Research on the Construction of an Ad-Hoc Network System for Flexibly Dealing with Disasters

Hikofumi Suzuki[1)], David K. Asano[1)], Mitsuru Komatsu[2)], Yuji Takeshita[2)],
Kazuaki Sawada[3)], Masato Futagawa[3)], Hiroaki Nose[4)], and Yasushi Fuwa[1)]

1) Shinshu University, 3-1-1, Asahi, Matsumoto, 390-8621 Japan 2) Okayama University
3) Toyohashi University of Technology 4) Nagano Prefectural Institute of Technology
1) {h-suzuki, fuwa}@shinshu-u.ac.jp

Abstract

In order to mitigate disasters, it is important to collect and use various kinds of information when a disaster strikes. Therefore, it is extremely important create sensor technology for acquiring information and to establish a communication infrastructure for conveying the acquired information. Here, we describe the communication infrastructure.

When a large-scale disaster occurs, the entire communication infrastructure may collapse. Also, when a disaster occurs in the mountainous area, there often isn't even a communication infrastructure present in that area in the first place. Therefore, we designed a communication infrastructure using an ad-hoc network. The ad-hoc network we have in mind does not involve placing transponders in advance, as is conventional, but instead aims to construct a communication infrastructure by quickly establishing transponders in times of emergency. In this essay, we touch on the problems and solutions in ad-hoc networks for creating such a communication infrastructure.

Keywords: Selected keywords relevant to the subject.

1. Introduction

When earthquakes, landslides, or other large-scale disasters occur, the municipalities must collect and transmit various information to ensure damage control. For example, information on how much damage has occurred at each location, or on whether the residents are safe or not, is extremely important. Moreover, the communication infrastructure for transmitting this kind of disaster-related information is also important.

However, if a large-scale disaster has occurred, the communication infrastructure will collapse. For example, in the 2011 Off the Pacific Coast of Tohoku Earthquake (March 11, 2011), the collapse of the communication infrastructure was a major obstacle in information transmission. So when a major disaster like this one occurs, continuity of communications cannot be guaranteed no matter what the method used for ensuring redundancy and robustness in the communication infrastructure. Moreover, if a disaster occurs in an area such as mountain districts where the communication infrastructure has not yet been extended, no communication infrastructure exists to transmit information about the disaster-stricken zone. Furthermore, since it is extremely difficult to predict locations where disasters may actually occur, ensuring redundancy and robustness in a communication infrastructure before the event is virtually impossible. As for this, the sensor network collecting the information of the stricken area is similar. Prior installation of sensor terminals and construction of a sensor network in an area where a disaster is predicted to occur is practically impossibile.

Thus, we have instituted the following objectives for research and development into systems that can reduce the damage during disasters.

(1) Develop a communication infrastructure system capable of a flexible response to disasters
(2) Use the communication infrastructure in (1), Develop a sensor network system capable of flexible response to disasters

With research and development in this system, we have realized a communication infrastructure that is capable of a flexible response when a disaster occurs, and a sensor network capable of collecting various information. In this paper, we describe its feasibility and our efforts to date

2. Research and Development Targets

For the communication infrastructure that is critical when a disaster occurs, rather than attempting redundancy and robustness, our target is construction of a flexible communication infrastructure through quick installation of communication equipment inside a disaster-stricken area. For this communication infrastructure, we decided to use the Ad-Hoc network technology. In other words, quick installation of an Ad-Hoc network of transponders achieves our research and development targets[1-3]. In the same way, for the sensor network to collect information about disaster conditions, sensor terminals will be quickly installed in the disaster-stricken areas. The Ad-Hoc network mentioned above is used, reducing restrictions on installation requirements and enabling rapid collection of disaster information.

To achieve these targets, we have set the following Issues in response to the research objectives above.

(Issue 1) Keep transponder and sensor terminal installation simple
(Issue 2) Develop functions capable of flexible response to transponder and sensor terminal installation conditions
(Issue 3) Achieve a sensor network capable of diverse sensing

Resolution of these Issues can achieve a communication infrastructure and sensor network capable of a quick and flexible response when disasters occur.

To resolve Issues 1 to 3 above, we have further set the following specific targets.

(Issue 1) Keep transponder and sensor terminal installation simple
- (Target 1-1) Automate grasping the transponder status
- (Target 1-2) Make the transponder more compact and lightweight
- (Target 1-3) Achieve diverse installation methods

(Issue 2) Develop functions capable of flexible response to transponder and sensor terminal installation conditions
- (Target 2-1) Automate grouping of transponders
- (Target 2-2) Achieve optimum transponder routing
- (Target 2-3) Achieve function for grasping communication areas

(Issue 3) Achieve a sensor network capable of diverse sensing
- (Target 3-1) Develop a common platform for sensor network terminals
- (Target 3-2) Develop a communications protocol suitable for sensor networks (to forecast landslide disasters)

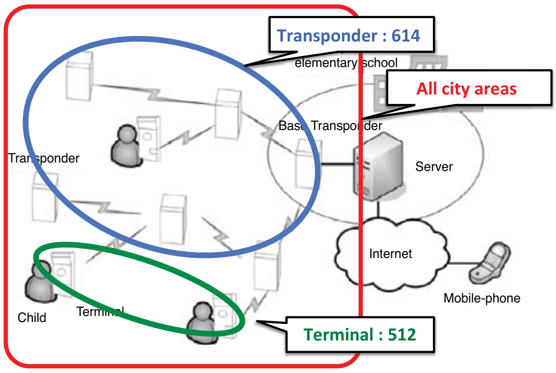

Figure 1: Ad-Hoc network system established in Shiojiri City (since 2008)

3. Efforts to Date, and Feasibility

To achieve the eight targets listed in Target 1-1 to Target 3-2 above, we have implemented various efforts to date. In our current research, we have since 2008 accumulated a performance record installing and operating an Ad-Hoc network of 614 transponders all around Shiojiri City in Nagano Prefecture (Figure 1). [1-3] With use of this Ad-Hoc network as a communication infrastructure, it constitutes a experiment toward achievement of the above-mentioned Targets. Here below we discuss the feasibility of these systems, based on knowledge that we have obtained to date.

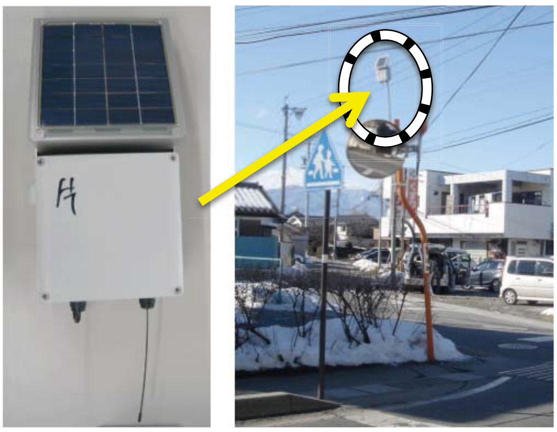

Figure 2: Ad-Hoc network transponder (left) and installation appearance (right)

3.1. Achievement of Compact Transponder and Verification of Ease of Installation

We can use an Ad-Hoc network currently in operation (Figure 1), to verify Targets 1-2 and 1-3. As shown in Figure 2, the transponders that we developed can be installed merely by mounting them on poles, etc., without the use of special tools. The only instruction needed is that the solar cell panel be positioned so that it faces southward. This transponder can be made even more compact, to achieve Targets 1-2 and 1-3.

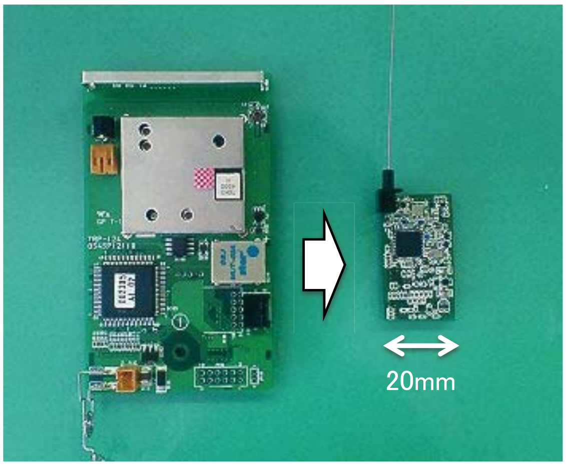

Figure 3: Wireless circuit currently in use (left), and prototype wireless module (right)

Also, in regards to compactness, as shown in Figure 3 we have made the wireless module much more compact. Developing the Ad-hoc network and a sensor network by using this wireless module, we can achieve Targets 1-2 and 1-3 in our research.[3]

3.2. Development of Landslide Sensor Terminal, and Installation in Mountains or Wilderness (Construction of Sensor Network)

Figure 4 shows a landslide sensor network that we have built. The sensor terminals shown in Figure 4 are prototype terminals.[3,4] This sensor network transmits data using the Ad-Hoc network shown in Figure 1 as a communication infrastructure. The sensors mounted in the sensor terminals are EC sensors[5] with low power consumption. We designed the sensor terminals to enable mounting of multiple sensors. As a result, use of this sensor network and sensor terminals enables achievement of Targets 3-1 and 3-2.

3.3. Improvement of Communication Protocols

In sensor networks for responding to disasters, a large number of sensors to confirm the disaster conditions must be installed. Moreover, installation of the sensor terminals and transponders is not really comparable to utilization of sensor networks in agriculture, since design of preset installation locations is difficult.

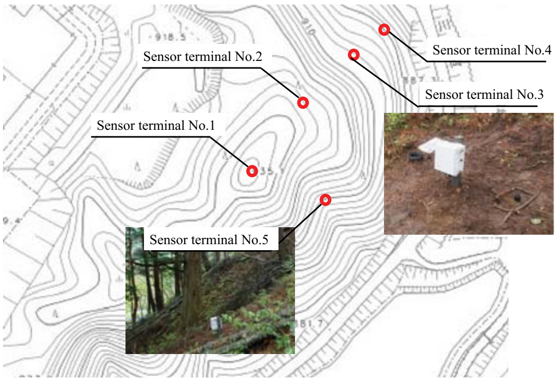

Figure 4: Landslide sensor terminal installed in the mountains of Shiojiri City (in 2012)

As a result, we have developed a protocol that can handle communication without trouble even when large numbers of sensor terminals have been installed. Specifically, we have developed a protocol for efficient communication between the transponders and sensor terminals.[4] Figure 5 shows losses rate in the protocol currently in development as compared to the conventional protocol.

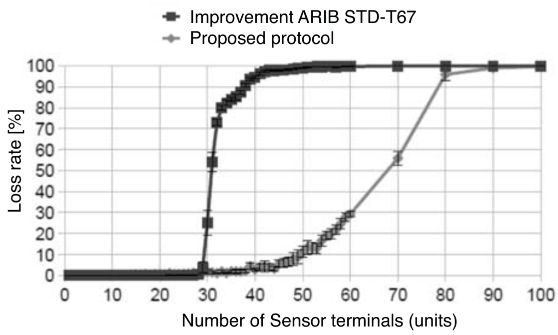

Figure 5: Comparison of loss rates for conventional protocol and proposed protocol

We evaluated this protocol in a simulation. In addition, we mounted the protocol on the sensor terminal shown in Figure 2 and installed it in mountains. This achieves Target 3-2.

4. Future Works

The Ad-Hoc network shown in Figure 1 is characterized by data relayed from terminals to a base transponder. In addition, the relay route is determined by the number of hops from the base transponder (Distance-Vector Method). This route is periodically updated to avoid communication malfunctions. However, the Distance-Vector Method cannot avoid concentration of communications in a few transponders on the route to the base transponder. To resolve this issue, we have verified a new route construction method using a metric that takes the transponder load state into consideration.[4,6] This achieves Target 2-2.

For the remaining Targets 1-1, 2-1, and 2-3, we have put a research and development system in place, and plan to use the Ad-Hoc network shown in Figure 1 to perform verification.

5. Conclusion

In this paper, we discussed the communication infrastructure and sensor network that is critical when disasters occur. As noted above, we use a sensor network for collection of disaster information that is necessary when a disaster occurs, and use an Ad-Hoc network for the communication infrastructure. The redundant or robust methods implemented in communication infrastructure to date are incapable of maintaining communications during large-scale disasters. In addition, since we never know where the disaster itself will occur, installation of sensors or construction of communication infrastructure based on predictions of where disasters will occur is impossible.

In response to this situation, we are engaged in research and development of systems that enable quick construction of communication infrastructure when disasters occur, and of sensor network systems capable of quick collection of disaster information. Since deployment of such a system enables quick construction of a flexible communication infrastructure in various disaster sites, and transmission of critical disaster information, damages from disasters can be reduced. Furthermore, the ability to construct a communication infrastructure without the need for special technical knowledge means that a communication infrastructure could be built even in emerging nations. As a result, this system can also be expected to contribute in the area of international aid.

Acknowledgements.

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References

[1] Hiroaki Nose, Yasushi Fuwa, Masaaki Niimura, Hisayoshi Kunimune, Eiki Motoyama, Haruo Kaneko : Development of Regional Protection System Using a Wireless Ad-Hoc Network; IEICE Trans. B, Volume J95-B, No.1, pp.30-47, Jan.2012.

[2] Hiroaki Nose, Eiki Motoyama, Hikofumi Suzuki, Yasushi Fuwa : Construction and Evaluation of a Regional Protection System Employing Power-saving Wireless Terminals without Using GPS Modules; The Ninth ACM International Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks 2012(PE-WASUN 2012), Proceedings of PE-WASUN 2012, pp.117-121, October 2012. (Paphos,Cyprus)

[3] Hikofumi Suzuki, Daichi Kuroyanagi, David K. Asano, Mitsuru Komatsu, Yuji Takeshita, Kazuaki Sawada, Masato Futagawa, Hiroaki Nose, Yasushi Fuwa: Construction of a Sensor Network to Forecast Landslide Disasters - Sensor Terminal Development and On-Site Experiments; The 11th International Conference on Wired/Wireless Internet Communications (WWIC 2013), June 2013. (Saint-Petersburg,Russia)

[4] Daichi Kuroyanagi, D. K. Asano, Hikofumi Suzuki, Yasushi Fuwa: A Sensor Network Terminal for Disaster Detection; Information and Communication Systems for Safe and Secure Life (ICSSSL) [IEICE], ICSSSL2011-04, Dec.2011.

[5] Masato Futagawa, Taichi Iwasaki, Toshihiko Noda, Hidekuni Takao, Makoto Ishida, Kazuaki Sawada: Miniaturization of Electrical Conductivity Sensors for a Multimodal Smart Microchip; Japanese Journal of Applied Physics, 48, 04C184, 2009.

[6] Shinnichi Karasawa, D.K.Asano, Hikofumi Suzuki, Yasushi Fuwa: A Realistic Evaluation of a Routing Algorithm for a Regional Protection System; Proceedings of the IEICE General Conference, AS-2-1, pp.S-9-10, Mar.2013.