of "connection technology," a challenge involves developing rapid relief networks in affected areas. Recently, various cloud services were introduced for use in the event of disasters such as disaster response management for local governments, disaster medical services for medical teams, and SIP4D (which is a cloud system to share central governmental disaster data that was developed in the present program in SIP). It should be noted that the cloud systems work when and where the Internet connection is available. It is not true in most cases in disaster affected areas immediately after a disaster occurs [1]. This corresponds to the target area to utilize rapid relief technologies in case of existing communications failure. In this context, the study examines several technologies including a portable ICT unit that enables temporal telephone service relief, a wireless mesh net-

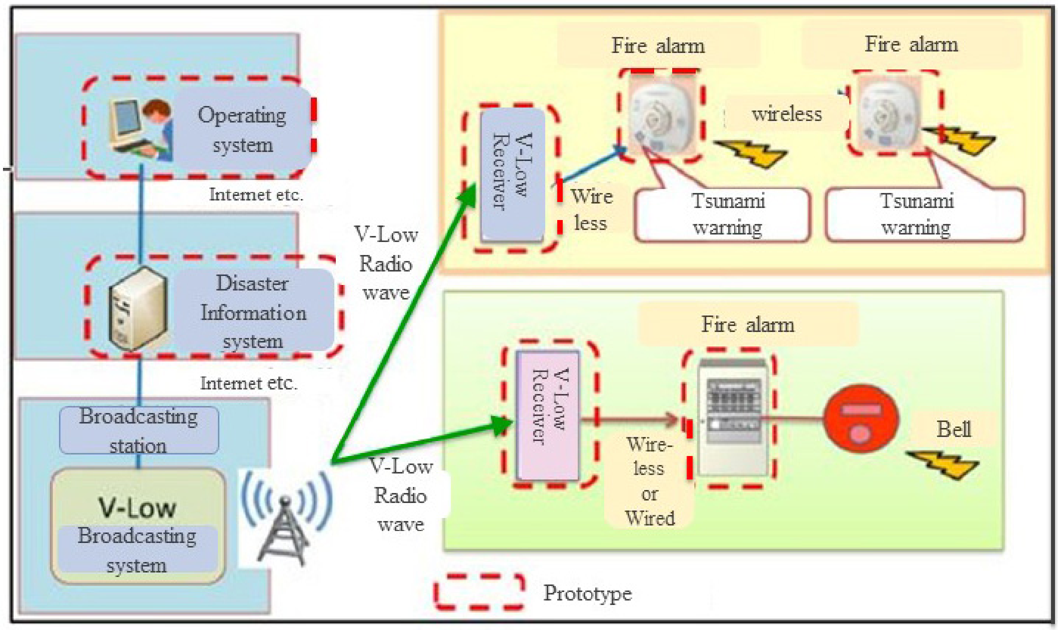


Fig. 1. Block diagram of V-Low alert system.

work technology to form a decentralized network, the Resilient Information Management System (RIM), and technologies to expand the access network area. In the study, new technologies developed for information exchange in disaster areas in the "Enhancement of Societal Resiliency against Natural Disasters (SIP)" are described in conjunction with activities for their proof experiments and use in disaster drills. Promotional activities for societal implementation are also discussed. Those for implementation in foreign areas are described in the separate paper [2].

2. Achievement of Research and Development

2.1. Alert Delivery with a Broadcasting Medium

Based on the experience of the Great East Japan Earthquake, the study examines disaster information delivery from national and local governments to local residents. Improvements in the efficiency and reliability of the process are expected by using multiple communication media and terminal devices. As a new information delivery technique, we focused on a method using the V-low multimedia broadcasting service (a new broadcasting medium) in which the service objectives include its use for disaster information delivery. Given the advantages of the system wherein the message reaches indoor residents better and areas covered are wider than existing methods, the system is installed in fire alarm device as an indoor terminal that every household is equipped with.

In the system development, a prototype of information delivery system, adapting the V-Low broadcasting facility was designed and attached. As an indoor terminal, a prototype system of a V-Low receiver to extract alarm messages from broadcasting signals and then make a sound or announce the messages were developed. A block diagram of the V-Low alert system is shown in **Fig. 1**. By using the prototype equipment, we performed a demonstration experiment by taking an opportunity of a disaster drill in an apartment in Arakawa City, Tokyo Prefecture. In the demonstration experiment, sets of V-Low receivers and fire alarm devices for residential use were placed inside seven house rooms, and the disaster alarm message was sent from V-Low broadcasting station to activate a fire alarm device sound. The system worked well in the experiment. We interviewed the residents of the houses after experiment on usability. In addition to the experiment for individual houses, fire alarm sound demonstration was performed for all the drill participants, and responses for questionnaire sheets were collected from them.

The participants rated the system positively in terms of its use when mobile phones are not available (i.e., when individuals do not carry them, during battery depletion, and power failure) and negatively in terms of concern about false alarms, lack of necessity since everyone (even children) carry smartphones, and insufficiency in delivering a more detailed message. In addition, a questionnaire on the effectiveness of message delivery for indoor residents with fire alarm device was sent to 1741 local governments throughout Japan, and 861 responses were obtained. The answers to the questionnaire suggested that the system is highly effective in terms of its use in bedrooms and other rooms that are different from living rooms in houses and also in houses for aged residents. The results are shown in **Fig. 2**. Conversely, concerns were raised that the message can cause confusion with fire alarm and also that it can be misunderstood due to the presence of only short and fixed messages. Based on the demonstration experiments and answers to the ques-

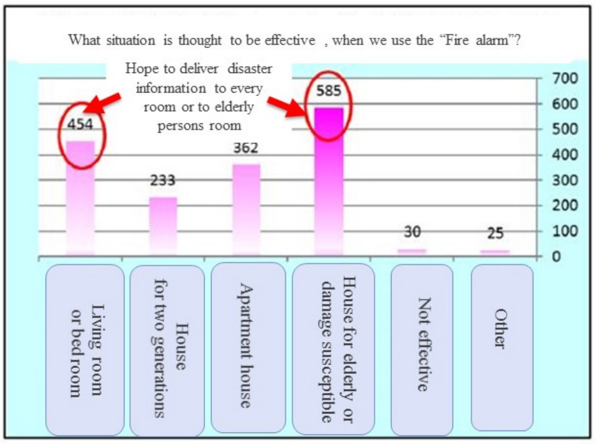


Fig. 2. Household situations where the indoor terminal of the system is effective (answers from questionnaire to local governments).

tionnaire, a report on the use of a model of disaster alarm delivery system by using V-Low multimedia broadcasting service was compiled. The report includes use cases and explanations on integration and setting up the terminal device. Another report toward product manufacturing includes design considerations and draft specifications of the product. The two reports were completed and are open to the public in the website home page of the "Enhancement of Societal Resiliency against Natural Disasters" of SIP [3].

We applied the study results obtained to date and started in building a Disaster Information System of Kitakata-City and included multi-layered information delivery function linking with V-Low multimedia broadcasting service since 2017. The system can simultaneously deliver disaster information through various communication media, such as V-Low receiving radio terminal, outdoor loudspeaker stations, social network service (SNS), registered e-mail, home page of Kitakata-City, and community FM broadcast, in a multiplexed manner. This is the first disaster information delivery system in Japan that utilizes the V-Low broadcasting service. It is expected that the disaster information system using the V-Low broadcasting service can be used in wider areas of local governments with the expansion of the V-Low service areas and, improvements and lowering of the cost of terminal devices of V-Low receivers. Based on the knowledge and know-how obtained during the introduction of the system to Kitakata-City, it is expected that the system can be further extended to other local governments.

2.2. Early Warning Mail Service to Be Recognized by Various Receivers

There are many natural disasters in Japan such as earthquakes, tsunamis, heavy rain, and floods. In any case, an effective early warning system contributes to significantly mitigating disaster damages. Mobile phone operators in Japan have services of early warning mail system in which the national or local governments send messages

Fig. 3. Pictogram images in early warning mail for earthquake and tsunami.

to residents in designated areas. The system is pervasive and plays the important role of sending an advance notice. However, the warning message in the service is only written in Japanese, and thus it is generally difficult for foreigners and individuals with disabilities to comprehend Japanese text. Hence, NTT DOCOMO is working to solve the problem.

In this section, the following technology development is explained:

- Multilingual and pictogram display of early warning mails for earthquakes and tsunamis;
- Translation function and effort to improve the accuracy of the early warning mail sent from local governments.

We first developed a system to convey early warning messages for earthquakes and tsunamis that were sent from Japan Meteorological Agency to a wider class of residents. The warning messages are composed of fixed Japanese sentences, and thus we developed an application in the smartphone terminal that displays messages in a foreign language or reading-out in Japanese. In the application, the received message is displayed by the selected language or the voice guidance is announced based on the language selection of a user in the terminal. The application is currently compatible with five foreign languages including English, Chinese, Korean, Spanish, and Portuguese. The translated messages in the five languages refer to a multilingual disaster glossary prepared by the Japan Meteorological Agency. Further, we introduced a pictogram display for earthquakes and tsunamis in conjunction with text messages. The pictogram information even aids users who exhibit difficulties in understanding Japanese and the aforementioned five languages in recognizing the meaning. The pictogram images are standardized among mobile phone operators in Japan as shown in **Fig. 3**. Currently, NTT DOCOMO and KDDI introduced the multilingual operational service, and NTT DOCOMO introduced the operational service with pictograms.

Messages of the early warning for earthquake and tsunami delivered from the Japan Meteorological Agency are composed of fixed sentences, and thus corresponding multilingual messages are stored in the application in user terminals. However, a different approach is needed for the early warning messages sent from local governments to the local residents in the cases as evacuation advisories in weather hazards. Possible candidate approaches include the following:

1. Embedding a translation engine in the terminal application,
2. Including generic translation sentences into the terminal application,
3. Translating by using a translation server after receiving Japanese messages.

After examination among the three proposed approaches, the third one is adopted because of size of application development and flexibility. NTT DOCOMO introduced the service with this approach since September 2016. Translation is available in three languages, namely English, Chinese, and Korean via the DOCOMO translation server. Translation to other languages is available by using other translation servers.

After the introduction of this function, it proved that the translation accuracy was insufficient with respect to Japanese place names and sentence compositions. The total performance was not high. The following effort was implemented to improve the translation performance.

Register place names, evacuation sites, and disaster terminology (approximately 200 thousand corpuses),

Register all messages ever sent from local governments such as evacuation advisories (approximately 1200 messages).

In order to evaluate the improvements after the enhancement efforts, the following study was applied. A hundred sentences randomly selected from all the messages ever sent by local governments were translated from Japanese to English, Chinese, and Korean via the translation server before and after improvement. Native speakers of these languages evaluated the translation in terms of grammar and meaning. Subsequently, cases wherein the evaluation point equals or exceeds 3.0 in the 5-level rating are counted. The numbers in **Table 1** show the percentages of cases that satisfy the aforementioned rating, and the improvement obtained ranged from 15 to 28 % before and after in the three categories. The results still indicate that translation accuracy degrades for long sentences and sentences with unregistered place names. The translation accuracy could be improved by letting local governments send messages in almost fixed sentences using templates that include sufficient alert information corresponding to disaster cases.

Table 1. Ratio of higher ratings in translation before and after corpus enhancement.

Translation	Before	After
Japanese ⇒ English	30%	47%
Japanese ⇒ Chinese	32%	60%
Japanese ⇒ Korean	53%	68%

2.3. Communication Relief Technology in Affected Areas

A lesson learned from the Great East Japan Earthquake and Tsunami in March 11, 2011, is that an information communication network should respond to rapid increases in communication demand in wide areas. The communication demand changes depending on time elapse from the disaster event. Immediately after the disaster, the demand for real-time communications, typically as telephone services, increases explosively to verify personal safety. A few days after the disaster, when the demand for real-time communication is settled, the demand for data communication, collection, and processing increases which is mainly originated from local governments and industries. After that, demand for communication approaches a normal state. Therefore, it is necessary for communication networks to respond to the two peaks of different demands after large-scale disasters.

The NTT Network Innovation Laboratory proposed a "Mobile ICT Unit (or MDRU: Movable Deployable ICT Resource Unit)" that enables the immediate provision of minimum services in disaster affected area and has been conducting the research and development of it [4]. The mobile ICT unit is equipped with servers and storage that operate as a small data center. The use of network virtualization technology provides flexible capability both for real-time communications and data system communications. A mobile ICT unit is a portable unit that contains devices necessary for ICT services of which the operation image is shown in **Fig. 4**. The unit is quickly carried and installed in affected areas. After the installation, a local network is constructed in a short time, and necessary minimum ICT services are provided to users in local area. The unit can be connected to a wide area network via a remaining optical fiber link or portable satellite earth station in the affected area. Once the unit is connected to a wide area network, it operates as an information hub in the affected area connecting it to unaffected areas [5, 6].

The IP-PBX (Internet Protocol-based Private Branch eXchange) is a main function of the mobile ICT unit, and it provides temporary telephone-call service in an environment wherein public communication services are unavailable.

A smartphone that is connected to a wireless access network formed around the ICT unit can make a call with regular mobile phone numbers. A smartphone owned by an individual with a regular number is registered as an extension number by downloading an application from IP-PBX. In this system, daily used regular telephone numbers can be used. Another advantage is that a telephone call does not depend on carrier operator due to the connection to the access network via wireless LAN. By connecting with a mobile satellite station or a remaining optical line, the IP-PBX enables us to make an external telephone call to the areas outside affected area. A portable IP-PBX as shown in **Fig. 5** is equipped with an IP-PBX for dis-

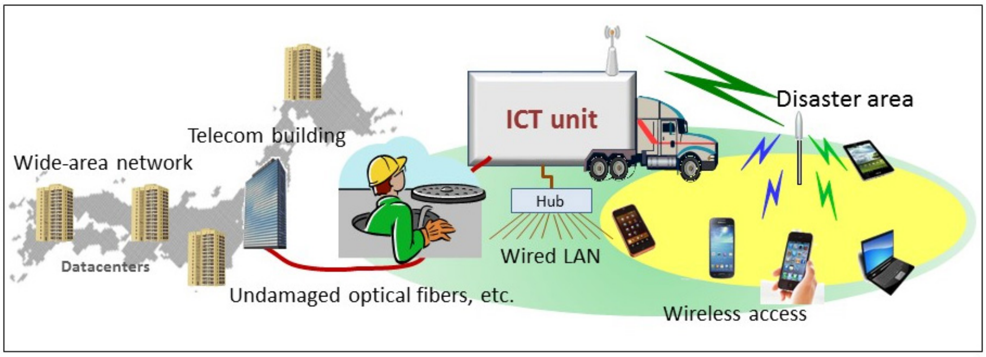


Fig. 4. A use image of mobile ICT unit.

Fig. 5. Portable IP-PBX.

aster, wireless LAN (Wi-Fi) access point (AP), an analog gateway (GW), and a battery in a waterproof case. It immediately provides minimum communication tools in the disaster affected areas. It is a compact system with a registration capacity of 5000 terminals wherein 100 calls can be simultaneously handled by an IP-PBX for disaster. Its battery permits an operation time of approximately 8 hours.

An important application service equipped with IP-PBX is the on-premises GIS. The system enables disaster response staff to use geographical map information and, collect and share local site information on the map even in an environment wherein the internet connection is unavailable. **Fig. 6** shows a use case image of the function in disaster affected area. By using the function, pictures taken by smartphone or all-sky camera in affected areas are displayed on the map and shared with a response center. Another use image to support rescue activity is that the response center and staff in the site share information related to staff location on the map and necessary messages by using the function. Demonstration experiments by using the aforementioned ICT services are described in the following section.

2.4. Mesh Network Technology and Testbed Function Development

We develop a mesh network technology termed as "NerveNet" that is characterized by a self-sustained and decentralized network [7, 8]. The network function has two major characteristics. The first characteristic involves mesh topology access networking to realize robust and redundant network connectivity. If a route in the network shuts down, the connection is quickly restored by finding an alternative route in the network. The other characteristic involves functions of distributed servers and database platform that operate as servers for various applications even inside the local network to provide user application service without relying on clouds or an Internet connection. These characteristics are especially advantageous in the case of rapid communication relief in disaster affected areas where public networks are disrupted [9]. The usability of the NerveNet system is characterized by the fact that general purpose commodity devices can be used as terminal devices. Personal smartphones can also be used by downloading the application. An image of a NerveNet node (base station) and a use image of temporal network relief in disaster affected area are shown in **Fig. 7**.

The mesh network instruments by the NerveNet architecture are developed as a part of the testbed system developed in the research program. The main function involves conducting field experiments to evaluate a new function that can be used in disaster cases and to provide demonstrations to users. The visualization of network configuration and performance is an important task to fulfil research targets. The visualization function is developed to observe the network connection configuration and traffic situation in the field experiments from a laboratory in real-time. Also, the system can be used for post experiment analysis to solve problems and improve the system.

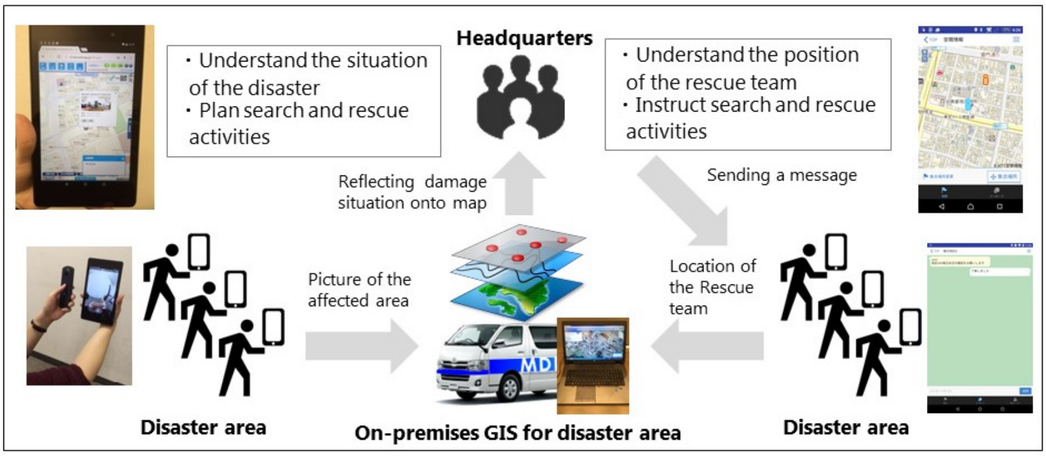


Fig. 6. A use case image of on-premise GIS for disaster affected area.

Fig. 7. Photo of a NerveNet node (base station) and a use image of temporal network relief in disaster affected area.

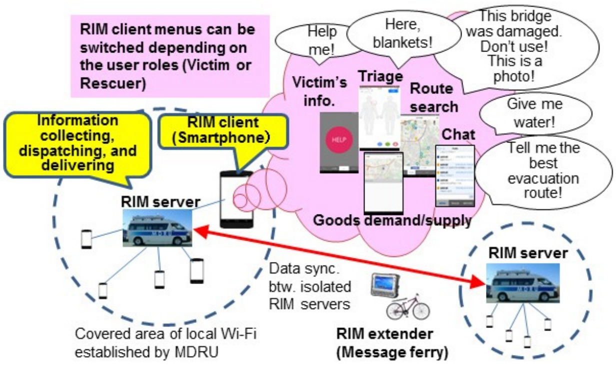


Fig. 8. Overview of RIM system.

2.5. Development of Resilient Information Management (RIM) System

A Resilient Information Management (RIM) system was developed to share different types of information related to disaster-hit areas. **Fig. 8** shows an overview of the RIM system. It consists of several mobile terminals, such as smartphones and/or tablets, and a RIM server. By using the RIM system, individuals can manage and share important information including medical information for rescue plans and actions, damage occurrence and its location as well as goods supply/demand information. The RIM system uses a locally established Wi-Fi network environment which is generated by an MDRU. Thus, a RIM system can be deployed even where the Internet and any other communication network infrastructure cannot be used.

The RIM server has a relational database management system (RDBMS) and a map information server to manage the information collected from mobile terminals. An application program termed as RIM client runs on each mobile terminal. Users view information stored in the RIM server on their mobile terminals and share it with others. They also input information through their own mobile terminals. To obtain location information using maps is available with a map information server in the RIM even in the disaster situations wherein the communication infrastructure and Internet-based map services, such as Google Maps [10], are unavailable. **Fig. 9** shows typical views of the RIM client application. There are two view modes, namely the normal mode and medical mode. The normal mode is for normal users or victims while the medical mode is for rescuers or doctors. The view modes can be switched based on the user role or situation. As shown in **Figs. 9(a)** and **(b)**, they exhibit the same icons from (1) to (6), and (8). Icon (7) in the normal mode (i.e., the "Help" icon) is for reporting victims while icon (7) in the medical mode (i.e., "Triage" icon) supports the rescuer/doctor to triage victims at the disaster scene based on the standard triage method that is termed as "START [11]." Icon (9) only exists in the medical mode, and it is used to display demands and infor-

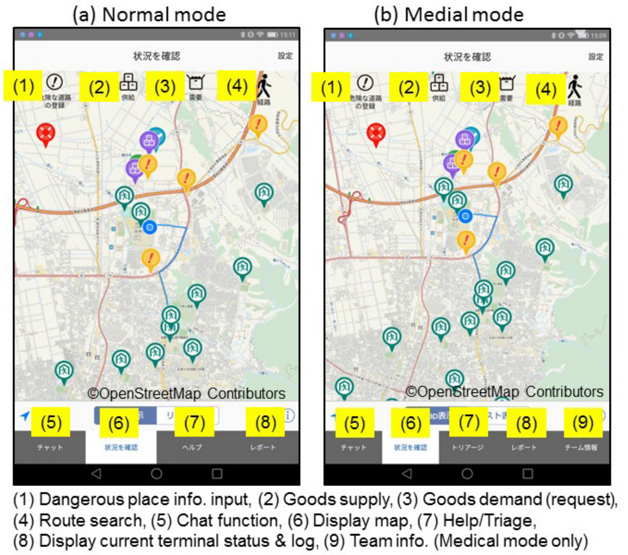


Fig. 9. Screen snapshots of the RIM client application.

mation for the rescue team that the individual belongs to. All the information is displayed by using pin marks on a map as shown in **Fig. 9**. Detailed information is displayed by tapping a pin. With respect to input of new information, it can be input by following the menu displayed after tapping a corresponding icon among icons (1) to (9) as shown in **Fig. 9**. A few icons, such as dangerous place information input icon, support photo taking and voice recording by using smartphone's camera and microphone in addition to text input.

The Wi-Fi environment established by the MDRU is not always stable, and it is occasionally difficult to transfer data from RIM terminals to the RIM server, especially when the geographical distance between them is large. In order to resolve the situation, we developed a mobile relay node that is termed as the RIM extender. The RIM extender exhibits functions similar to the RIM server with the exception of the map information server. Thus, the mobile terminal connects to the RIM extender and uploads some data to it with the same functions and protocols as those of the RIM server. The RIM extender is deployed by using several carriers including a human, bicycle, and drone because it is a small mobile device. It should be noted that we currently use a small laptop PC to realize the RIM extender. In addition, the RIM extender can be used as a message ferry [12] to carry data between two isolated RIM servers to synchronize the data stored in the servers without the Internet or any other communication network services.

A prototype of the RIM system is developed and the feasibility of all functions is confirmed. We demonstrated the usability of the system to professional rescuers and residents by using it in some events. We also started a collaboration project with Aizu-Wakamatsu city office, Fukushima, Japan to combine the RIM client with their product named "Pe.com.in [13]," which is a map-based SNS smartphone application that is used in daily life. The user interface of "Pe.com.in" is similar to that of the RIM client. Thus, the "Pe.com.in" user naturally uses the RIM client in a disaster scene. We consider that this is a good basis to encourage individuals to install the RIM client application into their own smartphones to prepare for disasters.

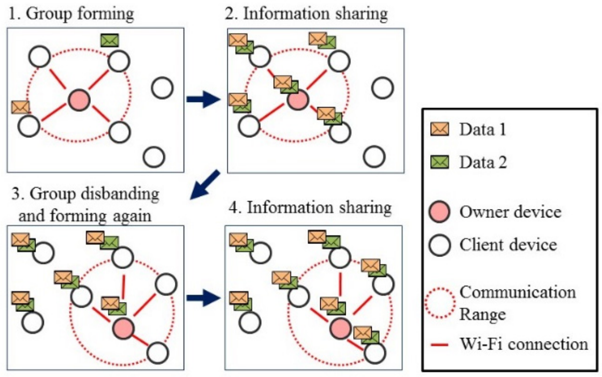


Fig. 10. Procedure of sharing information.

2.6. Technology for Expanding Access Network Areas

In this section, we introduce the relay by smart device technology that expands access network areas. In disaster areas, it is difficult for residents to utilize their communication devices, such as smartphones or tablet computers, in the case of a public network failure. Thus, a means of communication that does not require network infrastructures is useful.

To address this problem, we examined the relay by smart device technology based on Wi-Fi Direct (WFD) and delay-tolerant network (DTN) [14, 15]. The procedure of sharing information using the relay by smart device technology is shown in **Fig. 10**. Initially, connection groups are formed by using WFD. Next, mobile devices share data within their own group by using the DTN function. Furthermore, once the group is disbanded, another group is constructed with different members, and mobile devices exchange data again. Thus, this technology enables multi-hop D2D communication networks between mobile devices only.

Figure 11 shows the overview of the scenario using relay by smart devices in disaster areas. Outside the wireless local area network, the information is shared only among smartphones by using the relay by smart device technology. In the wireless local area network, smartphones are connected with the ICT unit and information is spread in the nearby and remote areas through the ICT unit. Therefore, the fusion of the relay by smart device technology and the ICT unit enables individuals in disaster areas to send and receive the information through the Internet even if there is no infrastructure nearby.

In order to confirm the usefulness of our technology development, we conducted demonstrations by using a network as shown in **Fig. 11** in San Remigio, Philippines, and the results indicated that the data from the smartphone outside the wireless local area network can certainly reach

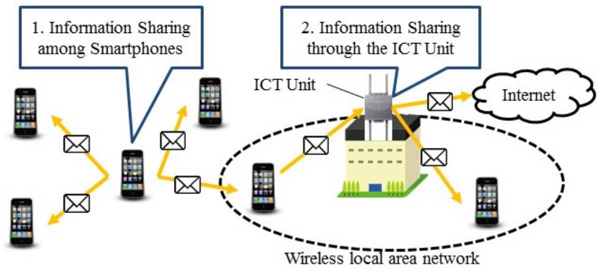


Fig. 11. Overview of scenario of using relay by smart device.

the ICT unit. In addition, we asked local residents to use smartphones with the relay by smart device technology, and found future study items of focusing on ease-of-use of this technology for ordinary individuals.

3. Demonstration Experiments to Promote Implementation

Research results from individual technology development were described in the previous chapter. The developed technologies are not individually used to cope with disaster. Conversely, they should be used together in a coordinated manner. In the Program, a systematic study is performed as "delivery technology" and "connecting technology." In order for the technologies to be used in disasters, it is necessary to demonstrate them to users and for users to experience their usefulness and effectiveness. Specifically, with respect to "connecting technology," an integrated demonstration of network link with terminal equipment is useful. These demonstration activities enable procuring user consent to the usefulness of the new technologies and facilitate social implementation.

3.1. Portable ICT Unit Utilization to Relief Communications Network in Local Area

The objective of development of the portable ICT unit involves quickly relieving communication in local area. In order to validate the development achievement, we conducted several field experiments and demonstrations using the system. Specifically, we sent the unit to Takamori-Town, Kumamoto Pref. of Kumamoto Earthquake affected area in April 2016 [9]. Other activities mostly involved participating in disaster drills in coordination with local governments wherein emergency communication practice was performed by using temporal network relief by response staff and residents.

A typical example is explained as follows: a field demonstration in conjunction with disaster drill was conducted in Onna-Town, Okinawa Pref. on July 13, 2017. It was assumed that an earthquake with seismic coefficient level 7 occurred in the area in one of the leading resort areas in Okinawa Prefecture. An exercise was conducted in collaboration between local government and private sector (a resort hotel) to verify disaster measures for the evacuation of residents and tourists both domestic and overseas. The overall configuration of the drill is shown in **Fig. 12**. In the drill, the relief network connected three sites including the Onna-Town office, Okinawa Institute of Science and Technology, and Rizzan Sea-Park-Hotel, Tancha-Bay. Three base sites were connected with FWA (fixed wireless access) private wireless links, and portable ICT units were placed at these sites. In the drill, telephone communication by smartphones, voice paging, and transmission of video images among sites were performed. It is verified that the situation of other base sites was monitored from the response center located at the town office. Additionally, the Internet connection through high-speed satellite link with mobile earth station to WINDS satellite was used for language translation of the messages for foreign tourists with Voice-Tra.

A questionnaire survey was given to individuals who joined and used the terminal devices in the drill to examine effectiveness of the system if it was used in a response center or evacuation center in the event of a disaster. A hundred percent of the responses indicated that the system was "very useful" or "useful." Furthermore, interviews of local government staff resulted in positive comments related to the system including "useful for communication among staff members," "effective if introduced," and "this is the system actually needed."

3.2. Utilization of the Integrated System of the Mesh-Network and Portable ICT Unit Connecting Many Base Stations in Disaster Drills

The development of the NerveNet mesh network was explained in Section 2.4. The assumed use scene of the system corresponds to a first aid for communication relief in disaster affected areas with the private wireless network. Furthermore, it is probable to connect important base sites with the private wireless network in a local area ahead of a disaster. Actually, the introduction of a private wireless network among government response centers or disaster base hospitals is being considered separately from public networks. An example of utilization of combined mesh network and portable ICT unit in a disaster drill is explained here. The setting up of alternative response centers in suburban areas is planned in preparedness for the supposed Tokyo Inland Earthquake that can lead to damage to government functions in the Metropolitan area. The drill was conducted to practice the procedure by using a private communication network composed of the NerveNet technology developed in the program.

The mesh network connects 8 nodes (base stations) with the mesh configuration providing robust network connectivity. A portable ICT unit was placed at each base station. A concept of network for the drill is shown in **Fig. 13**. In order to provide communication capability to all participating groups, plurality groups were accommodated under each portable ICT unit. It was verified that eight portable ICT units located at network nodes successfully worked in coordination to create an extension environment for all the terminal devices in the network. In the arrangement, telephone call and teleconference among

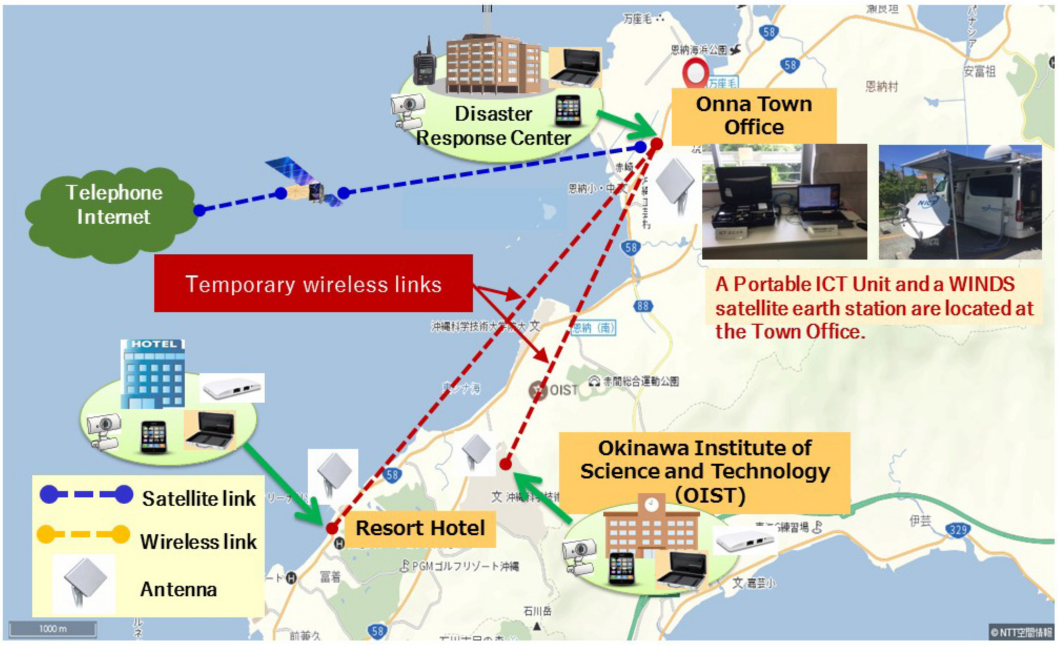


Fig. 12. Overall configuration of the disaster drill at Onna-Town.

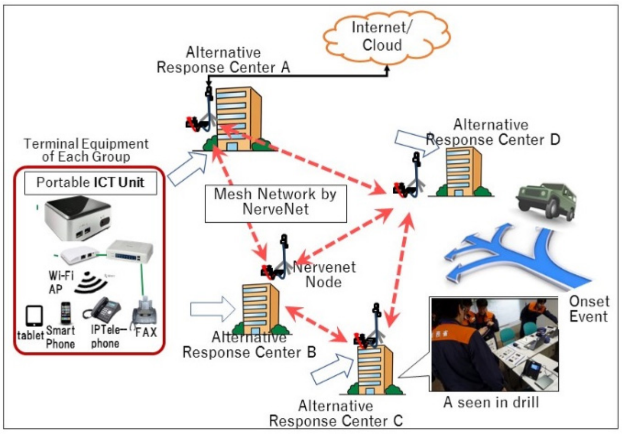


Fig. 13. A concept of network among alternative response centers in drill.

all participant groups were performed by using terminal devices of desktop telephones and smartphones. Document sharing with tablets were performed for all groups, and facsimile and video exchange were also implemented for a few groups. The overall network throughput corresponded to approximately several 10 Mbps and all communication items planned in the drill were successfully achieved. Additionally, various practical drill practices including the Internet connection via network gateway, interconnection with MCA wireless system via a conversion unit, and connection to mobile satellite terminal with portable ICT unit were successfully conducted.

3.3. Progress in Societal Implementation

The cases of societal implementation of the portable ICT units to various institutions increased through promotion activities such as demonstration experiments and drills. Implementation of the units is achieved in the government institutions under several ministries. With respect to the institutions other than the government, the disaster response departments of telecommunications carrier companies and medical institutions introduced them. International standardization of the portable ICT unit (MDRU) is completed in ITU-T in 2016 [16], and this contributed to its introduction overseas. Promotion activities conducted outside Japan are reported by a separate paper in the same issue [2]. Currently, the number of cases wherein the technology was introduced overseas corresponded to 7. The total number of cases of introduction correspond to 53 sets for 19 institutions (as of August 2018).

4. Conclusion

The study describes the results and activities for their societal implementation of the information and communications technologies in disasters in the "Enhancement of Societal Resiliency against Natural Disasters" of SIP. Information exchange capability is the basis of disaster response and recovery, and thus it is extremely important to ensure information delivery and to maintain secure communications in the event of disaster.

With respect to the "delivery technology," two themes were examined, namely a message delivery technique to indoor residents by using a new broadcasting medium and a message delivery measure for individuals with disabilities and difficulties in understanding Japanese in the early warning mail system. A pictogram expression service was added to the early warning mail after Japanese cellphone operators agreed on the pictogram images for earthquake and tsunami alerts. The new functions enhanced disaster measures of the early warning mail that were already in operational service of cellphone operators. A significant achievement in this study of SIP was that the research results were promptly used in societal services with standardization. Although progress was achieved in alert message delivery measures in disasters, a major issue still involved the delivery of messages to residents to ensure prompt action. Further studies should focus on the future direction of disaster message delivery to ensure that all residents receive massages and recognize their meaning correctly.

With respect to the "connecting technology," the portable ICT unit as a communications terminal with many practical functions in the event of disaster was already implemented in more than 50 units in Japan and overseas. The mesh network technology is suitable for connection among sites in disaster area in combination with the portable ICT unit. Public communication networks are well convenient and reliable in normal life, and thus people tend to consider that the public communication networks can be used in the event of disasters as well. However, the lessons learned from the Great East Japan Earthquake indicated that the public communications networks and the Internet connection suffered damage due to tsunamis and longtime power outage. Furthermore, the surge of communication requests immediately after disasters caused traffic congestion leading to communication failure in areas wider than those that were directly affected.

Although, the problem has been currently improved to a certain extent by the efforts of carrier operators in Japan, this does not sufficiently guarantee that the same issue will not recur in the event of a significant disaster. In planning disaster drills, it is necessary to consider that the public communication networks can be disrupted, and thus preparedness for alternative communication means is required in this case. Actually, the mesh network technology and portable ICT unit developed in the study have been utilized in various drill exercises described in Section 3.2. The continuation of technology development and effort for societal implementation will contribute to mitigating damages in coming disasters.

Acknowledgements

The authors thank Professor M. Hori, Program Director (University of Tokyo) and Emeritus Professor Y. Nemoto, Sub-Program Director (Tohoku University) for their continuous guidance and encouragement throughout the study. The study was fully supported by the Strategic Innovation Promotion Program (SIP) of The Cabinet Office.

References:

[1] Y. Nemoto and K. Hamaguchi, "Resilient ICT research based on lessons learned from the Great East Japan Earthquake," IEEE Communications Magazine, Vol.52, No.3, pp. 38-43, 2014.

[2] Y. Shimizu, Y. Suzuki, R. Sasazawa, Y. Kawamoto, H. Nishiyama, N. Kato, A. Yamamoto, and S. Kotabe, "Development of Movable and Deployable ICT Resource Unit (MDRU) and its overseas activities," J. Disaster Res., Vol.14, No.2, 2019.

[3] http://www.jst.go.jp/sip/k08_result.html (in Japanese) [accessed December 7, 2018]

[4] T. Sakano, Z. M. Fadlullah, T. Ngo, H. Nishiyama, M. Nakazawa, F. Adachi, N. Kato, A. Takahara, T. Kumagai, H. Kasahara, and S. Kurihara, "Disaster-resilient Networking: a new vision based on movable and deployable resource units," IEEE Network, Vol.27, No.4, pp. 40-46, 2013.

[5] S. Kotabe, T. Sakano, and T. Komukai, "ICT Service for MDRUs," NTT Technical Review, Vol.13, No.5, 2015.

[6] S. Kotabe, T. Komukai, Y. Shimizu, and H. Tojo, "Realization of resilient ICT by mobile ICT unit," IEICE Trans. Electrn., Vol.J100-C, No.3, pp. 141-148, 2017 (in Japanese).

[7] M. Inoue and Y. Owada, "NerveNet Architecture and Its Pilot Test in Shirahama for Resilient Social Infrastructure," IEICE Trans. Commun., Vol.E100-B, No.9, pp. 1526-1537, 2017.

[8] M. Inoue, M. Ohnishi, C. Peng, R. Li, and Y. Owada, "NerveNet: A Regional Platform Network for Context-Aware Services with Sensors and Actuators," IEICE Trans. Commun., Vol.E94-B, No.3, pp. 618-629, 2011.

[9] Y. Owada, B. Jeong, H. Kumagai, Y. Takahashi, M. Inoue, G. Sato, K. Temma, and T. Kuri, "Resilient Mesh Network System Utilized in Areas Affected by the Kumamoto Earthquakes," 5th Int. Conf. on Information and Communication Technologies for Disaster Management (ICT-DM 2018), S3.5, 2018.

[10] "Google Maps," https://www.google.com/maps [accessed August 21, 2018]

[11] M. Benson, K. L. Koenig, and C. H. Schultz, "Disaster triage: START, then SAVE-a new method of dynamic triage for victims of a catastrophic earthquake," Prehospital Disaster Med., Vol.11, No.2, pp. 117-124, 1996.

[12] M. M. Bin Tariq, M. Ammar, and E. Zegura, "Message ferry route design for sparse ad hoc networks with mobile nodes," Proc. of 7th ACM Int. Symp. on Mobile Ad Hoc Networking and Computing (MobiHoc'06), pp. 37-48, 2006.

[13] "Pe.com.in," http://pecomin.jp/ (in Japanese) [accessed August 21, 2018]

[14] H. Nishiyama, M. Ito, and N. Kato, "Relay-by-Smartphone: Realizing Multihop Device-to-Device Communications," IEEE Communications Magazine, Vol.52, No.4, pp. 56-65, 2014.

[15] H. Nishiyama, T. Ngo, S. Oiyama, and N. Kato, "Relay by Smart Device: Innovative Communications for Efficient Information Sharing Among Vehicles and Pedestrians," IEEE Vehicular Technology Magazine, Vol.10, No.4, pp. 54-62, 2015.

[16] ITU-T Recommendations, "Disaster management for improving network resilience and recovery with movable and deployable information and communication technology (ICT) resource units," ITU-T L.392, 2016.

Name:
Hiroshi Kumagai

Affiliation:
Research Executive Director, Social Innovation Unit, National Institute of Information and Communications Technology (NICT)

Address:
4-2-1 Nukui-kita, Koganei, Tokyo 184-8795, Japan

Brief Career:
1978 Joined Radio Research Laboratory (currently NICT)
2009- Vice President, NICT
2016- Director General, The Resilient ICT Research Center

Academic Societies & Scientific Organizations:
- Institute of Electrical and Electronics Engineers (IEEE)
- Institute of Electronics, Information and Communication Engineers (IEICE)

Name:
Hiroshi Sakurauchi

Affiliation:
NTT DATA Corporation

Address:
3-3-3 Toyosu, Koto-ku, Tokyo 135-6030, Japan
Brief Career:
1988- Development of Road Management System, Nippon Telephone Telegram
1999- Development of Disaster Prevention Systems, NTT DATA Corporation

Name:
Shinsuke Koitabashi

Affiliation:
NTT DATA Corporation

Address:
1-3-5 Sanno, Oota-ku, Tokyo 143-0023, Japan
Brief Career:
1998- Development of Road Management System
2014- Development of Disaster Prevention System
Academic Societies & Scientific Organizations:
- International Tsunami Disaster Prevention Society

Name:
Takeshi Uchiyama

Affiliation:
NTT DATA Corporation

Address:
1-3-5 Sanno, Oota-ku, Tokyo 143-0023, Japan
Brief Career:
1994- Sales and Development of Road Management System, Intelligent Transport Systems, Geographic Information System
2014- Sales and Development of Disaster Prevention System
Academic Societies & Scientific Organizations:
- International Tsunami Disaster Prevention Society

Name:
Shinichi Sasaki

Affiliation:
NTT DOCOMO, INC.

Address:
1-8-1 Akasaka, Minato-ku, Tokyo 107-0052, Japan
Brief Career:
2017- Researcher of NTT DOCOMO, INC.

Name:
Kazuhide Noda

Affiliation:
NTT DOCOMO, INC.

Address:
1-8-1 Akasaka, Minato-ku, Tokyo 107-0052, Japan
Brief Career:
2016- Researcher of NTT DOCOMO, INC.

Name:
Makoto Ishizaki

Affiliation:
NTT DOCOMO, INC.

Address:
1-8-1 Akasaka, Minato-ku, Tokyo 107-0052, Japan
Brief Career:
2016- Researcher of NTT DOCOMO, INC.

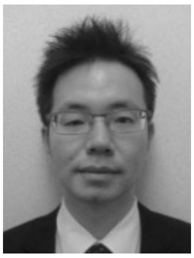
Name:
Satoshi Kotabe

Affiliation:
Senior Research Engineer, Supervisor, NTT Network Innovation Laboratories, NTT Corporation

Address:
1-1 Hikari-no-oka, Yokosuka, Kanagawa 239-0847, Japan

Brief Career:
1995- Joined NTT Laboratories
2012- Development of Movable and Deployable ICT Resource Unit (MDRU), NTT Network Innovation Laboratories

Academic Societies & Scientific Organizations:
• Institute of Electronics, Information and Communication Engineers (IEICE)



Name:
Atsushi Yamamoto

Affiliation:
Senior Research Engineer, NTT Network Innovation Laboratories, NTT Corporation

Address:
1-1 Hikari-no-oka, Yokosuka, Kanagawa 239-0847, Japan

Brief Career:
2003- Joined NTT Network Innovation Laboratories
2009- Engineer, NTT Information Sharing Platform Laboratories
2011- Research Engineer/Senior Research Engineer, NTT Network Innovation Laboratories

Academic Societies & Scientific Organizations:
• Institute of Electronics, Information and Communication Engineers (IEICE)
• Information Processing Society of Japan (IPSJ)

Name:
Yoshitaka Shimizu

Affiliation:
Senior Research Engineer, NTT Network Innovation Laboratories, NTT Corporation

Address:
1-1 Hikari-no-oka, Yokosuka, Kanagawa 239-0847, Japan

Brief Career:
1997- Joined NTT Laboratories
2012- Development of Movable and Deployable ICT Resource Unit (MDRU), NTT Network Innovation Laboratories

Academic Societies & Scientific Organizations:
• Institute of Electronics, Information and Communication Engineers (IEICE)

Name:
Yasuo Suzuki

Affiliation:
NTT Network Innovation Laboratories, NTT Corporation

Address:
1-1 Hikari-no-oka Yokosuka, Kanagawa 239-0847, Japan

Brief Career:
1991- Joined Nippon Telegraph and Telephone Corporation
2008- Advanced Telecommunications Research Institute International
2011- NTT Network Innovation Laboratories

Academic Societies & Scientific Organizations:
• Institute of Electronics, Information and Communication Engineers (IEICE)

Name:
Yasunori Owada

Affiliation:
Resilient ICT Research Center, National Institute of Information and Communications Technology

Address:
2-1-3 Katahira, Aoba-ku, Sendai, Miyagi 980-0812, Japan

Brief Career:
2007- Assistant Professor, Niigata University
2008- President, Space-Time Engineering Japan Inc.
2010- Researcher, National Institute of Information and Communications Technology
2013- Senior Researcher, National Institute of Information and Communications Technology

Selected Publications:
• M. Inoue and Y. Owada, "NerveNet Architecture and Its Pilot Test in Shirahama for Resilient Social Infrastructure," IEICE Trans. on Commun., Vol.E100-B, No.9, pp. 1526-1537, 2017.

Academic Societies & Scientific Organizations:
• Institute of Electrical and Electronics Engineers (IEEE)
• Institute of Electronics, Information and Communication Engineers (IEICE)
• Information Processing Society of Japan (IPSJ)

Name:
Katsuhiro Temma

Affiliation:
Resilient ICT Research Center, National Institute of Information and Communications Technology

Address:
2-1-3 Katahira, Aoba-ku, Sendai, Miyagi 980-0812, Japan

Brief Career:
2016- Researcher, National Institute of Information and Communications Technology

Selected Publications:
• K. Temma, T. Yamamoto, K. Lee, and F. Adachi, "2-step QRM-MLBD for Broadband Single-carrier Transmission," IEICE Trans. Commun., Vol.E95-B, No.4, pp. 1366-1374, 2012.

Academic Societies & Scientific Organizations:
• Institute of Electrical and Electronics Engineers (IEEE)
• Institute of Electronics, Information and Communication Engineers (IEICE)

Name:
Goshi Sato

Affiliation:
Researcher, Resilient ICT Research Center, National Institute of Information and Communications Technology

Address:
2-1-3 Katahira, Aoba-ku, Sendai, Miyagi 980-0812, Japan

Brief Career:
2016- Project Researcher, Iwate Prefectural University
2017 Joined National Institute of Information and Communications Technology

Selected Publications:
• "Resilient Disaster Network Based on Software Defined Cognitive Wireless Network Technology," Mobile Information Systems, Vol.2015, Article ID 308194, 2015.

Academic Societies & Scientific Organizations:
• Information Processing Society of Japan (IPSJ)

Name:
Toshiaki Miyazaki

Affiliation:
Regent and Dean, School of Computer Science and Engineering, The University of Aizu

Address:
Tsuruga, Ikki-machi, Aizu-wakamatsu, Fukushima 965-8580, Japan

Brief Career:
1983 Joined NTT Laboratories
2005- Professor, The University of Aizu
2014- Regent and Dean, School of Computer Science and Engineering

Selected Publications:
• "Demand-Addressable Sensor Network: Toward Large-Scale Active Information Acquisition," IEEE Sensors J., Vol.16, No.20, pp. 7421-7432, 2016.

Academic Societies & Scientific Organizations:
• Institute of Electrical and Electronics Engineers (IEEE)
• Institute of Electronics, Information and Communication Engineers (IEICE)
• Information Processing Society of Japan (IPSJ)
• Engineering Academy of Japan (EAJ)

Name:
Peng Li

Affiliation:
Engineering, The University of Aizu

Address:
Tsuruga, Ikki-machi, Aizu-wakamatsu, Fukushima 965-8580, Japan

Brief Career:
2009-2012 Ph.D. Student, The University of Aizu
2013-2014 Postdoc Fellow, The University of Aizu
2014-2018 Associate Professor, The University of Aizu

Selected Publications:
• "Traffic-aware Geo-distributed Big Data Analytics with Predictable Job Completion Time," IEEE Trans. on Parallel and Distributed Systems, Vol.28, No.6, pp. 1785-1796, 2017.

Academic Societies & Scientific Organizations:
• Institute of Electrical and Electronics Engineers (IEEE) Communication Society
• IEEE Computer Society

Name:
Yuichi Kawamoto

Affiliation:
Graduate School of Information Sciences, Tohoku University

Address:
6-3 Aza-Aoba, Aramaki, Aoba-ku, Sendai, Miyagi 980-8578, Japan

Brief Career:

2011 B.E. degree in Information Engineering from The Tohoku University
2013 M.S. degree from The Graduate School of Information Science (GSIS), Tohoku University
2016 Ph.D. degree from The Graduate School of Information Science (GSIS), Tohoku University
2016- Assistant Professor, The Graduate School of Information Science (GSIS), Tohoku University

Selected Publications:

• Y. Kawamoto, H. Nishiyama, N. Kato, F. Ono, and R. Miura, "Toward Future Unmanned Aerial Vehicle Networks: Architecture, Resource Allocation and Field Experiments," IEEE Wireless Communications Magazine, (In press).

Name:
Nei Kato

Affiliation:
Graduate School of Information Sciences, Tohoku University

Address:
6-3 Aza-Aoba, Aramaki, Aoba-ku, Sendai, Miyagi 980-8578, Japan

Brief Career:

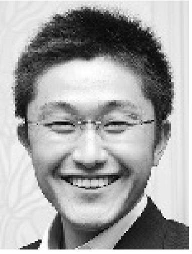
2003- Full Professor with the Graduate School of Information Sciences, Tohoku University
2015- Director of the Research Organization of Electrical Communication (ROEC), Tohoku University

Selected Publications:

• N. Kato, Z. Md. Fadlullah, B. Mao, F. Tang, O. Akashi, T. Inoue, and K. Mizutani, "The Deep Learning Vision for Heterogeneous Network Traffic Control – Proposal, Challenges, and Future Perspective –," IEEE Wireless Communications (WCM), Vol.24, No.3, pp. 146-153, 2016.

Academic Societies & Scientific Organizations:

• Vice-President (Member & Global Activities) of IEEE Communications Society (2018-2019)
• Editor-in-Chief of IEEE Network Magazine (2015-2017)
• Editor-in-Chief of IEEE Transactions on Vehicular Technology (2017-)
• Associate Editor-in-Chief of IEEE Internet of Things Journal (2013-)
• Chair of IEEE Communications Society Sendai Chapter
• IEEE Communications Society (2014-2016)
• Vice Chair of Fellow Committee of IEEE Computer Society (2016)
• IEEE Computer Society Award Committee (2015-2016)
• IEEE Communications Society Award Committee (2015-2017)
• Chair of Satellite and Space Communications Technical Committee (2010-2012)
• Ad Hoc & Sensor Networks Technical Committee of IEEE Communications Society (2014-2015)
• Fellow of IEICE
• His awards include Minoru Ishida Foundation Research Encouragement Prize (2003), Distinguished Contributions to Satellite Communications Award from the IEEE Communications Society, Satellite and Space Communications Technical Committee (2005), the FUNAI information Science Award (2007), the TELCOM System Technology Award from Foundation for Electrical Communications Diffusion (2008), the IEICE Network System Research Award (2009), the IEICE Satellite Communications Research Award (2011), the KDDI Foundation Excellent Research Award (2012), IEICE Communications Society Distinguished Service Award (2012), IEICE Communications Society Best Paper Award (2012), Distinguished Contributions to Disaster-resilient Networks R&D Award from Ministry of Internal Affairs and Communications, Japan (2014), Outstanding Service and Leadership Recognition Award 2016 from IEEE Communications Society Ad Hoc & Sensor Networks Technical Committee, Radio Achievements Award from Ministry of Internal Affairs and Communications, Japan (2016) and Best Paper Awards from IEEE ICC/GLOBECOM/WCNC/VTC



Name:
Hiroki Nishiyama

Affiliation:
Graduate School of Information Sciences, Tohoku University

Address:
6-3 Aza-Aoba, Aramaki, Aoba-ku, Sendai, Miyagi 980-8578, Japan

Brief Career:
2007 M.S. degree in Information Science from Tohoku University
2008 Ph.D. in Information Science from Tohoku University
2012- Associate Professor, Graduate School of Information Sciences (GSIS), Tohoku University

Selected Publications:
- H. Nishiyama, M. Ito, and N. Kato, "Relay-by-Smartphone: Realizing Multi-Hop Device-to-Device Communications," IEEE Communications Magazine, Vol.52, No.4, pp. 56-65, 2014.

Academic Societies & Scientific Organizations:
- Senior Member of Institute of Electrical and Electronics Engineers (IEEE)
- Senior Member of Institute of Electronics, Information and Communication Engineers (IEICE)
- Secretary of IEEE ComSoc Sendai Chapter