USE OF QZSS FOR THE ACUTE PERIOD OF DISASTER MITIGATION

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Abstract - In this paper, we report a case study of designing and implementing a system by employing national satellite system, QZSS (Quasi-Zenith Satellite System). Our system is for the Acute Stage of Enormous-scale Disasters Damages Mitigations. We have gone through national crises caused by earthquakes and tsunamis. Through these experiences we have established advanced communication systems and advanced disaster medical response systems. However, Japan was devastated by the Great East Japan Earthquake occurred on March 11th, 2011. Huge tsunamis swept a vast area of Tohoku causing a complete breakdown of all the infrastructures including telecommunications. Communication of emergency information was limited causing a serious delay in the initial rescue and medical operation. For the emergency rescue and medical operations, it is the most important to identify the number of casualties, their locations and states and to dispatch doctors and rescue workers from multiple organizations. In the case of the Tohoku earthquake, the dispatching mechanism and/or decision support system did not exist to allocate the appropriate number of doctors and locate disaster victims. Even though the doctors and rescue workers from multiple government organizations have their own dedicated communication system, the systems are not interoperable. In the area of the disaster management, introduction of cutting edge ICT is urgently needed. In this paper, we propose a design concept of Emergency Temporal Information Network System designed by using national satellite system, QZSS for the Acute Stage of Large-scale Disasters Damage Mitigation. While simulating on the desk, it turned out that it took about 48 hours or more to start the rescue operation after the disaster, around 24 hours after the disaster.

Index Terms - Satellite systems communication, QZSS, Crisis management, Disaster Mitigation

I. INTRODUCTION

The background of our system concept is based on the Great East Japan Earthquake occurred on March 11th, 2011. Through many experiences of national crises caused by earthquakes and tsunamis we have established advanced communication systems and advanced disaster medical response systems. However, Japan was devastated by Huge tsunamis swept a vast area of Tohoku causing a complete breakdown of all the infrastructures including telecommunications. Therefore, we noticed that we need interdisciplinary collaboration between science of disaster medicine, regional administrative sociology, satellite communication technology and systems engineering experts. Communication of emergency information was limited causing a serious delay in the initial rescue and medical operation. For the emergency rescue and medical operations, the most important thing is to identify the number of casualties, their locations and status and to dispatch doctors and rescue workers from multiple organizations. In the case of the Tohoku earthquake, the dispatching mechanism and/or decision support system did not exist to allocate the appropriate number of doctors and locate disaster victims. Even though the doctors and rescue workers from multiple government organizations have their own dedicated communication system, the systems are not interoperable. This paper is structured as follows; we describe our motivation of our developing a system in chapter II. Chapter III shows Ad-Hoc Communication Methods for devastated area, needs to giant disaster occurrence. This chapter has also a reason of choosing QZSS (Quasi-Zenith Satellite System) as our system's component. Double usage strategy of QZSS is described Chapter IV. Chapter V explains our systems design and Chapter VI has our system evaluation.

II. OUR MOTIVATION OF OUR PROJECT

Japan is a country with an advanced telecommunications infrastructure [1]. We are also equipped with an advanced medical response system at the time of disaster [2]. Despite that, Japan suffered a serious damage at the time of the Great East Japan Earthquake occurred on March 11th, 2011. Japan's advanced telecommunications network is used for people to enjoy digital video contents and TV phone calls at normal times. At the time of large-scale disasters, it is also used as a wide-area medical emergency information system. This system is developed by the Health, Welfare and Labor Ministry and it's an application of the public communication network to emergency use. At the time of disasters, doctors and paramedics entered information about the casualties including the medical triage results into the system. Then it allocates patients to emergency hospitals across the nation to provide the appropriate medical care. At the time of 3.11 disaster, the system

was there but did not work as it was intended [3]. Meanwhile, Japan's medical response system for large-scale disasters has been improved through serious disaster experiences [4]. Today, the Japan Self Defense Forces and inter-prefectural medical teams are called to form Disaster Medical Assistance Team (DMAT) at the time of large-scale disasters. At the time of 3.11, DMAT was appropriately formed and dispatched to the disaster sites in Tohoku immediately after the earthquake but failed to maximize its duty [5]. On March 11, 2011, huge tsunamis swept the vast area of Tohoku, causing a complete breakdown of all the infrastructures including telecommunications (Fig. 1). Without tele-communications network available, the wide-area medical emergency information system failed to activate and there was no way to locate casualties who are in need of emergency medical treatment. Without such information available, it is assumed that DMAT was not able to perform its best to save lives. The disaster rescue operation is conducted in four phases: the first 72 hours, one week, one month and until the normal life is restored. At the time of large-scale disasters, the rescue operation during the first 72 hours is critical to minimize the casualties. The successful operation requires accurate information about the number of casualties, their locations and states. And such information must be acquired as soon as possible (Fig. 2). Our concept is to develop a network function that would connect the disaster sites and the new-generation network to communicate accurate information about the casualties during the initial rescue operation. This would significantly increase the survival rate of the casualties. This paper presents why we decided QZSS is the best solution for this challenge and how an operational model of our system would work. Also, the result of simulation is reported.

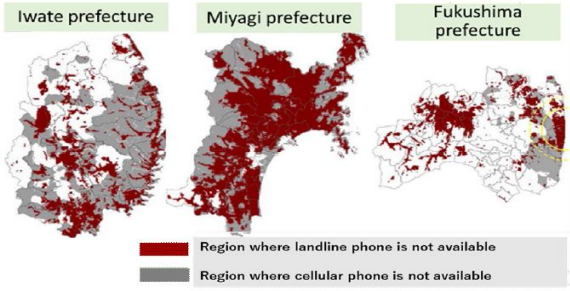


Fig. 1 Communication discontinuation situation 10 days after the disaster occurrence [6]

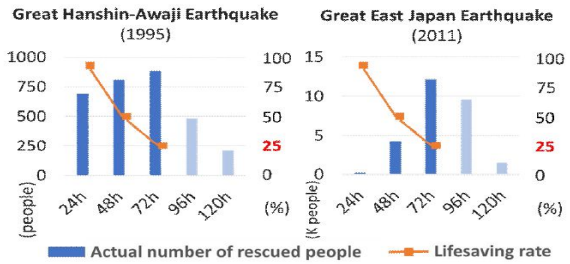


Fig2. Survival rate for rescue by elapsed time after disaster and Actual Numbers of Rescue

III. APPROPRIATE AD-HOC COMMUNICATION METHOD FOR AN AUTE PERIOD OF GIANT DISASTER

The search and rescue are the most important mitigation methodology at giant disaster. We must start the rescue immediately, after occurring disaster. However, the peak of rescue has an awful tendency to reach after 72 hours, as mentioned above. That is because nobody receives the digital signals severe victims, because the areas are devastated and communication infrastructures are also broken. Therefore, crisis measures of communication relaying tools for disaster mitigation are needed. In this chapter, the result of our comparative survey of those tools based on necessary requirement.

A. Ad-Hoc Communication Methods

We selected 6 ad-hoc communication methods based on an investigation. It was executed from the viewpoint of availability for an acute period of huge disaster occurrence. (1) vehicles (passenger cars) with communication relay, e.g. wireless LAN terminals and ARTB STD-T109 mobile communications system on the 700MHZ [6], (2) balloons with the same relay equipment, (3) UAV (Unmanned Aerial Vehicles) with the same one, (4) satellites for commercials, (5) Satellites for scientific experiments and (6) QZSS (Quasi-Zenith Satellite System). A lot of telecommunication companies have been executing experimental stories of how work vehicles with relay equipment for communication break area. UAV and balloons have possibility of covering wide area even with small number of them.

On the other hand, alternative usages of commercial satellites are raised, for instance INMARSAT (international maritime satellite). Also, we have an actual example of utilizing a scientific experiment satellite (Kizuna) for communication between local governments at great east Japan earthquake. QZSS is a Japanese satellite positioning system centered on a quasi-zenith orbit (QZO) satellite. One of the biggest national projects in 21st Century. The satellite positioning system calculates the position information using the satellite signal. One famous example is the American Global Positioning System (GPS). QZSS is sometimes called "Japanese GPS" [7]. We focused on the unique orbit of QZSS. Although the usual geostationary satellite is located on the equator, its orbit is inclined diagonally and it makes it orbit to pass over directly over Japan [8]. However, one satellite is not always staying over Japan. As the orbits are inclined diagonally, the satellite also changes its angle little by little as the Earth rotates, and moves to the north and south. The time that one satellite can stay directly above Japan is about 7 to 9 hours. Therefore, by replacing multiple machines by time difference, one will always stay in Asia and South Pacific (Fig. 3).

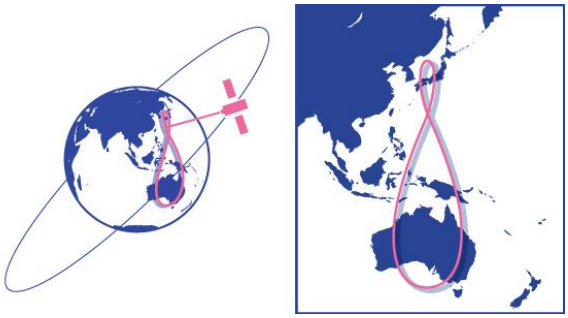


Fig3. QZSS Orbit [8]

B. Critical Needs for Disaster Mitigation

The ad-hoc communication methods for around 24 hours after giant disaster occurrence, must have 2 main needs of performance. Those are (a) communication and (b) operational one. Furthermore, the former is classified 3 and the latter is classified to 3. More precisely, (a-1) coverage for wide area of 100km2, (a-2) less affectedness of weather, (a-3) less affectedness of physical subject (buildings or rocks), (b-1) easiness of operation start-up, (b-2) immediacy of signal sending without waiting time or temporary data storage, and (b-3) safety for avoiding secondary disaster.

C. Methods Comparison

TABLE 1 presents the summarization of above descriptions. The main issue of our challenge is delivering position address of severe victims as mention in Chapter 1. We had better select utilizing satellite communication prefer to select utilizing vehicles with relays. The latter cannot make coverage for wide area (a-1) and less affectedness of weather (a-2). By contrast, satellite communication can. Especially, QZSS has the highest availability between other 2 types of satellite, since it's designed for dual-use operation. However, they can be expected to play a complementary role, even it is hard to play a core role. For instance, Kizuna mentioned above was utilized as a hotline between Iwate prefecture government and Kamaishi city government. Telephone line goes into congestion state, during acute period of disaster. Scientific experimental satellites communication can be adequately adopted as hotlines among critical facilities.

In addition, vehicles with communication relay can be adopted for particular small areas, for instance, where stable communication with artificial satellites cannot be performed due to the influence of such as collapsed buildings, or where much location information exceeding the performance of satellite is transmitted, and so on. Altogether, by selectively placing them, it is considered possible to reinforce communication by satellite, even we need to take measures such as deploying vehicles and balloons all over the country before a disaster occurs.

Table 1 OMPARATIVE RESULT WHICH AD-HOC COMMUNICATION METHODS IS BEST FOR ACUTE PERIOD OF GIANT DISASTER

		With relay			Satellite		
		Car	balloon	UAV	Commercialized	scientific experiments	QZSS
Communicaton Capability	Communication Coverage	×	△	△	○	○	○
	less affectedness of weather	○	×	×	○	△	○
	less affectedness of physical subject	○	○	○	×	×	×
Operational Capability	easiness of operation start-up,	×	×	○	△	×	○
	immediacy of signal sending	○	○	△	○	○	○
	safety for avoiding secondary disaster	△	×	×	○	○	○

IV. DOUBLE-USE STRATEGY OF QZSS

A. Primary Usage Of QZSS

Quasi-Zenith Satellite System (QZSS) in one of Japanese National Project, which is executed by the Management Strategy Division of Space in Cabinet Office Japan. Primary service of QZSS is performing highly accurate positioning by using it with GPS. In order to realize this, positioning signals of the same frequency and same time as GPS are transmitted from QZSS. The positioning distance error caused by the GPS satellite is the sum of satellite orbit error and satellite clock error. The distance is less than 1 m in theory of GPS positioning. However, a large error of about 10 m has occurred, in general. There are two main reasons for this.

One is an error due to a small number of satellites, the other is the error due to the ionosphere. Especially, the latter's radio wave delay due to the ionosphere is occupied the largest part. The ionosphere is the layer of the atmosphere with the electricity in the vicinity of 100 to 1000 km above the sky. The speed slows down; when the radio waves from the satellite pass through the ionosphere. The errors will occur, because calculating the distance between the satellite and the user is executed longer than the actual distance, according to the radio arrival delay. QZSS is a solution to these problems. As described above, the main function of the QZSS is supplementing the US GPS which calculates the position information by radio waves from the satellite.

B. Secondary Usage Of QZSS

QZSS has secondary mission which is executed in the event of devastated disaster. It's called "Q-ANPI." The infrastructures of the disaster area are almost

destroyed, when a large-scale disaster such as a giant earthquake or tsunami occurs. There is a Q-ANPI plan in which the two-way communication function of QZSS, on S band, is used as an infrastructure for the serious disaster area. Some applications are being designed by National teams. For instance, there is a service to notify the location of evacuation centers and information on establishment, the number of refugees and the status of evacuation centers. In Japan, when disasters occur, pre-named public facilities are used as designated evacuation centers. Citizens in the vicinity come to evacuate to them. Rescue measures for these evacuation centers are preferentially taken according to our law. In these evacuation centers, equipment for two-way communication with QANPI is installed.

C. Our System Design Based On QANPI

What we focused on is the hyper acute phase when a huge disaster occurs (chapter 2). In this paper, it means about 24 hours after a disaster. The more severe the disaster, the more destructive the infrastructure is in that area, during this period. Communication infrastructure is no exception. Because of this, rescue experts cannot find out where people need life-saving measures.

And they take about 48 hours after the disaster to search for them. To solve this problem, we decided to solve this problem by developing a dedicated application on the personal computer of the designated shelter where the QANPI communication device is installed. In other words, QANPI is used as an emergency communication infrastructure in the hyper acute period when a huge disaster occurs. We will explain the following two points in the next chapter. One is how to estimate the location of a person who needs life-saving measures and the other is the structure of the whole system.

V. SYSTEM DESIGN

A. Ad-Hoc Network

Our system concept for realizing ad-hoc network is to employ Q-ANPI of QZSS, according to previous section. More precisely, installing a computer equipped with a communication device for Q-ANPI on all evacuation centers in Japan. In Japan, when large-scale disasters occur, public facilities such as elementary schools automatically have the functions of evacuation centers. Meanwhile, it is intuitively conceivable to mount an equipment (chip) that can communicate with Q-ANPI on a smart phone. In fact, a huge development cost occurs. On the other hand, Large-scale disasters occur only once in decades. This clearly shows that it is not cost effective. Therefore, we adopted a method to construct ad-hoc network connecting evacuation center and a crisis management center via Q-ANPI (Fig. 4).

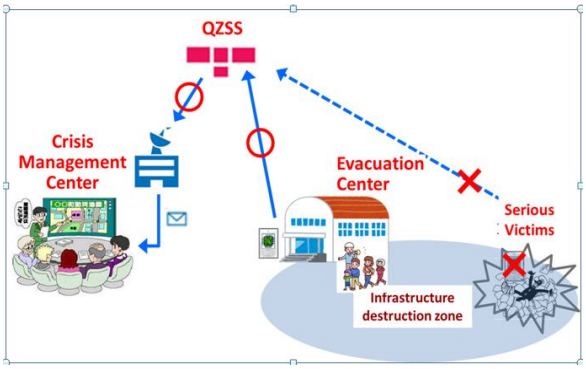


Fig. 4 System Design: Ad-hoc network

B. Application

Our problem consciousness is how to estimate the location of victims who need urgency, as mentioned in Chapter II. As indicated in the previous section, information via Q-ANPI is transmitted from evacuation centers. Therefore, unless there is a victim in charge of a seriously injured person, no one can send the location of them. Therefore, we designed the following method to implement an application for a computer connected to a communication device for Q-ANPI.

We will use the meshed geographic information in MGRS (Military Grid Reference System) [9]. Our application system has data on how many people live per area. For instance, you can see that there are 12 inhabitants in the area in the top leftmost column in Fig. 5. On the other hand, you can also see that 11 people from the same area are escaping to evacuation centers. That means most of civilians can escaped from the area. But then, in the area in the lowermost row on the rightmost row, only 22 people have escaped to evacuation despite the presence of 22 people. It is supposed that this area has severe victims.

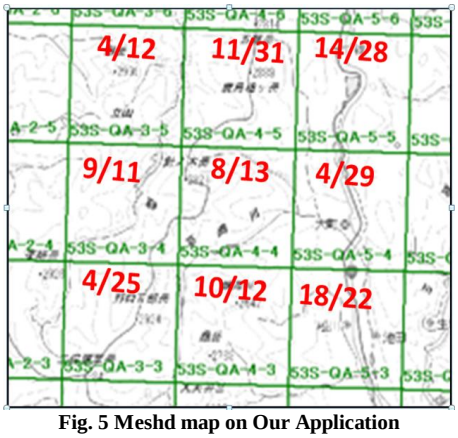


Fig. 5 Meshd map on Our Application

C. Data Transition

The biggest challenge when using Q-ANPI on QZSS as a communication infrastructure is a small transmittable capacity. It is a specification that Q-ANPI receives 9 messages in which 84 bits length each, at regular intervals [7]. Further restricted, the amount of information actually available is 40 bits with one message (Fig. 6). That is, the amount of

information that can be transmitted at one time is 360 bits length. In other words, it was necessary to solve both the problem of waiting until the transmission timing and the problem of capacity limitation. We used the wait time until the transmission timing and decided to accumulate the number of flights from where it ran away for each mesh in the application. This method also contributes to the saving of transmission information amount. Identification of the location of where you escaped from can be expressed in three parts using MGRS. For Japan, as the largest classification method, it applies to either 51R, 52R, 52S, 53Q, 53R, 53S, 54R, 54S, 54T, 55R, 55T or 56R. This information needs 4 bits. Next, the position when it is divided by 100000-meter square is expressed by two letters of alphabet. This information needs 10 bits. The last thing you need is the east longitude and the north latitude, which is expressed as a number from 000000 to 999999. This information needs 20 bits. And the most important point is how many people are escaping from each area (how many people could escape from). With respect to this number, assuming that it can be input to infinity, it cannot transmit with the Q-ANPI specification. Therefore, we asked for directions from experts in disaster medical care, and when we exceeded 63 people we decided to simply treat it as a large number. Due to this restriction, the number of people escaping from each area is 6 bits. Likewise, according to the guidance of disaster medical experts, I decided to send the severity of evacuees. Also, in this case, it is possible to suppress the amount of transmission information by setting the upper limit of the number of people. The TABLE 2 is a summary of the above.

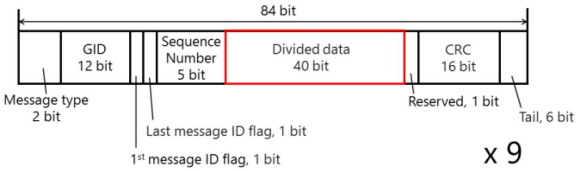


Fig. 6 Q-ANPI message structure

Table 2 DATA DESIGN for applying Q-ANPI specification

Table	Attribute		Data size (bit)	Value range
message ID			8	
Where escaped from?	MGRS identi-fication	Grid Zone Designation	4	51R/52R/52S/53Q/ 53R/53S/54R/54S/ 54T/55R/55T/56R (In case of Japan)
		100000 meter square identifier	10	AA–ZZ
		Easting / Northing	20	000000–999999
	Number of Evacuees		6	0–63
How severe condit-ion?	Lost consciousness		7	0–127
	Oxygen inhaler		5	0–31
	Dialysis		5	0–31
	Medical prescription		5	0–31
	Infant		5	0–31
	Pregnancy		5	0–31

D. GUIs for Systems Operation

Our system design consists of 3 subsystems. One is for evacuation facilities, second is for crisis management center and the last one is for disaster life-saving medical doctors, DMAT (Disaster Medical Assistant Team). Fig. 7 is representative GUIs of one subsystem operated in evacuation facilities during disaster occurrence. The user selects an arbitrary mesh on left map from where he/she escapes, and selects how severe situation on right menus. Fig. 8 is representative GUIs of another subsystem operated in crisis management center during disaster occurrence. Information sent from above evacuation facilities is aggregated and displayed on the meshed map. Also, victim's severe levels are on each evacuation facility. Fig. 9 is representative GUIs of the other system operated by disaster life-saving doctors. They use special protocol for sharing information for disasters and lifesaving, therefore this GUI is designed to handle it. The result of their inputs is available to see on the above subsystem at crisis management center. Therefore, they can utilize this information for choosing and providing an appropriate team of disaster life-saving doctors into each mesh.



Fig. 7 GUI for Evacuation Center



Fig. 8 GUI for Crisis Management Center



Fig. 9 GUI for Medical Doctors at Devastated Area

VI. EVALUATION

We positioned our problem issue in Chapter 1. That is how to suppose the area of severe victims during an acute period of giant disasters. Since it was difficult to do so, it took time to search and rescue started after 48 hours since the disaster. The model is presented as dotted line in Fig. 10. We examined the effect of the developed system. Specifically, in the area where it is expected that the next big earthquake and tsunami will come next time, it was assumed that it occurred, and the application was operated at the evacuation center. As a result, it turned out to be a solid line model in the same Fig. 10.

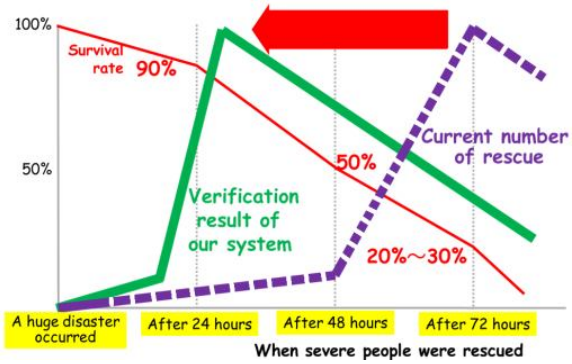


Fig. 10 Result of simulation of how shift will be realized of the peak of rescue and change of survival rate

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