Performance Tests of Mobile Satellite Communication System with High Data Rate

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An onboard switch enables satellite communications systems with a multi-beam structure to operate more efficiently. The Engineering Test Satellite VIII (ETS-VIII) with the onboard packet switch has been launched in December 2006. The adoption of the function as bridges for this onboard switch make it possible that the highly flexible network is constructed. The bit error rate test results for the demodulator of the onboard switch on the up-link under the Rician fading environment show that the degradation of performance is 3 dB in the case that the BER is 1×10^{-5}.

1 Introduction

The Engineering Test Satellite VIII (ETS-VIII) launched in 2006 has packet switches for high-speed data communication[1]-[4]. This packet switch mounted on the satellite has functions corresponding to Ethernet bridge and controls address table of MAC address that is an address in the data link layer. In the mobile satellite communication system, the satellite is equipped with a switching function which allows construction of a flexible network and at the same time, improvement of link usage efficiency is expected. After launching the satellite, basic performance evaluation tests of the onboard equipment were performed, and functions and performances of the packet switch as anticipated at the beginning could be demonstrated even in orbit[5]. After confirmation of the basic performances, verification tests as the mobile satellite communication system were carried out including file transfer tests and performance tests while the mobile earth station was running. This paper deals with results of data file transfer test using File Transfer Protocol (FTP) that is a typical file transfer protocol in the communication network and results of the measurement of switching processing time when more than one signal is input to the packet switch. Further, measurements of signal power of the satellite link at movement were made and based on the results of this measurement, mobile environments were simulated by using a fading simulator and bit error rate characteristics in the packet switch under mobile environments were obtained. Results thus obtained are also covered in this paper.

2 Packet switching system

Packet switch (PKT) mounted onboard ETS-VIII is composed of modulation/demodulation unit (PKT-MODEM) and switching control unit (PKT-CONT). As for input/output, it is equipped with 2 ports for feeder link connecting the base earth station using Ka-band (30 GHz/20 GHz) and the satellite, and 2 ports for mobile link connecting the mobile earth station using S-band (2.6 GHz/2.5 GHz) frequency and mobile earth station, and executes switching control of the packet signal on the satellite. The switching control unit is a fully redundant system for the sake of improvement of the reliability and in the modulation/demodulation unit, internal oscillator and command processing systems are also of redundant composition. Since control information for switching is included in the packet, all packet signals to be transmitted are subject to regenerative repeating and switching control is performed based on the control information obtained. Table 1 shows principal particulars of the packet switch.

The earth station used for high-speed data transmission

Table 1 Major specification of onboard packet switch

Modulation:	PI/4 shift QPSK
Demodulation:	Coherent detection
Transmission rate:	1024 kbps
Error correction:	FEC, ARQ
Packet length:	8msec (normal) [32msec at maximum]
Access scheme:	Slotted ALOHA, Reserved packet
Switching function:	Bridges
Size:	MODEM part: 440×285×278 mm, Baseband switch part: 280×285×278 mm
Weight:	MODEM part: 21 kg, Baseband switch part: 11 kg
Power consumption:	MODEM part: 86 watts, Baseband switch part: 34 watts

via packet switch targets vehicle mounted mobile earth station and portable type small earth station, and its Equivalent Isotropically Radiated Power (EIRP) is about 18 dBW and Figure of merit (G/T) is about - 22 dBK. Transmission rate of satellite link is 1024 kbps, error correction is of Forward Error Correction (FEC) using convolution coding (constraint length 7, encoding ratio 1/2)/Viterbi decoding (3 bit soft decision) and in addition, automatic resend processing by Auto Repeat reQuest (ARQ) is performed. If 3 dB is considered for device degradation when information rate is 512 kbps, signal versus noise power density ratio (C/No) with bit error rate of 1×10^{-5} becomes about 65 dBHz[4].

Packet length of a packet signal to be transmitted could be expanded up to 32 msec (max) while standard length is 8 msec. As for the access method, random access by Slotted ALOHA method and packet reservation method are combined to improve link efficiency and to allow for continuous data transmission. Reservation of the slot by packet reservation method is made by sending a burst signal by Slotted ALOHA method. As for switching control, a function for reservation control is added to the switching function corresponding to bridge of Ethernet.

Figure 1 shows the concept diagram of the satellite communication system using packet switch. In the mobile link, one beam in multibeam corresponds to one segment in the network. In the packet switch, address table of MAC address that is address in the data link layer is maintained and controlled. With Ethernet, at signal transmission in the same segment, signal input to the bridge is disposed. Meanwhile, with this system, when earth station, that is address of the packet signal to be input to the packet switch, is in the same beam, that packet signal received is not disposed but subject to processing in the switch and is output to the same beam. On the satellite, the earth station located in each beam is known which means that function identical with location registration function in the mobile communication system having multibeam is available. Software for switching control employs the method of uploading from the earth station to allow for experiments by various protocols. In addition to the above, the packet switch is equipped with an ON/OFF change-over function of FEC, function to transmit a continuously burst packet signal composed of pseudonoise (PN), non-modulated wave (CW) signal transmission function, modulator output signal ON/OFF change-over function and others.

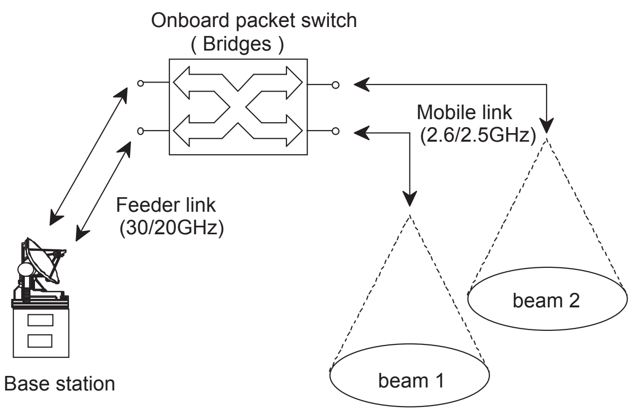

Fig. 1 Configuration of onboard packet switch network

3 Data file transfer experiments

As the basic test of satellite communication systems using digital signals, a data file transfer test was performed using FTP that is a typical file transfer protocol in the network. FTP is a protocol in the fifth layer in the network. As for data transfer by TCP that is a protocol for the fourth layer (next layer below), maximum data transfer rate R is expressed as follows using Round Trip Time (RTT) and Window Size (WS).

$$R = WS/RTT$$

Figure 2 shows results of measurement of transfer speed with regard to window size. Although error correction processing was not provided in the test, the level of signal power vs. noise power density ratio (C/No) of the link is sufficiently high and no data error was noticed at file transfer. Actual measurement of RTT is 735 msec on average, while Fig. 2 shows maximum transfer speed of

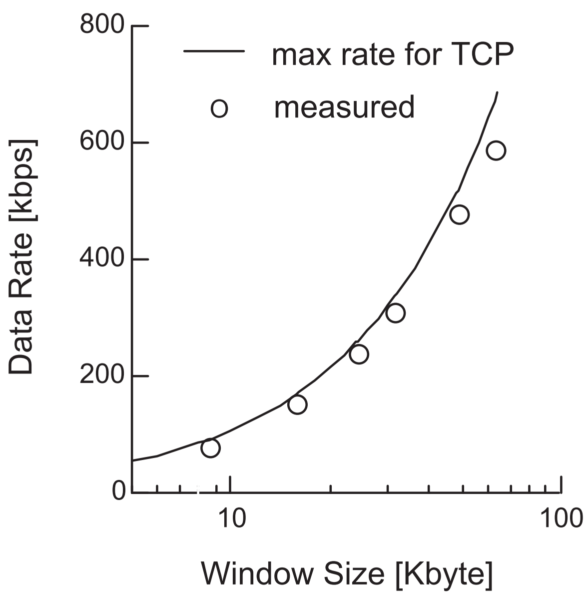

Fig. 2 Data transmission test using FTP

TCP when RTT is 735 msec. Although the data transmission rate degraded slightly with WS of 64 Kbyte, this is considered to be attributable to influences of slow start by TCP because size of the file transmitted is about 3.5 Mbyte and time for transmission is comparatively short (about 50 sec). As shown, the measured value is nearly identical with the maximum transfer speed and from this, it was demonstrated that the bridge function of the packet switch is functioning as prescribed on the network.

4 Characteristics of switching processing time delay

Although as a result of the basic performance evaluation test, packet signal processing time delay is about 85 msec on average, only one packet signal is sent in this test for measurement of processing time delay[5]. In reality, however, more than one packet signal is sent from more than one mobile earth station and switching control is made. Then, processing time delay according to the traffic amount of the signal to be input to the switch was measured for performance evaluation. As shown in the concept diagram of communication system in Fig. 1, the packet switch has four input/output ports and switching control is performed between them. In the measurement, the packet signal for congestion is input to one of these four input/output ports and packet signal for processing time measurement is input to another one port. Packet signal for congestion and packet signal for processing time measurement are output from the same port and the time needed for switching processing of the packet signal for processing time delay measurement is measured, while the number of packets per unit time of congestion packet signal to be input is changed. In the measurement of processing time, the difference of signal transmission time between transmission time of a signal via packet switch and transmission time of a signal in bent pipe mode not via packet switch is measured by a spectrum analyzer to obtain switching processing time delay in the packet switch. The packet switch has four sets of modulator/demodulator corresponding to each input/output port. Then, the packet signal for congestion is sent from No. 3 (DEMOD3) of the demodulator to No. 4 (MOD4) of the modulator and at the same time, received signal of No. 2 (DEMOD2) of the demodulator is sent to No. 4 (MOD4) of the modulator, and the processing time delay for the case congestion signal exists is measured. Meanwhile, processing of error correction code (FEC) is not made in the test.

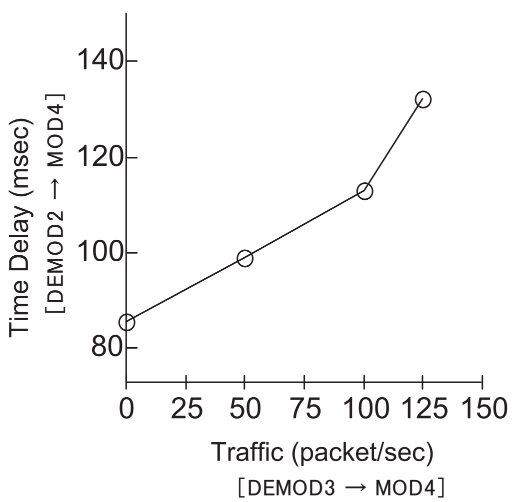

Fig. 3 Processing time delay with traffic

Figure 3 shows results of the measurement. Slotted ALOHA method is used for the access method of the packet signal, while its slot length is 8 msec. The satellite sends an information packet signal for controls every 128 msec and the maximum number of packets per sec capable of being accommodated in the downlink that is a link from the satellite to earth station is calculated to be (128/8-1)/0.128 = 117.2, i.e., 117 packets. The packet switch employs a simple method by which signals received are processed sequentially and sent to the transmission side. If traffic amount of signals to be processed by the packet switch is less, time for switching processing increases in proportion to the increase in the traffic, while if traffic amount exceeds the circuit capacity of the downlink, time for processing increases suddenly.

Although the packet switch uses a simple processing method called First-In-Frist-Out, it is supposed that urgency, real-time feature and the like are required depending on the contents of data. It is therefore considered that QoS control which controls the quality of network service is essential to future satellite mounted switches.

5 Transmission characteristics under mobile environments

5.1 Signal transmission characteristics in down-link

It is known that when the satellite could be seen through in the mobile satellite communication, transmission signal power value of the radio wave from the satellite during movement is in accordance with Rician distribution[6]. Measurement of transmission signal power by running a test was performed in Kashima City, Ibaraki Prefecture, around Mito station, Makuhari district, Chiba Prefecture, and around Chiba station. As for the antenna of mobile earth station, a helical antenna with beam half-width of about 30° which is omnidirectional in azimuth direction and points nearly satellite direction in elevation angle direction is used. Figure 4 shows measurement example. Meanwhile, acquisition of received power data is made every 6 mm of the movement.

A curve shown at the upper portion of Fig. 4 shows the received power fluctuation aspect while moving along the road around Chiba station in an area of office buildings several stories high and the satellite could be observed. Lower data was taken while travelling close to the sound barrier on the expressway where the satellite could be seen also. The satellite is located at diagonally forward from the left of the direction of running (nearly ten o'clock), elevation angle of the satellite is 48°, the sound barrier is at the right (nearly three o'clock). It is considered that reflected waves from the sound barrier are also received which is known from wider fluctuation width of the level.

As for statistical properties of level fluctuation in each level, CM ratio that is a parameter showing ratio of power of direct waves to power of indirect waves (reflected waves and scattered waves) in Rician distribution became nearly identical with the distribution of 21.5 dB and 10.5 dB, as shown in Fig. 5. Solid lines show each of the theoretical curves, mark × and mark ○ show cumulative distribution of the measurements, respectively, and the dotted line shows the theoretical line of Rayleigh distribution. Meanwhile, signal power versus noise power density ratio (C/No) in the received signal is being set to about 60 dBHz and the resolution band width (RBW) of the spectrum analyzer used in the measurements is set to 1 kHz and therefore, SN ratio of about 30 dB is secured in the measurement.

Data were taken while travelling in Mito City and Makuhari district. Characteristics obtained are identical with Rician distribution around 20 dB in terms of CM ratio. In the suburbs such as Kashima City, level fluctuation is not significant and CM ratio obtained from the data acquired is higher (about 25 dB), but SN ratio at the measurement is 30 dB which is not sufficiently higher as compared with CM ratio. Data acquired is greatly influenced by white noise in the receiving system and it may be said that although CM ratio could not be obtained directly, moving environments of more than about 25 dB as CM ratio were used.

5.2 Signal transmission characteristics in uplink

Although measurement examples in the downlink are shown in **5.1**, in the experiments, receiving performances of the regenerative repeating device onboard the satellite are measured. It is then necessary to grasp characteristics in the uplink that is a link going to the satellite from the mobile earth station. The receiving system of the large deployable antenna of ETS-VIII is unable to be used due to trouble, while the backup parabola antenna with 1 m diameter is used for communication signal receiving[6] and receiving gain is about 20 dB lower than the anticipated level. For this reason, available link quality of the uplink is low and even if a high power amplifier (40 W) is used in the mobile earth station, C/No value ensured is around 47 dBHz. At the measurements, signal is received by the mobile earth station and at the same time, signal is transmitted from the mobile earth station. The satellite is

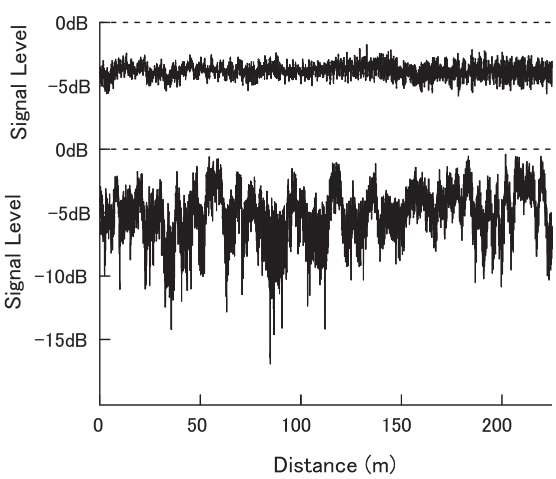

Fig. 4 Examples of receiving signal level on the down-link

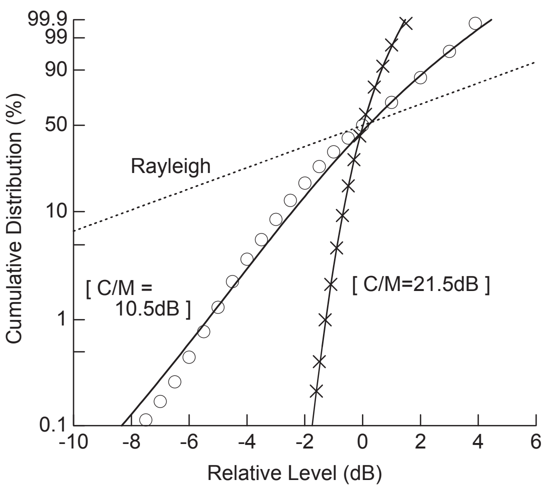

Fig. 5 Cumulative distribution of the received signal level for the down-link

set to bent pipe mode for repeating the signal and signal power measurement was made by the base station side. Resolution band width (RBW) of the spectrum analyzer used in the measurement is set to 1 kHz in the same way as mentioned in **5.1** and therefore, the SN ratio in the signal measured is about 17 dB. When SN ratio is low, statistical processing like in case of high SN ratio is difficult; however, it is assumed that fading in the uplink also follows Rician distribution according to [Reciprocity theorem]. Then, a link that ensures C/No value of about 47 dBHz is set, transmission signal passed through the fading simulator is sent to the uplink to acquire the data, data by the fading simulator and data taken during movement is compared to the assumed CM ratio in the uplink. Results obtained are shown in Fig. 6.

In Figure 6, mark × and mark ○ show cumulative distribution of each measurement, respectively. The CM ratio is changed by the fading simulator, data is taken and a comparison is made. As a result, the CM value showed distribution similar to the measurements, 14 dB and 6 dB, respectively. The Data of CM ratio 14 dB and 6 dB is shown by solid lines in Fig. 6. It is therefore assumed that the distribution in the uplink will follow Rician distribution, the CM ratio in the uplink is lower than those in the downlink shown in **5.1** (21.5 dB and 10.5 dB). This is considered to be attributable to the differences between the transmission antenna pattern and the receiving antenna pattern of the mobile earth station. Differences of the two are such that with transmission antenna pattern, maximum directivity in elevation angle direction is about 40° and beam half-width value is about 25° while with receiving antenna pattern, maximum directivity in elevation angle direction is about 50° and beam half-width value is about 30°. In the present measurement, about 10 dB difference is caused in the dynamic range in receiving and transmission and therefore, when designing a satellite communication system, care should be taken of differences of transmission and receiving antennas.

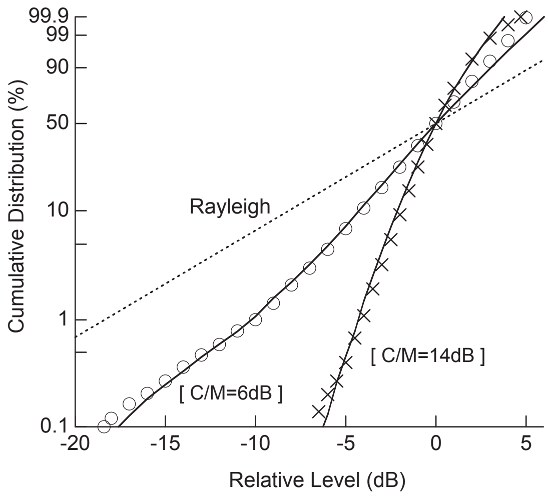

Fig. 6 Cumulative distribution of the received signal level for the up-link

5.3 Bit error rate characteristics

Bit error rate that is a basic performance of the demodulator on the satellite is measured. Composition as shown in Fig. 7 is used, fading caused in the uplink during movement is simulated using a simulator, and a large parabola antenna with 3.6 m in diameter is used for the earth station. This is because as mentioned previously, use of receiving systems of large deployable antenna for the satellite is not possible and therefore, link quality is too low to obtain data directly by running the mobile earth station.

As mentioned in **5.1**, it is assumed that fading occurring in the uplink follows Rician distribution and then, bit error rate characteristics are obtained with several CM ratios using a fading simulator. Although the packet switch itself onboard the satellite is not equipped with a device capable of measuring bit error rate, such a function is provided that signal demodulated on the satellite is modulated without modification and transmitted. Since link quality in the down link is sufficiently high, bit error observed by the earth station is identical with bit error in the packet switch demodulator. Results obtained are shown in Fig. 8. In Figure 8, are shown characteristics with error correction and without error correction for CM ratio of

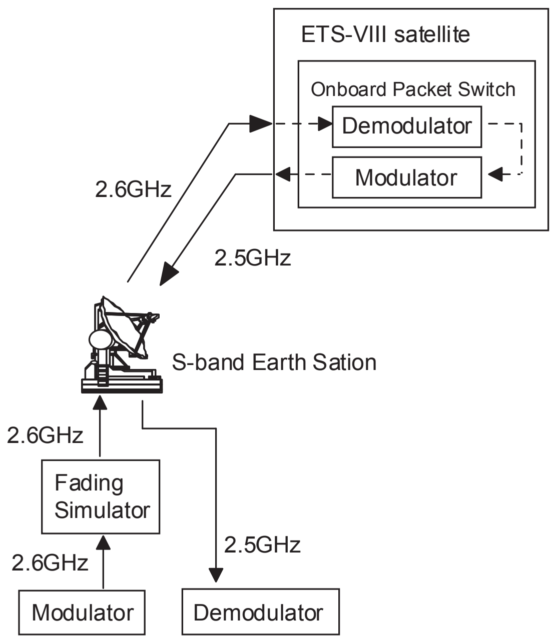

Fig. 7 Block diagram for BER performance measurement

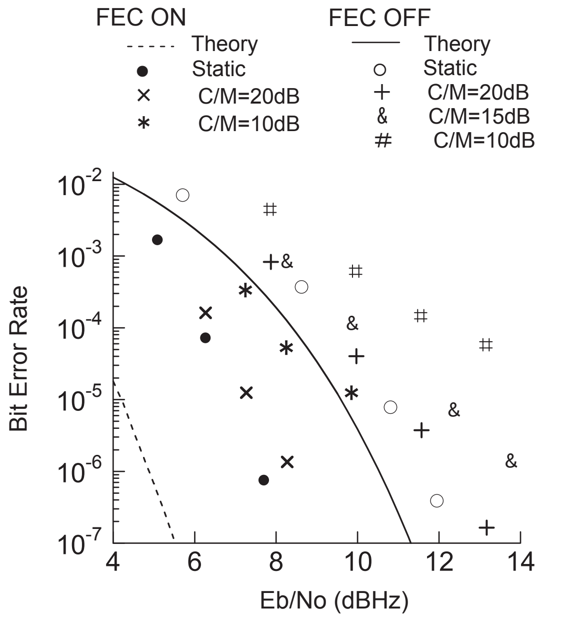

Fig. 8 BER performance under Rician fading environment

20 dB and 10 dB, and characteristics in static condition without fading.

The switch mounted on ETS-VIII is designed with high-speed and wide range capturing for demodulation[7], and no special fading measures is provided to the modulation/demodulation unit. As shown in Fig. 8, the amount of degradation from static condition is about 3 dB for the case where CM ratio is 10 dB, with error correction, and bit error rate is 1×10^{-5}. Particularly with uplink in the mobile satellite communication system, link margin is insufficient in many cases and it is therefore considered that the influence of degradation amount is significant. Measures for fading should be provided in the future development of satellite mounted switches.

6 Conclusions

Performance evaluation tests of high-speed data communication system for mobile object using satellite mounted packet switch were performed. It has been revealed that in the test using FTP that is typical data file transfer protocol, the system develops performances nearly close to the theoretical value. It is also confirmed that signal the processing time delay in the system increases in proportion to traffic volume and if link capacity of the downlink is exceeded, signals are accumulated in the switch memory and processing time delay increases suddenly. It is considered that for future satellite mounted switches, QoS control function considering signal processing priority should be taken into account in lieu of simple processing as used in the present study. The packet switch was developed to be used exclusively for mobile satellite communication and therefore, bit error rate performances of the demodulator under fading environments were acquired. In the test, first, signal power measurements in the uplink during movement were carried out, it was shown that fading characteristics follow Rician distribution as the result of statistical processing of the data acquired, fading environments which follow Rician distribution was then simulated by the simulator, and bit error arte characteristics in the uplink were obtained. As a result, the amount of degradation of Eb/No value from still state was about 3 dB for the case where error correction was made with CM ratio of 10 dB and bit error rate of 1×10^{-5}. Although countermeasures for fading is not provided for the packet switch in ETS-VIII, it is considered that this issue may be significant particularly in the mobile satellite communication system having such a feature that link margin of the uplink is insufficient.

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References

1 S. Taira, Y. Matsumoto, S. Hama, and N. Hamamoto, "An onboard packet switching system for the mobile satellite communication network," 49th International Astronautical Congress, Paper Number: IAF-98-M.3.03, Sept. 1998.

2 N. Hamamoto, Y. Hashimoto, M. Sakasai, Y. Tsuchihashi, and M. Yoneda, "An experimental multimedia mobile satellite communication system using the ETS-VIII satellite," AIAA-98-1301, A collection of technical papers of 17th International Communications Satellite Systems Conference, pp. 408–416, Feb. 1998.

3 S. Taira, T. Ide, and S. Hama, "Development of an onboard packet switch for the mobile satellite communication system," 18th International Communications Satellite Systems Conference, Paper Number: AIAA-2000-1111, April 2000.

4 S. Taira, M. Tanaka, and Y. Hashimoto, "An Experimental Mobile Satellite Communication Network with an Onboard Packet Switch System," 2002 IEEE 56th Vehicular Technology Conference, Sept. 2002.

5 S. Taira, S. Yamamoto, S. Kozono, and M. Yoneda, "Performance of an Onboard Packet Switch for Mobile Satellite Communications in Geostationary Satellite Orbit," 59th International Astronautical Congress, IAC-08-B2.2.9, September 2008.

5 J. Takada, "Radiowave propagation for mobile satellite communications," IEICE Technical Report, SAT2004-168, Feb. 2005. (in Japanese)
6 H. Noda, K. Sano, and S. Hama, "High Accuracy Clock," pp. 101107, Vol. 50, Nos. 3/4, Sept./Dec. 2003.
7 M. Yoneda, O. Takeda, Y. Tsuchihashi, N. Hamamoto, and S. Taira, "The Characteristics of Digital Modulation and Demodulation for Engineering Test Satellite-VIII (ETS-VIII) Onboard Packet Switch," IEICE Technical Report, 19th International Communications Satellite Systems Conference, Paper Number: AIAA-2001-051, April 2001.

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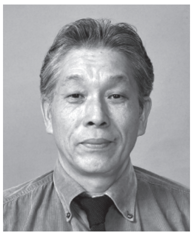

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