Research and Development Issues of Satellite Communications Systems for Large Scale Disaster Relief

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SUMMARY  It is well known that satellite communications systems are effective and essential communication infrastructure for disaster relief. NICT sent researchers to Tsunami stricken area in March right after the Great East Japan Earthquake and provided broadband satellite communications link to support rescue activities. Through this experience, we learned many kinds of requirements of communications for such purposes. In this paper, we list up the requirements and report what kind of satellite communications technologies are needed, and research and development issues.

key words: disaster relief, satellite communications, broadband, mobile communications, channelizer

1. Introduction

The massive great East Japan Earthquake struck off the eastern seaboard of Japan on March 11, 2011, affecting a wide area ranging from the Tohoku to Kanto regions, triggering a giant tsunami, and leaving thousands of victims in its wake [1].

Following the earthquake, the National Institute of Information and Communications technology (NICT) contributed to rescue activities using the Wideband Inter-Networking engineering test and Demonstration Satellite (WINDS) [2] to provide broadband satellite links between disaster stricken areas and Tokyo headquarters with high definition video conferencing system and IP connection [3]. This experience taught us what kinds of communications are practically needed for rescue teams in disaster stricken areas, and that requirement of communications is changing day by day.

From this point of view, this paper describes how we utilized WINDS system to support rescue activities in disaster stricken areas, requirements of communications for rescue and recovery activities, satellite systems for large scale disaster mitigation and research issues to realize it.

2. Disaster relief Support Activities Using WINDS

The Great East Japan Earthquake attacked eastern Japan on March 11, 2011. Power failure followed the massive earthquake and the tsunami, and the terrestrial networks including cellular phones were damaged. Fourteen thousand cellular phone base stations were rendered unusable and the troubled affected 1.5 million telephone lines. Large scale congestion was brought by the rapidly increased communication traffic at tens of times its capacity.

NICT set up the WINDS transportable earth station at Kesennuma and Higashimatsushima in Miyagi Prefecture and established the temporal broadband satellite link between the disaster stricken area and Tokyo area.

NICT received a request from the Tokyo Fire Department for providing of a broadband link using WINDS between Tokyo and Kesennuma, the tsunami-hit and heavily damaged city, where a Fire Emergency Response Team was sent.

On March 14, NICT prepared the transportable WINDS station and moved to Kesennuma with the Fire Emergency Response Team. The transportable station was set up atop the Kesennuma fire station, where the disaster control station was established. The WINDS broadband link was established on March 15 between the Kesennuma fire station and Tokyo Fire Department headquarters located at Otemachi, Tokyo as shown in Fig. 1. The devices typically used in WINDS experiments, such as the HDTV conference system, IP telephone, and PCs, were connected to the WINDS earth station. These devices were used for gathering local information in the affected areas.

NICT moved the WINDS earth station from Kesennuma to Higashimatsushima. From March 20 to April 5, NICT established a temporally broadband satellite link between Higashimatsushima (Miyagi Prefecture) and Iruma (Saitama Prefecture) as shown in Fig. 2. The NICT Kashima Space Technology Center was also connected to Higashimatsushima in order to give the Internet access.

Fig. 1  Satellite connection between Kesennuma and Otemachi.
3. Requirements of Communications in Disaster Stricken Areas

Through the experience gained in the rescue-supporting activities described above, we learned several issues we have to solve and found that several functions of communication systems should furnish. The following were the requests from rescue teams deployed in the disaster stricken areas.

- a) Keeping link operability between headquarters
- b) Sending large-size files
- c) Exchanging high-definition images
- d) Internet access
- e) Fax transmission
- f) Wireless phone access
- g) Communication with remote places around VSATs

Items a)–d) were executable but the satellite transponder was not used effectively because of assignment of bandwidth was not done flexibly. Items e), f) could not be executed and are identified as future tasks.

We also studied what kind of communication is needed along with timeline from occurrence of disaster as shown in Fig. 3.

Right after a disaster occurs, public sector should send alert to people, gather information of damage and rapidly start rescue activities. In this phase, broadband communication is not required, but highly reliable connectivity is required. Alert system requires effective broadcasting function. Emergency communications terminals held by local government, fire department, etc. require voice communication and simple document communication such as facsimile. From this point of view, satellite communication systems in L/S-band is quite effective.

Ground-based communications infrastructures may be heavily damaged, and base stations of cellular phone system lose battery capacity day by day. Therefore, people need robust communication tool to send and receive safety information among family and community.

In this case, special communication terminal is not suitable for common people, and it is important how quick to recover environment that people can use cellular phone terminal as usual. In this situation, transportable cellular phone base station which equips satellite link connectivity should be delivered in the disaster stricken area as soon as possible. Medium capacity satellite link is required because the base station carries multiplexed information sent from many individual terminals. Therefore, Ku/Ka-band satellite link seems better than L/S-band.

Rescue teams require mainly voice communication during their activities, and terrestrial wireless communication technologies such as wireless mesh system employing white-space radio technology can be applied for it. On the other hand, once large scale disaster relief activities start, conferencing system and data communication systems are required for information sharing among rescue team, headquarters/command, supply depots etc. in order to perform effective rescue activities. For these applications, broadband satellite link in Ku/Ka-band is required.

After a week or so, recovery of terrestrial communications systems is proceeded. In this phase, role of satellite communication systems gradually reduced in an area where rich terrestrial communication infrastructure is facilitated, but in other areas, satellite communication systems are still important to support continuing recovery effort. Wireless communications environment is changing day by day because terrestrial wireless systems gradually recovered. Cognitive radio technology is quite useful in this situation because it can detect available communications links automatically, and utilize those links effectively.

Thus, communications environment is changing day by day, and appropriate communication system for each case is different. Therefore, robust and flexible communication systems should be prepared for disaster relief and recovery. Concurrently, satellite communication systems should be maintained in ordinary time, then it should be usable for common applications and services which can be paid based on healthy economic balance.

4. Satellite Communication Systems and Network for Disaster Relief

4.1 L/S-Band Satellite Communications Systems

As mentioned in previous section, satellite-based mobile phone system in L or S-band is one of essential communications systems for quick start of rescue activities. In order to provide required highly reliable connectivity, L or S-band is appropriate because its characteristics of low rain attenuation and applicability of small antennas and terminals. It is also very useful for monitoring disaster occurrence covering wide area such as tsunami detection in ordinary time.

- (1) Satellite-based mobile phone system

It seems that having two different mobile phone terminals for terrestrial system and satellite system is not practical. A part of IMT-2000 band can be used for both terrestrial systems and satellite systems as shown in Fig. 4. A common
terminal for both systems can be developed and it should be effective in case of disaster as the emergency communication terminal for public sectors such as regional government and fire department. SkyTerra in the U. S. is one of mobile satellite service (MSS)/Ancillary Terrestrial Component (ATC) system providing satellite/terrestrial common terminals.

A Satellite/Terrestrial Integrated Communication System (STICS) [4] is in research phase conducted by NICT in Japan as such system. Figure 5 shows the system concept of STICS. The biggest issue of this system is to avoid interferences between terrestrial system and satellite system. Large scale satellite onboard antenna with low sidelobe, super multibeam, high-linearity amplifier and efficient satellite resource allocation technologies for mobile handy terminal are other technical issues.

(2) Disaster detection networks covering wide area
It is quite difficult to predict when and where a disaster occurs. Therefore, disaster detection network covering wide area is very important. S-band super multibeam technology mentioned above can realize wide coverage sensor networks including oceanic area for this purpose. Especially, offshore tsunami monitoring GPS sensor has been developed [5], and satellite network covering around 100 km offshore area is required for its application. A technical issue for this system is to develop long-life, light-weight, small size and waterproofing satellite communications terminal for sensor node.

4.2 Ku/Ka-Band Broadband Satellite Communications Systems
Satellite based entrance link for cellular phone base station and broadband satellite communication systems are also important factors in disaster recovery phase. For these purposes, Ku or Ka-band system is useful for those applications which require medium to high capacity transmission because it can provide broadband transmission links.

(1) Satellite based entrance link for cellular phone base station
Many temporary cellular phone base stations were delivered when the Great East Japan Earthquake occurred in disaster strucken areas. Many of those equipped satellite link access capability, and satellite systems were used to provide connections between core network and base stations. In order to carry traffic for huge number of victims, medium to high capacity satellite links are required, and small ground terminal is preferable. Therefore, Ku or Ka-band system is appro-
appropriate. On the other hand, hybrid use with S-band system is considerable to avoid disconnection by rain attenuation.

(2) Broadband satellite network
As described in Sect. 2, WINDS system was effectively used to support rescue teams by providing high definition video (HDV) conferencing system and IP connectivity. One of technical issues we learned is to develop easy-to-use ground terminal. Ground terminal for broadband Ka-band satellite system requires high gain antenna, and it is difficult to set up terminal for non-expert operators. The link set up procedure is also complicated when HDV conferencing system or broadband IP connection is provided. In order to utilize broadband communication capability of Ka-band satellite systems in case of disaster, the terminal which can be operated by members of rescue teams should be developed.

Broadband satellite link is also very important for temporary use as trunk line network in case that fiber optic trunk line network is damaged. The biggest issue is congestion control over networks. Firstly, effective frequency/power allocation function for satellite transponders are required. Figure 6 shows a block diagram and operation concept of digital channelizer which can provide such function. This
technology is under development in STICS project, but wide bandwidth channelizer can be applied to Ku/Ka-band systems and contributes to realize effective usage of satellite transponder resources. Secondly, routing schemes to avoid congestion overall satellite/terrestrial network should be developed. This technology has not been studied sufficiently yet, and we should design and demonstrate it as soon as possible.

4.3 System Concept

(1) Space segment
From considerations described above, S-band/Ka-band hybrid satellite network is one of candidates as the disaster relief. Wideband digital channelizer connecting S-band and Ka-band channels is effective to utilize frequency and power resources efficiently. Digital channelizer can include packet based switching function to achieve highly efficient channel utilization by packet-based multiplexing effect. Prototype of digital channelizer is under development in STICS project [5], and we already obtained technical feasibility to realize digital channelizer with more than 100 MHz bandwidth. Multi-port amplifier (MPA) is also effective to enhance efficient use of transponder’s power resource. S-band MPA was developed for ETS-VI launched in 1994 [6], and Ka-band MPA was developed for WINDS and is currently working properly in orbit. Figure 7 shows an example of block diagram of satellite transponder including technologies mentioned above.

(2) Ground segment
Based on the requirement from users in disaster stricken areas, ground terminals shown in Table 1 are needed: a) S-band satellite/terrestrial cellular phone for very important public sectors (up to 10 kbps), b) S-band mobile terminal for rescue teams and various sensor nodes (up to 1 Mbps), c) cellular phone base station with Ka-band satellite based entrance link (1–5 Mbps), d) easy-to-use Ka-band broadband ground terminal (transportable, vehicle mounted, aircraft mounted, etc., 1–50 Mbps). Several technical issues remains to realize these ground terminals. Most important factor to realize these terminals is “easy-to-use” feature because if there are any difficulty for users, the technology cannot be used properly and efficiently in emergency cases. Most of common carriers, manufactures, service providers and R&D organizations in satellite communications field have been aware of this point through experience of the Great East Japan Earthquake, and started to develop easy-to-use ground terminals. We already started to develop easy-to-use Ka-band broadband terminal for WINDS. This terminal has automatic satellite signal capturing, automatic initial uplink testing, association to establish logical link and IP connection functions which can be used without expert engineers. We also started to develop vehicle/vessel mounted type antenna subsystems for Ka-band broadband mobile satellite communication systems which can be used during moving to disaster stricken areas.

![Fig. 7 An example of satellite transponder for disaster mitigation.](image)

<table>
<thead>
<tr>
<th>Terminal type</th>
<th>a) Handy phone type</th>
<th>b) Mobile data terminal</th>
<th>c) Base station entrance terminal</th>
<th>d) Broadband terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission rate</td>
<td>5-50 kbps</td>
<td>up to 1 Mbps</td>
<td>1 - 5 Mbps</td>
<td>1 - 50 Mbps</td>
</tr>
<tr>
<td>Freq. band</td>
<td>S-band</td>
<td>S-band</td>
<td>Ku/Ka-band</td>
<td>Ka-band</td>
</tr>
<tr>
<td>Applications</td>
<td>Emergency important communications for public sectors (voice/fax)</td>
<td>Communications among rescue teams and local command(voice/data/image), sensor networking for information gathering, etc.</td>
<td>Entrance linking for base stations of cellular phone networks</td>
<td>High capacity data, remote conferencing, HD video, etc.</td>
</tr>
<tr>
<td>Key features</td>
<td>Highly reliable connectivity</td>
<td>Highly reliable connectivity and flexible mobility, easy setup, etc.</td>
<td>Highly reliable connectivity, efficient multiplexing, cognitive radio, etc.</td>
<td>Easy deployment and setup, common user I/F, high throughput, etc.</td>
</tr>
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</table>

Table 1 Ground terminals required for rescue and disaster recovery applications.
5. Conclusions

Satellite communications systems are believed to be essential as one of life lines in case of disaster, and we recognized it experiencing to support rescue activities in case of the Great East Japan Earthquake. We also learned the requirements of communications in disaster stricken areas. Based on these experiences, we have studied satellite communication networks for large scale disaster relief. Both of S-band mobile systems providing robust and high reliable communications and Ku/Ka-band broadband systems providing high capacity transmission capability for exchanging enormous amount of data between disaster stricken areas and disaster countermeasure headquarters/public networks are needed. We also point out several technical issues such as digital channelizer, congestion control schemes over network of several different communication systems. NICT focuses on the research and development of those technologies in cooperation with satellite communication systems manufacturers, common carriers, universities, local governments in disaster stricken areas and organizations for disaster relief.

References


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