Sensor Network Experiment

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We performed an experiment of a sensor network using Engineering Test Satellite VIII (ETS-VIII). ETS-VIII is equipped with the S-band large deployable antenna, it is suitable for communication with a small and simple earth stations. In experiment using a small and low power consumption terminal and non-directional antenna, confirmed can be to transmitted a sensor data by satellite link. And measured a frame error rate as the basic characteristic, and a level fluctuation by reflected wave from the surface of the water. Furthermore, we performed the data transmission experiment from the buoy, and demonstrated that it is effective as a system for early detection of tsunami.

1 Preface

In recent years, extensive damage has been caused by natural disasters such as landslides due to heavy rain and tsunami on an unexpected scale. It is expected that it will enable early evacuation instructions, accurate rescue and damage mitigation if we can detect such disasters at an early stage. However, in some cases it may be difficult to collect information from the areas where disaster has occurred or might occur. This is due to the difficulty in communicating accurate information and in securing sufficient power. The cause is that supplying electric power and communication means for transmitting the collected information are difficult. We will consider the use of satellite links as a means of collecting information at satellite information service areas that extensively cover the lands and waters of Japan; for example, for the purpose of early tsunami detection, buoys could be placed far offshore.

On the other hand, terminals for transmission of the collected information should be small-sized, light weight and easy to handle so that they can be easily installed at necessary places, and should be operable for a long term period even at a place where is hard to secure a commercial power supply.

Thus, we carried out a communication experiment using the ETS-VIII by developing small and low-power-consumption terminals.

In the experiment, we carried out the measurement of transmission characteristics to the base station from a small terminal, the functional test of the terminal for energy saving, the measurements of the variations in the signal level caused by reflected waves from the water surface, and the experiment of transmission of a wave height information through a satellite link by installing a terminal on a buoy floating on the ocean with the aim of early tsunami detection. In this paper, we will report on the results of this experiment.

2 Overview of a satellite sensor network

The satellite sensor network is a system to collect a data through wired or wireless connections, from many sensors which were installed in needed places for measuring various information. For example, a system that is used for weather forecast by collecting weather information such as temperature and atmospheric pressure that are measured at various places in Japan is also one of the sensor networks.

Here, a sensor network to use the satellite links to transmit measured data will be called the satellite sensor network. Figure 1 shows an overview of a satellite sensor network.

The satellite sensor network is a system for collecting required information and transmitting to the base station via a satellite link by installing small terminals at places where it is not possible to obtain any terrestrial means of communication means and commercial power supply. As illustrated in Fig. 1, we considered that the network is useful for collecting important information for early detection of disasters such as the information on the status of volcanic activities and gas emissions in areas that are difficult of access, the water levels of rivers and dammed lakes made by a landslide in mountainous areas, and on

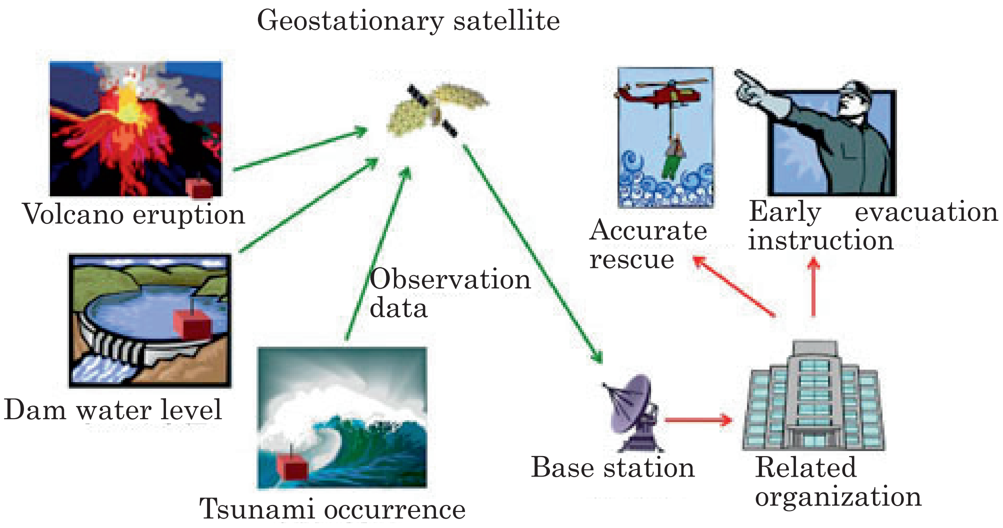


Fig. 1 Overview of a satellite sensor network

situations observed at buoys that are installed far offshore for early detection of disasters. We consider that it is possible to reduce damage by transmission of such information via satellites links to the base stations which are installed at the disaster prevention agency, the early prediction of the occurrence of disasters by based on collected information, and giving an instruction of appropriate evacuation and rescue procedures.

Table 1 shows the main specifications of a small terminal (hereinafter referred to as a sensor station) used for the experiment.

The helical antenna that was used was omnidirectional in the azimuth angle direction and has a gain half-width of about 20 degrees in the elevation direction. The satellite elevation angle is nearly constant at about 45 degrees in Japan; therefore, we can easily install antennas without regard to satellite directions.

The sensor station transmission power and modulation rate are 0.8 W and 250 bps respectively. The sensor station will be required for low power consumption, it is necessary to minimize the transmission output power. Therefore, the received signal level at the base station becomes low, and a binary phase shift keying (hereinafter referred to as BPSK) modulation scheme is used to enable demodulation even with a low S/N (signal-to-noise power ratio). Moreover, synchronization of received signals is made easier at the base station by employing a spread spectrum modulation in secondary modulation. We use time division multiple access (TDMA) as a communication method – the number of multiplex connections is two per carrier for TDMA signals and the transmission frame length is two seconds per connection.

Table 1 Main specifications of a small earth station (sensor station)

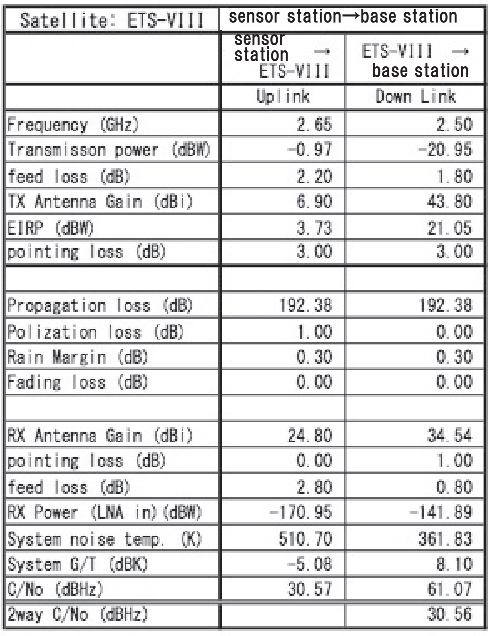
Usable frequency	Transmission, 2.6 GHz band Reception, 2.5 GHz band
Transmission power	0.8 W
Modulation method	BPSK+SS(32 kcps)
Modulation rate	250 bps
Communication method	TDMA (2 multiple/carrier)
Error-correcting system	Code rate for convolution coding R=1/2 constraint length =9 Viterbi decoding
Transmission frame length	2 seconds
Power supply	DC12 V (rechargeable battery + solar cell)
Size	160×240×100 (mm)
Weight	1.5 kg (antenna not included)
Antenna	Helical antenna Gain: Transmission, 6.9 dBi; Reception, 6.5 dBi Directionality: Omnidirectional in the horizontal plane Polarized wave: left hand circular polarization (both transmission and reception)

The number of bits allocated to transferable information, excluding bits for the guard time and preamble for synchronization and the cyclic redundancy check (CRC) code for error detection and bits for convolution coding for error correction, is 184 bits per two seconds – the transmission frame length per connection; thus, the average information rate is 46 bits per connection (184 bit / 2 seconds / 2 connections). Also, it uses the time division duplex (TDD) method for transmission and reception of signal and receives control signals from the base station in between transmissions of frame signals. Consequently, this allows downsizing of equipment because there is no need for a large degree of separation of duplexer. Although we used the antenna both transmission and reception this time because of easiness to install, if the small transmission and reception separated antenna is used, the diplexer is not necessary, and more downsizing of the equipments can be expected.

On the other hand, the base station transmits control signals to the sensor station while receiving frame signals via the satellite from the sensor station. The base station transmits control signals and receives their return signals via the satellite and performs auto frequency control (AFC) to the transmit frequency by the received frequency of such return signals. This is a countermeasure taken to address the issue that the allowable frequency deviation is narrowed when the base station receives signals of a low transmission rate from the sensor station. Also, the sensor station receives control signals from the base station and performs AFC to the frequency of received signals, thereby it can make the frequency deviation received at the base station keep within the allowable value. Moreover, by receiving control signals via satellite from the base station, the sensor station receives the information on the transmission timing of frame signals, and the information of the sensor station, and then carries out data transmission accordingly.

Table 2 shows an example of the link budget. This is an example of a design for communication (return link) assuming the data transmission from the sensor station and the data reception at the base station via satellite. Although ETS-VIII is equipped with a large deployable antenna for S-band, it can provide comparable performance equivalent to 13 m Φ parabolic antenna in orbit, and is appropriate for the sensor network using a small and simple earth station, but from the beginning the satellite was launched, it was in a state that cannot be used the reception large deployable antenna by the failure of the receiving system[1]. For this reason, we used a 1 m diameter parabolic antenna for backup as a reception antenna on the side of satellite. As shown in Table 2, the value of C/No (carrier-to-noise-density ratio) of a return link assumed in the experiment system is about 30.6 dB. When the error rate of frame signals is 1×10^{-2}, that is, when the throughput of frame signals is 99%, the required C/No value which expected 2 dB as the implementation loss of the base station becomes about 30.0 dB, then this system design becomes very few link margin.

Table 2 An example of link budget



Satellite: ETS-VIII	sensor station→base station	
	sensor station → ETS-VIII	ETS-VIII → base station
	Uplink	Down Link
Frequency (GHz)	2.65	2.50
Transmisson power (dBW)	-0.97	-20.95
feed loss (dB)	2.20	1.80
TX Antenna Gain (dBi)	6.90	43.80
EIRP (dBW)	3.73	21.05
pointing loss (dB)	3.00	3.00
Propagation loss (dB)	192.38	192.38
Polization loss (dB)	1.00	0.00
Rain Margin (dB)	0.30	0.30
Fading loss (dB)	0.00	0.00
RX Antenna Gain (dBi)	24.80	34.54
pointing loss (dB)	0.00	1.00
feed loss (dB)	2.80	0.80
RX Power (LNA in) (dBW)	-170.95	-141.89
System noise temp. (K)	510.70	361.83
System G/T (dBK)	-5.08	8.10
C/No (dBHz)	30.57	61.07
2way C/No (dBHz)		30.56

Figure 2 shows the appearance of the sensor station used in the experiment. This design is aimed small and light weight: 160 × 240 × 100 mm in size and about 1.5 kg in weight.

Figure 3 shows the configuration of the sensor station. The sensor station is composed of a satellite communication unit (composed a modem, an up/down converter and a low noise amplifier), a power amplifier, a filter, a duplexer, a control board and others. The control board is to control of the satellite communication unit, and to collect and to confirm data from the sensor, and further, it is equipped a memory which can record the collected data. Also, it performs power control of the satellite communication unit and power amplifier, and has a function to reduce power consumption. Moreover, it has a function to set the time interval of data collection and transmission in 1 minute increments, and sets the time interval to the software of the control board in advance.

Fig. 2 Appearance of the sensor station

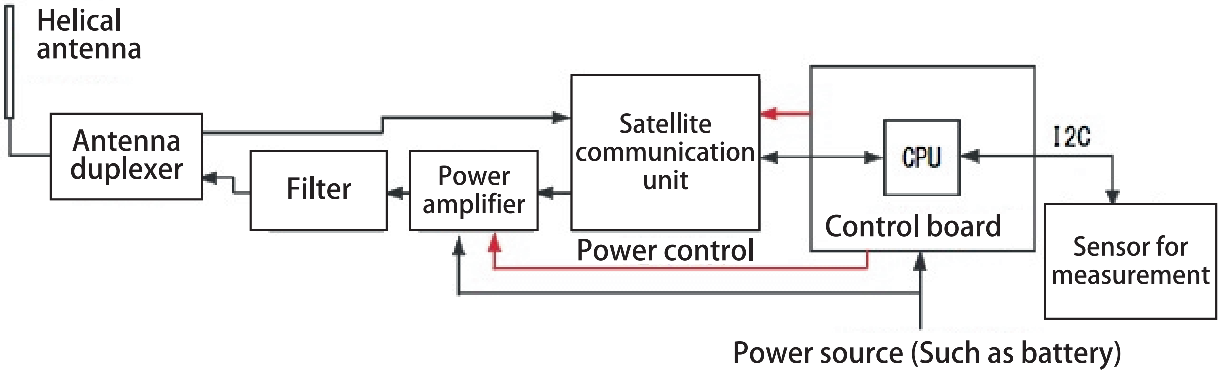


Fig. 3 Configuration of the sensor station

When not transmitting a signal, the power of the satellite communication unit and the power amplifier was in the off state (i.e. in sleep state); it is possible to apply power to them only when signal transmission is necessary. The current consumption of sleep state is about 5 mA, and the current consumption of the signal transmission is about 740 mA, and when waiting for the signal transmission (the satellite communication unit and power amplifier are kept power-on) is about 220 mA; that is, in sleep state is require only 3% of the current consumption compared with the state of waiting for signal transmission.

3 Sensor network experiment

3.1 Measurement of transmission characteristics

Figure 4 shows a configuration of the sensor network experiment. The base station is connected to an intermediate frequency (IF) of 140 MHz band of the S-band reference station installed at the Kashima Space Technology Center and transmits control signals to the sensor station. On the other hand, TDMA signals transmitted from the sensor station are received at the base station via ETS-VIII.

If an error is detected in received data by reference to the CRC code attached to a frame signal when the base station receives the frame signal from the sensor station, such data will be discarded as a frame error. Also, the frame error includes the cases where a frame signal cannot be demodulated due to defective synchronization when the signal is received.

In the experiment, the C/No of received signals of the base station as a parameter obtained the frame error rate (FER), change the C/No of received signals of the base station by changing the transmission power of the sensor station The transmission power was changed by inserting a variable attenuator between the transmission filter and the antenna duplexer. In the actual operation, when received a frame signals from the sensor station at the base station, the strength of received signals is changed. Therefore, the transmission signal level of the sensor station using the variable attenuator was changed and measured the transmission characteristics of the frame signal as the same situation as the actual operation in the base station side.

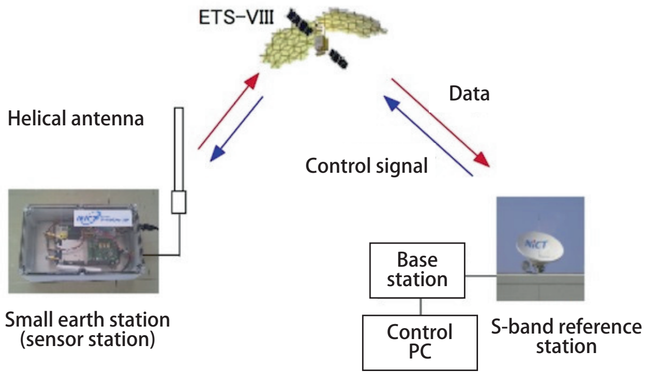


Fig. 4 Configuration of the sensor network experiment

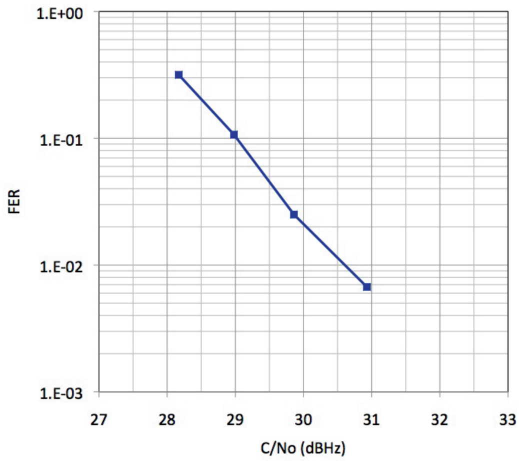


Fig. 5 Transmission characteristics of signals from the sensor station

Figure 5 shows the results. At the maximum transmission power (0.8 W), the C/No of a signal received at the base station is about 31 dBHz, and the FER obtained is about 7×10^{-3}.

The measurement result of transmission characteristics almost corresponds to the result of link budget which shown in Table 2, which verifies that the experimental system performs functions as desired.

3.2 Influence of reflected waves

Sensor stations are assumed to be installed at various places. A sensor station surrounded by buildings is under the influence of reflected waves from those buildings; therefore, greater influence can be expected when an omnidirectional antenna was used in the sensor station use. On the ground, it is possible to install the sensor stations avoiding such influence because it can be seen that those waves are reflected from fixed objects such as the ground and buildings. However, in the installation environment which water surface spreads to the azimuth angle direction of a satellite such as rivers, a lake, and the coastal, the influence of the interference by the scattering waves and reflected waves from the surface of the water is ever-changing by the size and cycle of water surface waves, and was considered that it appears as a signal level variation. Low elevation angle satellites receive more intense reflected waves because direct and reflected waves come from almost the same direction. Therefore, large fluctuations of level in the signals are occurred and known to provide a communication failure[2].

The ETS-VIII used in this experiment did not performed orbit control of the north-south directions at the time of performing the experiment. Therefore, a change in the order of about 48°±3° had occurred in satellite elevation angle. However, the angle is relatively high, and the reflected waves from the water surface come from much lower than horizontal level, so it causes an environment that has a large angle with respect to the direct waves.

In the experiment, in order to obtain data on the influence of reflected waves from the water surface in the case of using such a satellite with high elevation angle, a CW signal was transmitted from the S-band reference station at the NICT Kashima Space Technology Center, received downlink signal from the ETS-VIII, by the antenna of the mobile station and measured the received power.

Figure 6 shows the configuration of the experiment system. The mobile station was placed in a lake (Kasumigaura) that is spread the water surface to the azimuth direction of the satellite, and was the helical antenna which is omnidirectional in the horizontal plane, and has a beam pattern of 30° half width to about 50° elevation angle in the vertical plane. Figure 7 shows the receiving antenna pattern of the helical antenna used for the experiment.

One of the conditions of the water surface was almost calm, and the other one was a state which the wind of a few meters per second blew and waves were generated on the lake surface at the time of measurement. As for wave observations from the coast, for instance, the Japan Meteorological Agency measures significant wave height by using radar and supersonic waves. However, a simplified approach having visual measurements of the variation width at the water surface level from the coast using a scale was employed in this experiment. The variation width of the water surface level was up to about 1 cm in the calm state of water surface and about 10 cm in the state of rippling water surface. Hereinafter, we refer to the calm state of water surface as "no wave," and also refer to the rippling water surface as "10-cm wave height." Figure 8 shows the fluctuations in the received power for 10 seconds. There can be seen a somewhat difference on the average receiving power with and without a wave on the water surface. This is presumably caused by that had

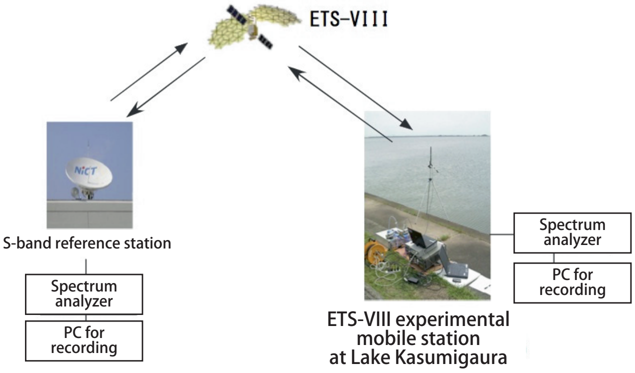


Fig. 6 Experiment configuration

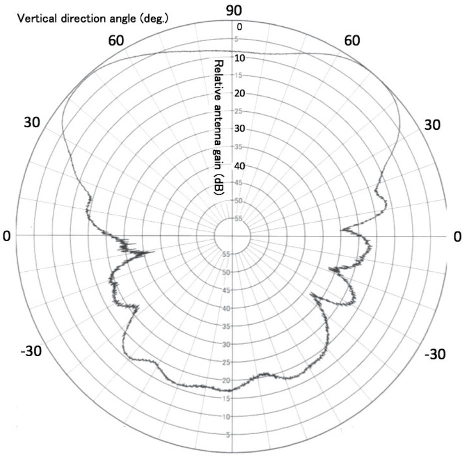


Fig. 7 Reception antenna pattern

somewhat the difference in satellite elevation angle, or that they were measured at a different date and time. Also, it can be considered that the influence of reflected waves changed by the change in the water surface level.

In Figure 8, if there are waves on the lake surface, variation of the received power is somewhat large as compared with the “no wave” case; it is considered as an influence of the interference by reflected waves from the water surface. When measuring the received power by a spectrum analyser for about one hour, and comparing the degrees of variations in the obtained data on received power using the standard deviation, “no wave” case was 0.25 dB and “wave” case was 0.88 dB, so that the variation width was larger in the case of “wave”. The C/N of signal for measuring using a spectrum analyser was 30 dB; sufficient C/N value is ensured for measurement.

Assuming 50° of the satellite elevation angle, the arrival direction of the reflected wave is assumed to be the direction of -50° from the horizontal surface when the lake surface was quiet. From the reception pattern of the used helical antenna, the gain of the arrival direction of the reflected wave is about 15 dB lower than relative to the gain of the satellite direction. It is considered that the variation of the received level is not so large since the signal of the reflected wave is received weakly in comparison with the direct wave. In addition, in the case of “no wave”, the reflection from the water surface will be almost specular reflection; there was observed a so-called “height pattern” in which the signal level varies according to the height of the antenna from the water surface. It is necessary to take the height of the antenna into consideration when installing a sensor station.

3.3 Data transmission experiment from a marine buoy

We conducted a data transmission experiment from a marine buoy aiming for early tsunami detection as a demonstration experiment of a satellite sensor network[3]. The purpose of this experiment is to demonstrate data transmission using satellite links, and obtain the basic data for satellite communication from a specific environment such as marine buoys. The buoy that was used for the experiment belongs to Kochi Prefecture and is anchored on the sea about 35 km offing the south of Cape Muroto. The buoy which was used in the experiments is anchored, but moves to a certain range by the tidal current and such sways by the waves. Consequently, seen from the sensor station fixed on the buoy, the satellite direction is ever changing. The relative satellite elevation angle seen from the sensor station varies depending on sway of the buoy caused by waves, which is between about 40 and 56 degrees. On the other hand, the relative satellite azimuth angle of the satellite changes over to all directions (360 degrees), because the buoy rotated to the left and right.

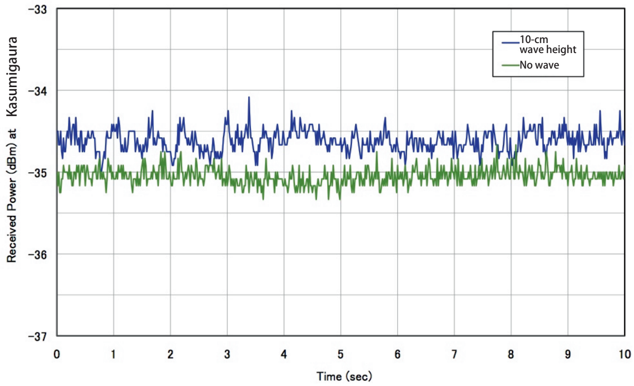


Fig. 8 Fluctuation in the reception level of a mobile station

The antenna used at the sensor station for this experiment is a helical antenna that is omnidirectional in the azimuth angle direction, and the maximum gain direction of elevation angle are about 40 degrees for transmission and about 50 degrees for reception. The beam half-width for each has the characteristics of about 20 degrees respectively, for this reason, estimated that the variations in the signal level caused by swaying of the buoy are about 1 dB in reception, and about 5 dB in transmission. The power supply for buoy mounted devices (such sensor station) is supplied by a buoy-mounted rechargeable battery. The battery is charged by a solar cell. In the buoy, the GPS tsunami gauge[4] to detect the wave information such as the height and period of the waves on the sea, and the inclinometer to measure the data of sway of the buoy, are mounted.

Figures 9 and 10 show the overview and configuration of the marine buoy experiment, respectively. From the lessons learned from the Great East Japan Earthquake, it was required to transmit buoy data to places other than affected areas and to distribute the transmitted data on a real-time basis. Hence the experiment was designed: to carry out measurement by a GPS tsunami gauge mounted on a buoy, to transmit the obtained wave height data (relative change in the height direction of waves of a short period of time) via ETS-VIII to the base station which located at the NICT Kashima Space Technology Center in Ibaraki Prefecture, and then to transmit the data obtained at the base station to the data server at the Kochi National College of Technology (KNCT) through the internet connection on a real-time. The information is usually transmitted through terrestrial radio to the ground base station located on a hill of Cape Muroto, and the data obtained at the ground base station is transferred to the data server of the KNCT through the Internet connection. We used these data in order to understand the situation of the satellite communication also in this experiment.

Figure 11 shows the installation status of a helical antenna. The buoy has a round shape and an eight meter diameter; the helical antenna is fixed at the upper part of the buoy, at about six meter height above the buoy platform. Figure 12 shows the transmission antenna pattern of the helical antenna.

We calculated the throughput of frame signals as transmission characteristics of the data transmission from the buoy to the base station.

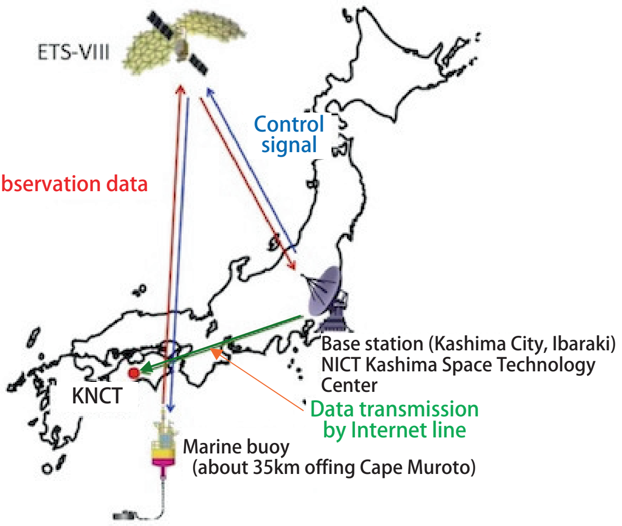


Fig. 9 Overview of the marine buoy experiment

Figure 13 shows the hourly variations in the throughput on a day when the sea wave status was distinctive during the period of the data transmission experiment. The time indicated for each marker is the center time of hourly collected data. Also, Figure 14 shows time variations in the significant wave height* on the sea, obtained on the same day. The significant wave height is calculated from the measurements of wave height for 20 minutes; the horizontal axis indicates time (JST) when the significant wave height was determined.

The data that indicates the throughput of #2 in Fig. 13 was obtained under a condition of relatively calm sea surface with almost no variation throughout the day – the significant wave height was about 1 m as indicated in #2 in Fig. 14. The throughput increased over time. This is considered because: the sea was calm and thus the buoy sway was small; the satellite orbit slightly deviated from the geostationary orbit, the satellite elevation angle became lower in the evening during the experiment period, and thus the transmission antenna pattern of the helical antenna got closer to the maximum gain direction. That is because the ETS-VIII that was used for data transmission had stopped the north-south direction orbit control.

According to the data #1, the throughput from 10 am to 12 am is small as about 0.85–0.90, but increased up to about 0.96 thereafter. The significant wave height #1 is about 1.8 m until 12 pm and then gradually decreased. Also, according to the data #3, the throughput and significant wave height undergo a great change since 1 pm, which reduced is shown clearly that the throughput declines as the significant wave height increases. The data

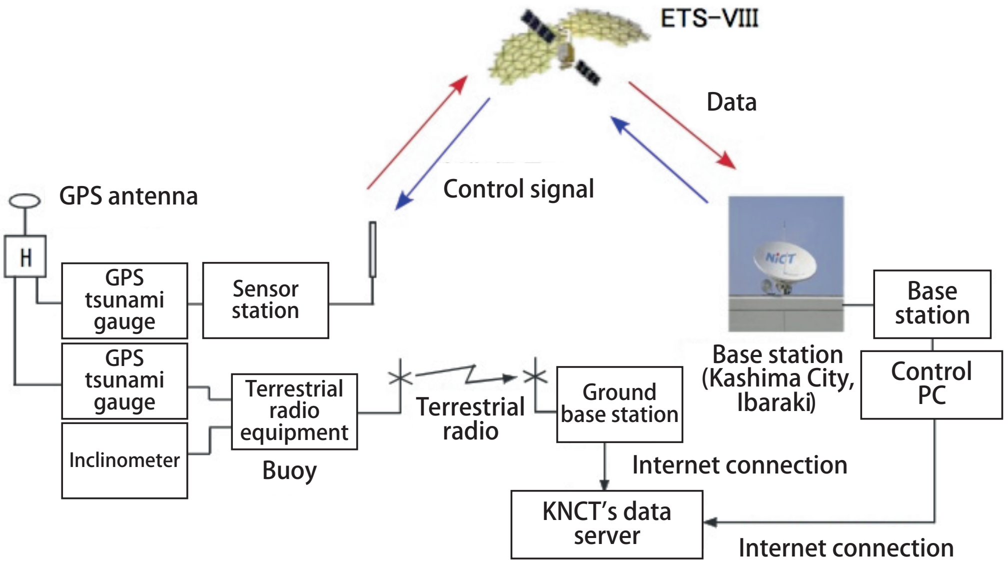


Fig. 10 Experiment configuration

Fig. 11 Exterior of a marine buoy and the status of antenna installation

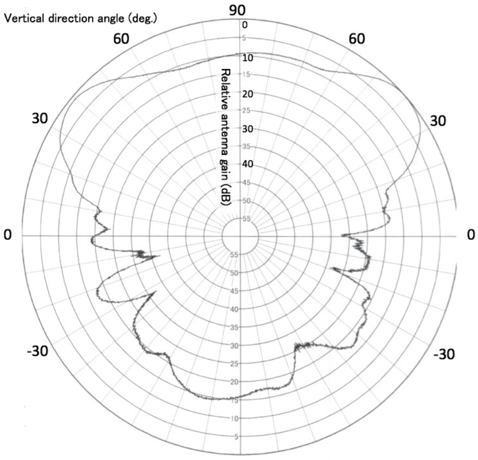


Fig. 12 Transmission antenna pattern

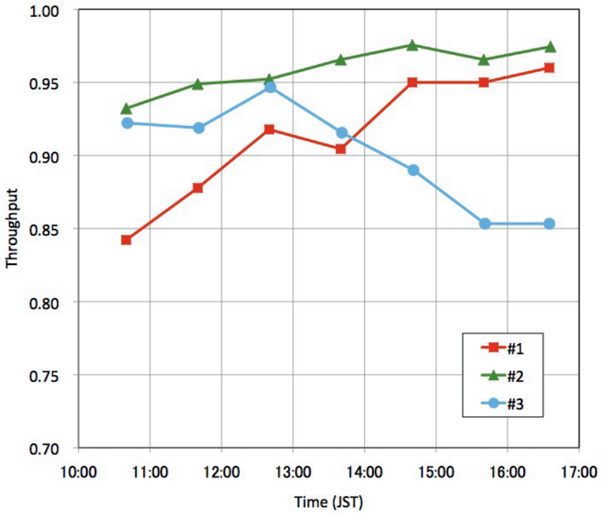


Fig. 13 Time variations in the throughput in data transmission from a marine buoy

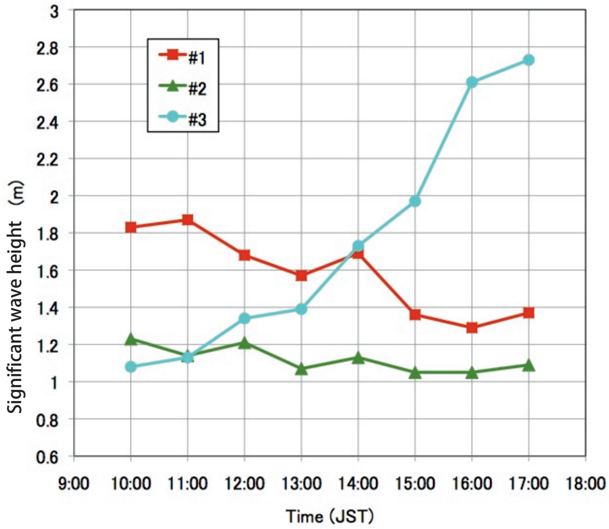


Fig. 14 Time variations in the significant wave height

indicates that there is a strong association between the values of significant wave height and throughput. We considered that the big waves cause deterioration in the transmission characteristics, caused by the sway of the buoy, variations of the value of Effective Isotropic Radiated Power (EIRP) in the satellite direction from the sensor station, and the variation of the value of C/No of signals received at the base station.

The magnitude of buoy sway is measured by using a buoy-mounted inclinometer. When the variations in the relative satellite elevation angle seen from the sensor station are calculated using the measured data, the sway widths are 40.5°–56.2° if the significant wave height exceeds two meters, and 43.9°–52.6°, i.e. narrower, if the significant wave height is at about 0.6 meters.

In this experiment, we studied the influence of the buoy sway caused by ocean waves on transmission signals by mounting a self-developed sensor station on the marine buoy. The wave period observed was a few seconds to ten and few seconds, the change in height of the wave by ocean wave, namely the altitude changes of the buoy follow this period basically. On the other hand, in the case of the tsunami which ranges from several minutes to over one hour in period, the changes in altitude by tsunami and the changes in altitude by ocean waves are easily distinguished by the data. Therefore, as in the present system, if it is possible to transmit the altitude data of the buoy at intervals of a few seconds, but if unable to understand the details of the altitude changed by ocean waves, it is sufficient

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* Significant wave height, Significant wave period

Usually, high waves and low waves are mixed in the sea. The statistics is used as a way of expressing briefly the state of the complex wave. When observing waves continuously at a certain point, the significant wave height and the significant wave period were averaged at a certain period along with wave height which selected the wave number of one-third of the entire from the wave of higher.

for detection of tsunami. However, if a loss of transmitted data occurs continuously, it is conceivable to hinder the detection of the tsunami. To construct a system that transmits data more reliably is a challenge for the future.

4 Conclusion

We conducted a sensor network experiment using the ETS-VIII and acquired the basic data such as transmission characteristics using a small-sized and low-power-consumption sensor station. We confirmed that, in the case of using the same system as used in this experiment, C/No of signal from the sensor station received at the base station was about 31 dBHz and about 7×10^{-3} was able to be obtained as FER. This indicates that there will be one frame error in about 10 minutes and data loss, which will not however be major obstacles if there is no rapid change in the observed data. Also, we installed a sensor station at the edge of the lake and measured fluctuations of received signal power under the environment with reflection and scattering from the water surface, as a result, when waves were high, we observed that despite using a high elevation angle satellite, variation of the signal level is increased due to the reflected waves from the water surface. Since the helical antenna used for the experiment had an antenna pattern which was less likely to receive the reflected waves from the direction of the water surface, that an effect was small. If installing the sensor station close to the water surface, is necessary to consider variations in the signal level by reflected waves and such from the water surface by the antenna to be used. Moreover, the sensor station installed on the marine buoy for the purpose of early detection of tsunami, carried out a demonstration of data transmission from a buoy and acquired the basic data. The data has shown that the buoy sway is a major cause of the deterioration of the transmission characteristics from the buoy to the base station according to the buoy sway and the transmission antenna pattern of the helical antenna mounted on the buoy. In this experiment, we obtained the basic data of the case of data transmission via a satellite link under a special environment such as the marine buoy, and got a lot of knowledge about the satellite communication system to be mounted on the buoy.

We believe the sensor network using a satellite is a valid system for early disaster detection, in order to build a system, it is necessary to examine various installation environments and design a system in which data transmission can be without failure. We considered that the results and knowledge obtained from the experiment is useful for system design.

Acknowledgment

We conducted the experiment of data transmission from the marine buoy in collaboration with the Kochi National College of Technology (KNCT), Earthquake Research Institute (University of Tokyo), Japan Aerospace Exploration Agency (JAXA), and Hitachi Zosen Corporation. We learned a lot from this experiment, which can be conducive to building an early tsunami warning system in the future. We express our hearty thanks to all. Also, we are grateful to Mr. Masahiro AOTA of FUJITSU WIRELESS SYSTEMS LIMITED, and Mr. Takeshi INOUE of FUJITSU Microelectronics Solutions Limited who gave us advices on the operation of the experiment and a great deal of cooperation in conducting the experiment.

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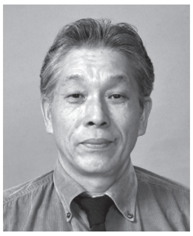

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