3-4 622/1,244 Mbit/s Dual Rate High-Speed Burst Modem TDMA Satellite Communication Experiments

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The WINDS communications satellite was jointly developed by the National Institute of Information and Communications Technology (NICT) and the Japan Aerospace Exploration Agency (JAXA). Using an H-IIA Launch Vehicle, WINDS was successfully launched on February 23, 2008 to establish an advanced communications network. In addition, a 622/1244 Mbit/s high-speed network using the bent-pipe relay mode of WINDS was developed by the NICT. We designed and developed a 622/1244 Mbit/s dual-rate burst modem, a Large Earth Terminal (LET; diameter, 4.8 m), and two Super-high Data Rate Very Small Aperture Terminals (SDR-VSAT; diameter, 2.4 m diameter) for high-speed satellite communications experiments. After the launch of WINDS, 622/1244 Mbit/s transmission tests were conducted on this system. This paper discusses the experimental bit error rates (BER) and UDP/TCP packet error rates (PER) achieved using 622/1244 Mbit/s dual-rate burst modems over the WINDS satellite link. We also discuss three-terminal communication over the 622 Mbit/s time-division multiple-access (TDMA) satellite communication system. Also, 3D, 4K-HDTV transmission experiment was successfully performed by this system.

1 Introduction

The Japan Aerospace Exploration Agency (JAXA) and the National Institute of Information and Communications Technology have developed “WINDS,” a communications satellite that enables super-high-speed data communications, in an effort to research and develop advanced information networks based on the Japanese government IT strategy “e-Japan Priority Policy Program [1]–[3]”. An H-IIA rocket carrying WINDS was launched on Feb.23, 2008, at Tanegashima Space Center of JAXA.

NICT developed the high-speed network with 622/1,244 Mbit/s using a bent-pipe relay line. The three earth terminals, Large Earth Terminal (LET) at NICT Kashima Space Technology Center and the two Super-high Data Rate Very Small Aperture Terminals (SDR-VSAT), were developed to construct a high-speed network with 622/1,244 Mbit/s. Also, a high-speed burst modem with high-performance FEC using turbo product code (TPC: $(128, 120)^2$) for a 622/1,244 Mbit/s dual rate high-speed network terminal was developed.

After the launch of WINDS, NICT performed transmission experiments with the 622/1,244 Mbit/s dual rate high-speed burst modem at 622/1,244 Mbit/s, and measured the BER characteristic and the UDP/TCP packet error rate. We also confirmed that the network operates normally as a TDMA satellite communication system in the 622 Mbit/s mode between the three terminals. We also succeeded in transmission experiments with 3D, 4K HDTV using this system. This paper reports the configuration and performance of a 622/1,244 Mbit/s TDMA satellite communication system and the results of 622/1,244 Mbit/s TDMA satellite communication experiments using a high-speed burst modem.

2 WINDS high-speed network system

2.1 High-speed network

We made progress in the development of a high-speed network using satellite lines. The purposes of this effort are to solve the digital divide, back up Internet backbone lines, and use temporary lines by installing mobile earth terminals in places where high-speed stationary lines are unavailable. The high-speed network of WINDS that operates in the bent-pipe TDMA mode is an SS (Satellite Switched)-TDMA system. Its system configuration is shown in Fig. 1.

WINDS is equipped with a switch matrix (SWMTX) composed of many 4 GHz band analog switches. WINDS switches reception beam/transmission beam connection combinations at a specific interval (2 milliseconds).

Synchronization of the onboard SWMTX and high-speed burst modem is maintained by a 155 Mbit/s reference burst (JRB) generated by a JAXA ground terminal. This JRB is 155 Mbit/s, QPSK, which is used for a regenerative transponder, and its error-correcting code is RS (255, 223). One of the NICT terminals transmits the reference burst (Winds RB: WRB) for a 622 Mbit/s bent-pipe transponder that is synchronized with the received JRB. The other earth terminals use only 622 Mbit/s WRB to synchronize with the SWMTX. The JRB carries slot allocation information of regenerative TDMA, and WRB carries slot allocation information for 622/1,244 Mbit/sTDMA. The frame configuration of TDMA is shown in Fig. 2.

The transmission timing of WRB and data burst are corrected to synchronize with the SWMTX by calculating the propagation delay time from the information on the positions of the satellite and earth terminals. The slot length of TDMA is 2 ms, including the guard time of 75 µs.

One frame consists of 20 slots, and one super-frame consists of 16 frames. The multi-beam antenna (MBA) is capable of receiving a maximum of eight beams. JRB and WRB are deployed at the front edge of the frame and are capable of transmitting signals in response to communication beams.

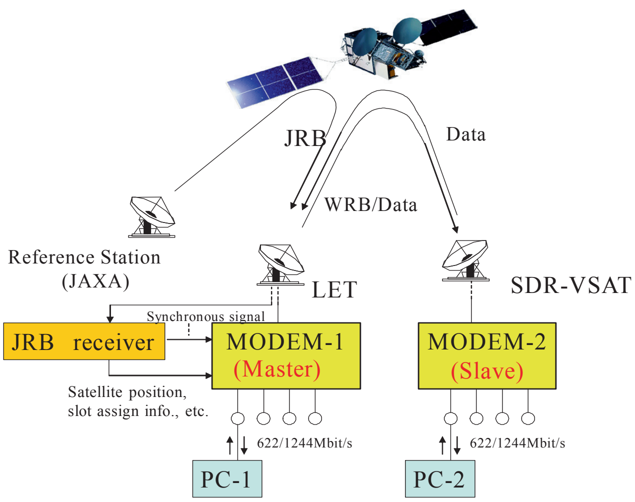

Fig. 1 High speed satellite TDMA communication

2.2 Satellite transponder and earth terminal

The onboard transponder of WINDS consists of two MBAs with an antenna aperture of 2.4m, an active phased array antenna (APAA: 128 pixels for both receiver and transmitter), a Tx/Rx-IF switch matrix (IF-SWMTX), an

Table 1 Satellite payload

Orbit	GEO (143 degrees East)
Mass	Approximately 2,700 kg (In Orbit)
Size	2 m × 3 m × 8 m (solar array paddles deployed: 21.5 m)
Design Life	5 years (targeted life)
Power	More than 5,200 W
Attitude Control	3-axis stabilized
Frequency Band	18.25 GHz / 28.05 GHz (1.1 GHz BW)
Antenna	MBA: Two dish of 2.4 m diameter APAA: 128 elements each TX and RX
EIRP	MBA: more than 68 dBW APAA: more than 55 dBW
G/T	MBA: more than 18 dB/K APAA: more than 7 dB/K
Communication Mode	Regenerative switch by ABS & IFS and Bent-pipe relay with IFS
Service Area	MBA: Japan and 10 Asian cities APAA: Asia and Pacific area
Launch Vehicle	H-IIA
Launch Date	February 23, 2008

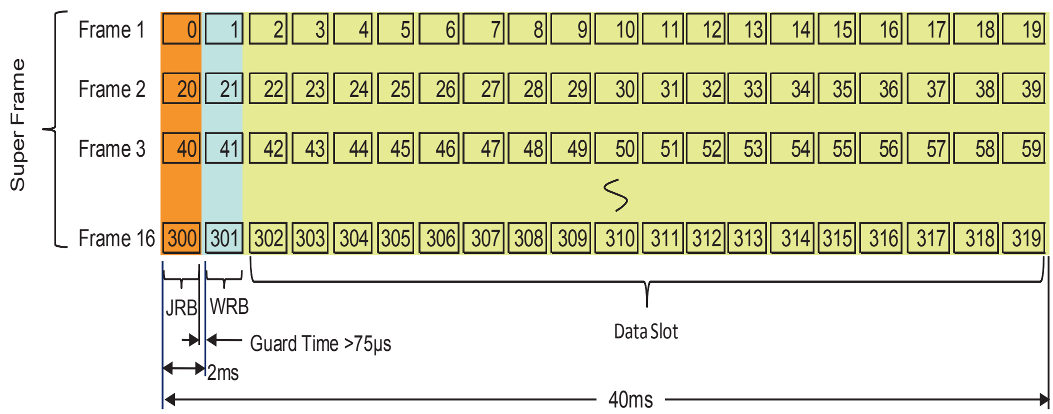

Fig. 2 TDMA frame format

onboard regenerative switch subsystem (ABS: ATM Baseband Switch subsystem), and a multi-port amplifier (MPA). The MBAs establish a communication line between the Japanese mainland and cities in Southeast Asia via 19 fixed spot beams. The APAA establishes a communication line within the earth coverage of two spot beams by hopping.

The adjacent fixed beams are separated by polarization (vertical, horizontal). The APAA is vertically polarized. The same frequency band can be used for both beams and the SS-TDMA transmits a TDMA slot to each beam. WINDS has both a regenerative mode and a bent-pipe transponder mode. Figure 1 shows the specifications of the WINDS transponder. The high-speed data transmission at 622/1244 Mbit/s using high-speed burst modem is operated by the bent-pipe TDMA mode.

Both the regenerative transponder mode and the bent-pipe transponder mode are an SS-TDMA system that enables an Internet IP connection.

There are six routes in the bent-pipe TDMA mode of WINDS. Four routes transmit via a broad band-pass filter and the other two routes transmit via a narrow band-pass filter in transmission and reception. There are six routes that pass band-pass filters (BPF-W1, W2, W3, W4, U1, and U2) from the communication pass of WINDS MBA-LNA/RX (or APAA) to MPA-MBA/TX (or APAA). The BPFs of BPF-W1 to BPF-W4 transmit over the entire frequency band of 1,100 MHz. The BPF-U1 and BPF-U2 transmit only the upper 600 MHz bandwidth of the 1,100 MHz frequency band. When using in the regenerative transponder mode, the upper band is used for the bent-pipe transponder mode and the lower band is used for the regenerative transponder mode [3].

SDR-VSAT and LET were developed for the purpose of establishing a high-speed network. SDR-VSAT consists of an earth terminal mounted on a vehicle (SDR-VSAT1) and a transportable mobile earth terminal (SDR-VSAT2). LET was constructed at Kashima Space Technology Center as a fixed earth terminal.

The views of LET, SDR-VSAT1 and SDR-VSAT2 are shown in Figs. 3, 4 and 5, respectively.

The specifications of the three earth terminals are shown in Table 2. The residual carrier of mission telemetry is used for antenna tracking of LET and SDR-VSAT1. SDRV-SAT2 does not have an antenna tracking system. The effect on level fluctuation by tracking is not large and there is no effect on level fluctuation by tracking in a short time experiment. The maximum power of HPA is 215 W. The bandwidth of transmission is 1,100 MHz and the center frequency of IF is 3,000 MHz.

An example of link design of the bent-pipe TDMA mode is shown in Table 3. The C/No margin of the com-

Table 2 Earth station specifications

	LET	SDR-VSAT1	SDR-VSAT2
Antenna	4.8 m Cassegrain reflector antenna	2.4 m offset feed Gregorian reflector antenna	2.4 m offset feed antenna
Antenna gain	Tx: 60.2(dbi) Rx: 56.5(dBi)	Tx: 53.9(dbi) Rx: 50.2(dBi)	Tx: 54.7(dbi) Rx: 51.8(dBi)
Frequency	Tx:28.05 GHz ± 550 MHzm Rx:18.25 GHz ± 550 MHz		
HPA output power	215 W		
EIRP	79.3 dBW	73.1 dBW	74.0 dBW
G/T	32.7 dB/K	26.3 dB/K	27.0 dB/K
Flatness	RF loop back: 2.55 dBp-p (1.1 GHz BW)		
Spurious	less than -60 dBc		

Fig. 3 LET

Fig. 4 SDR-VSAT1

Fig. 5 SDR-VSAT2

munication between LET and SDR-VSAT1 is from 4.1 dB to 13.3 dB according to the communication mode. Here the Eb/No necessary to be error-free ($<10^{-10}$) was targeted as Eb/No=10 dB. (The necessary Eb/No was measured as 13 dB for the 1,244 Mbit/s mode that is mentioned later.)

2.3 622 /1,244 Mbit/s dual rate burst modem

The high-speed burst modem was developed for the purpose of establishing high speed terminals. A prototype burst modem that operates at a user data rate of 622 Mbit/s was developed [4]–[7], and it was improved to work at a user rate of 1,244 Mbit/s.

The configuration of the 622/1,244 Mbit/s dual rate burst modem is shown in Fig. 6. Its view (two sets of photos) is shown in Fig. 7, and the specifications are summarized in Table 4. The burst modem consists of four boards: a modulation board, a demodulation board, a turbo product code (TPC) decoding board and a control

Table 3 Example of link budget

		LET⇒LET		LET⇒SDR-VSAT1		SDR-VSAT1⇒LET		SDR-VSAT1⇒SDR-VSAT1		Remarks
Up-Link										
Frequency	GHz	28.05		28.05		28.05		28.05		
Data Rate	Mbps	622	1244	622	1244	622	1244	622	1244	
EIRP	dBW	79.3		79.3		73.1		73.1		Earth Station 3dB Back-off
Pointing Loss	dB	0.5		0.5		0.5		0.5		
Free Space Loss	dB	212.8		212.8		212.8		212.8		
Atomospheric Loss	dB	0.5		0.5		0.5		0.5		
G/T	dB/K	18.0		18.0		18.0		18.0		Satellite
Up-Link C/N_0	dB/Hz	112.1		112.1		105.9		105.9		
Down-Link										
Frequency	GHz	18.25		18.25		18.25		18.25		
EIRP	dBW	68		68.0		68.0		68.0		Satellite 4dB Back-off
Free Space Loss	dB	201.9		201.9		201.9		201.9		
Atomospheric Loss	dB	0.5		0.5		0.5		0.5		
G/T	dB/K	32.7		26.3		32.7		26.3		Earth Station
Down-Link C/N_0	dB/Hz	126.4		120.0		126.4		120.0		
Total										
Total C/N_0	dB	111.9		111.4		105.9		105.7		
Transmission Rate	Mbps	824	1648	824	1648	824	1648	824	1648	QPSK FEC Cording Rate =0.879
Required C/N_0	dB/Hz	98.6	101.6	98.6	101.6	98.6	101.6	98.6	101.6	Eb/N_0=10dB
Margin										
C/N_0 Margin	dB	13.3	10.3	12.8	9.8	7.3	4.3	7.1	4.1	

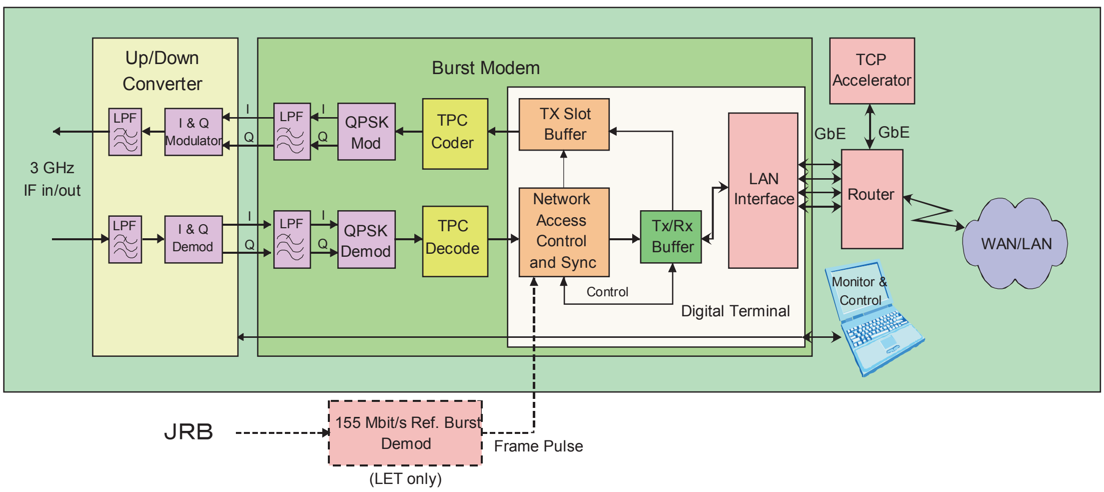

Fig. 6 Configuration of 622/1244 Mbit/s high speed burst modem

board. All of the boards consist of digital circuits using FPGAs. ATCA (Advanced Telecommunication Computing Architecture) is installed at the back plane.

Quadrature Phase Shift Keying baseband signals are transformed to IF frequency band signals in the RF unit. The turbo product code (TPC: (128, 120) ^{2}) for 4-bit soft decision is used as FEC. The coding gain attained by simulation is 9 dB for the case of a coding rate of 0.879 and the BER=10^{-10}. The transmission bit rate of QPSK modulation at the user rate of 1,244 Mbit/s is 1,648 Mbit/s (824 Msymbol/s).

It is 824 Mbit/s (412 Msymbol/s) at the user rate of 622 Mbit/s.

In order to correspond to the data rate of 1,244 Mbit/s, a D/A converter of 2 Gsample/s for a 4 × 1 multiplexer for a modulator was developed. In order to generate QPSK baseband signals of I and Q, a carrier frequency of 0 Hz is used for transmission at 1,244 Mbit/s, and both carrier frequencies of +273.6 MHz and -273.6 MHz are used for transmission at 622 Mbit/s. These signals are converted to 3,000 MHz band IF signals in the RF unit.

Fig. 7 622/1244 Mbps Dual-Rate Burst Modems (two sets)

Table 4 Specification of 622/1244 Mbps Dual-Rate Burst Modem

User data rate	622 Mbit/s	1244 Mbit/s
IF frequency	2726.4, 3273.6 MHz	3000.0 MHz
Modulation	QPSK	
Access method	SS-TDMA	
Modulation rate (before FEC)	724.2 Mbit/s	1448.4 Mbit/s
Modulation rate	824 Mbit/s	1648 Mbit/s
Error correction	Turbo product code (128, 120)^2 4bit soft decision	
Roll off	Root raised cosine Roll off factor = 0.35	
User interface	Giga bit Ethernet Router and TCP accelerator used	

The demodulator and decoder boards were improved by correcting the FPGA program for the prototype modem board (breadboard model for 622 Mbit/s).

The control board can be managed by Web application or telnet. A router is used for selection of routes. The TCP Accelerator is used to suppress the effect by transmission delay. In the experiment shown in this paper, the method to expand window size by Hybla/Reno is adopted.

3 Results of satellite communication experiment [8]–[11]

3.1 622 Mbit/s transmission experiment

(1) Kanto Beam 622 Mbit/s 1 wave transmission

The characteristics of bit error rate (BER) in 622 Mbit/s 1 wave continuous transmission are shown in Fig. 8. The transmission in the mode where a satellite switch of the satellite does not operate (normal bent-pipe mode) when using all frames of the modem TDMA is called 1 wave continuous transmission. The BER of 10^{-10} was achieved for 10 dB of Eb/No. The result of 10^{-10} means deterioration of 1-3 dB compared with the ground experiment (IF loop-back). The BER characteristic of this modem in ideal Gaussian noise channel obtained by simulation is 10^{-9} for 4 dB of Eb/N_0 [3].

The possible causes of deterioration of satellite lines are fluctuations in the received signal level, frequency performance of the transmitter or non-linear characteristics. The received signal level of LET fluctuates about 1 $dB_{p\text{-}p}$, and

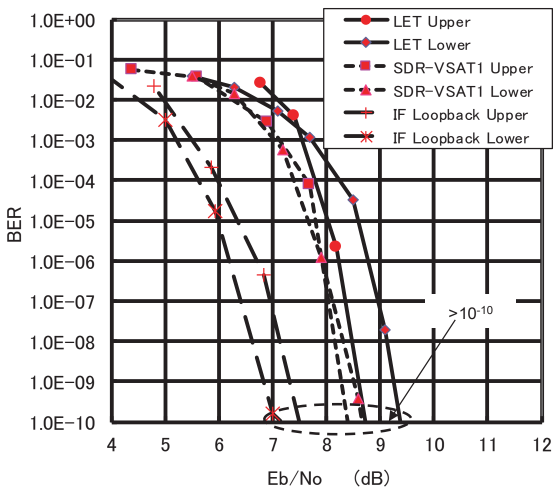

Fig. 8 BER result for 622 Mbit/s transmission test

there is a frequency deviation of about 2 $dB_{p\text{-}p}$ in the 550 MHz bandwidth in the signals of the 622 Mbit/s transmission (412 Msymbol/s). In principle, MPA operates in a linear region. It is supposed that the effect from the non-linear characteristics on the 1 wave TDMA signal is not large because of the output back-off by 4 dB in the maximum operation mode. Therefore, the main cause of deterioration of the BER characteristic is supposed to be unstable deviation of the frequency performance of satellite lines and the received signal level including earth terminals. It is supposed that fluctuation of the received signal level is affected by about 1 dB due to changes in conditions such as clouds or weather even during the short time of measurement for the signals in the frequency bands of 28 GHz for up-link and 18 GHz for down-link.

(2) Kanto Beam 622 Mbit/s TDMA communication experiment

The communication experiment of 622 Mbit/s TDMA was performed with the configuration shown in Fig. 1. It was performed between LET and SDR-VSAT1 at Kashima located within the Kanto Beam area. The reference burst (JRB) was transmitted from JAXA station and it was received at LET via JRB receiver. The modem of LET operated as a master modem. After receiving information on satellite positioning, slot allocation and synchronized timing, it transmitted WRB from the high-speed burst modem. Both JRB and WRB carried information on satellite positioning, slot allocation and synchronized timing. The SDR-VSAT1 received WRB from WINDS.

Then, in order to establish TDMA communication, the two modems sent burst signals on the basis of the positioning, slot allocation and synchronized timing carried by WRB.

The transmission timing of the burst signals was determined by calculating the delay time from the positioning of the satellite and earth terminal. The PC1 and the PC2 were connected to modem1 and the modem2, respectively, via LAN.

The result of measurement of UDP packet error using iperf which is free software to measure network throughput and packet error rate is shown in Table 5. This result is for the cases of full slot allocation and half slot allocation. The former case is that transmission signals were allocated continuously to all of the slots in the TDMA frame configuration shown in Fig. 2. The latter is the case that the data slot columns were divided into two groups with 9 slot columns of TDMA transmission signals for each group. Case (a) achieved a packet error rate of 0% at 100, 400, and 622 Mbit/s for unidirectional continuous wave operation of non-TDMA operation for full slot allocation. Case (b) achieved a packet error rate of 0% at 100, 200, and 300 Mbit/s for bidirectional transmission for half slot allocation.

The result of the iperf test for TCP is shown in Table 6. Figure 9 shows the time variation of TCP throughput when

Table 5 Half band UDP iperf test

(a) Iperf Test (Full Slot Assign. One Way)

	E_b/N_0	100 Mbps	400 Mbps	622 Mbps
SDR-VSAT1⇒LET (Upper Band)	14.9 dB	Loss 0 %	Loss 0 %	Loss 0 %
SDR-VSAT⇒LET (Lower Band)	15.1 dB	Loss 0 %	Loss 0 %	Loss 0 %

(b) Iperf Test (Half Slot Assign. TDMA)

	E_b/N_0	100 Mbps	200 Mbps	300 Mbps
SDR-VSAT1⇒LET (Upper Band)	17.1 dB	Loss 0 %	Loss 0%	Loss 0 %
LET⇒SDR-VSAT1 (Upper Band)	13.8 dB	Loss 0 %	Loss 0%	Loss 0 %

Table 6 Half band TCP iperf test

	time (sec)	Window size (Mbytes)	Bandwidth (Mbps)	Protocol
LET⇒SDR-VSAT1	301	64	256	hybla
	302	128	293	hybla
	302	64	257	reno
	301	128	261	reno
SDR-VSAT1⇒LET	301	64	200	hybla
(For UDP packet loss of about 0.002 %)	306	128	57	hybla
	374	64	36	reno
	478	128	6	reno

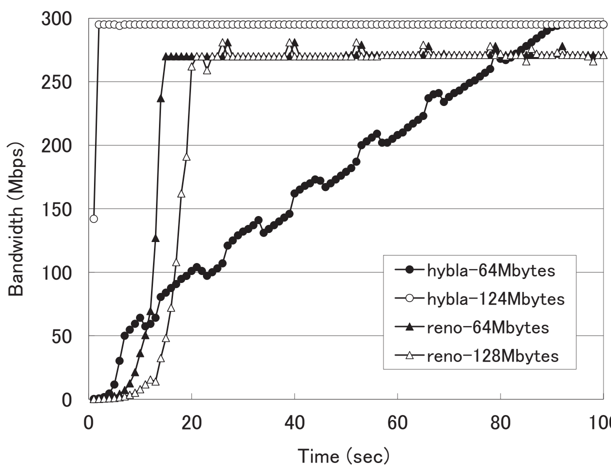

Fig. 9 TCP throughput change for no packet error

the packet error rate is 0%. Figure 10 shows the time variation of TCP throughput when the packet error rate is 0.002%. In Figure 9, the time to reach the maximum bandwidth by hybla is shorter than that by reno. It becomes shorter when the window size is larger. In Figure 10, in the case of finite packet error, the bandwidth to time variation is lower by reno, but it increases in hybla with some fluctuation.

In the case of zero packet error, both hybla and reno achieved the bandwidth of 250–290 Mbit/s for the window sizes of 64 MB and 128 MB. In the case of packet error of 0.002%, although the bandwidth by hybla achieved 200–260 Mbit/s, that by reno remained at low throughput of 6-36 Mbit/s. Compared with reno, hybla has high performance even under very delayed conditions, by increasing the window size quickly when packet errors occur.

(3) TDMA transmission experiment between three earth terminals

In order to establish the configuration for TDMA transmission experiments between three earth terminals, SDR-VSAT2 was developed. The configuration of transmission experiment between the three earth terminals is shown in Fig. 11. The experiment was performed under appropriate satellite line conditions (no bit errors). PCs were connected to LAN ports of modems at each earth terminal and an iperf experiment was performed between the PCs. The TDMA slot allocation for the TDMA transmission experiment between the three earth terminals is shown in Fig. 12. For one PC, unidirectional transmission was performed with 3 slot columns at 100 Mbit/s and bidirectional transmission was performed with 6 slot columns at 200 Mbit/s.

The test result of iperf to UDP was shown in Table 7. The packet error of 0% was confirmed for unidirectional transmission at 100 Mbit/s with 6 lines. It was confirmed that TDMA transmission with packet error of 0% between three earth terminals can be achieved as a mesh-type network using a 622 Mbit/s TDMA satellite communication system.

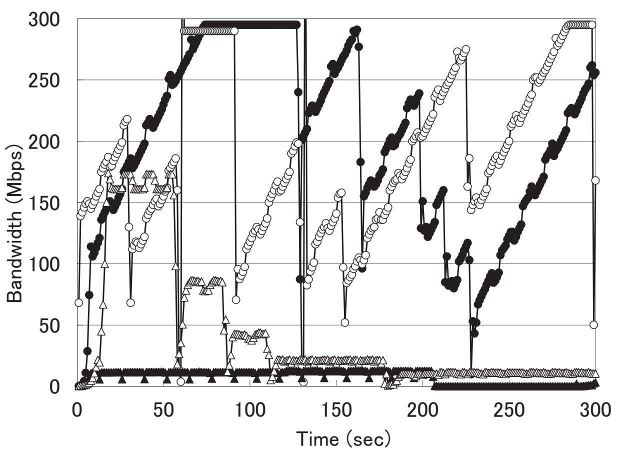

Fig. 10 TCP throughput change for packet error of about 0.002%

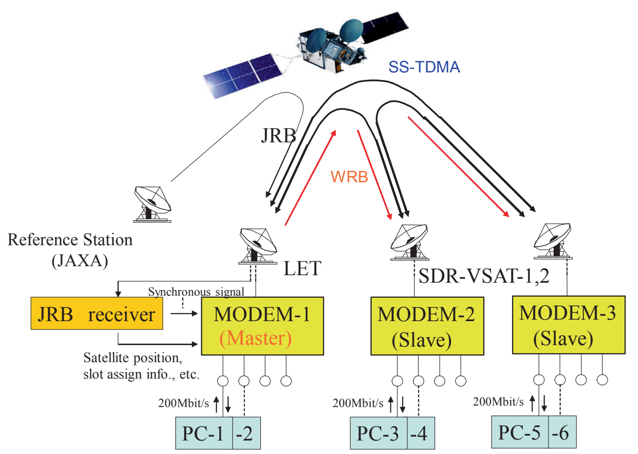

Fig. 11 Configuration of three terminals TDMA communication experiment

0			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
1	RB	WRB	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
2			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
3			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
4			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
5			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
6			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
7			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
8			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
9			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
10			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
11			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
12			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
13			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
14			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
15			1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6

1:LET>SDR-VSAT1 2:SDR-VSAT1>LET 3:SDR-VSAT1>SDR-VSAT2
4:SDR-VSAT2>SDR-VSAT1 5:SDR-VSAT2 > LET 6:LET > SDR-VSAT2

Fig. 12 TDMA slot allocation for three terminals communication

Table 7 Result of UDP iperf test about between three terminals

LET⇔SDR-VSAT1	Eb/No	100 Mbps	Remarks
Modem-1⇒Modem-2	16 dB-17 dB	Loss 0 %	3 slots in frame
Modem-2⇒Modem-1	16 dB-17 dB	Loss 0 %	3 slots in frame
LET⇔SDR-VSAT2			
Modem-1⇒Modem-3	16 dB-17 dB	Loss 0 %	3 slots in frame
Modem-3⇒Modem-1	16 dB-17 dB	Loss 0 %	3 slots in frame
SDR-VSAT1⇔SDR-VSAT2			
Modem-2⇒Modem-3	16dB-17 dB	Loss 0 %	3 slots in frame
Modem-3⇒Modem-2	16dB-17 dB	Loss 0 %	3 slots in frame

3.2 Transmission experiment at 1,244 Mbit/s

(1) Kanto Beam 1,244 Mbit/s 1 wave transmission

The characteristic of bit error rate (BER) in 1,244 Mbit/s 1 wave continuous transmission is shown in Fig. 13.

It is the property of LET-LET and of SDR-VSAT1-SDR-VSAT1 in the route of WINDS-BPF-W1. The BER achieved 10^{-10} when Eb/No is over 13 dB. The characteristic of turning of modem IF at BER of 10^{-10} shows deterioration of 4 dB. Because the transmission at 1,244 Mbit/s has broad bandwidth of 824 Msymbol/s, the signal quality degrades due to variation in frequency properties and receiving signal levels of satellite the line and earth terminals. At the time of experiment (2010), the data transmission with one carrier at 1,244 Mbit/s was the fastest in the world in RF satellite transmission.

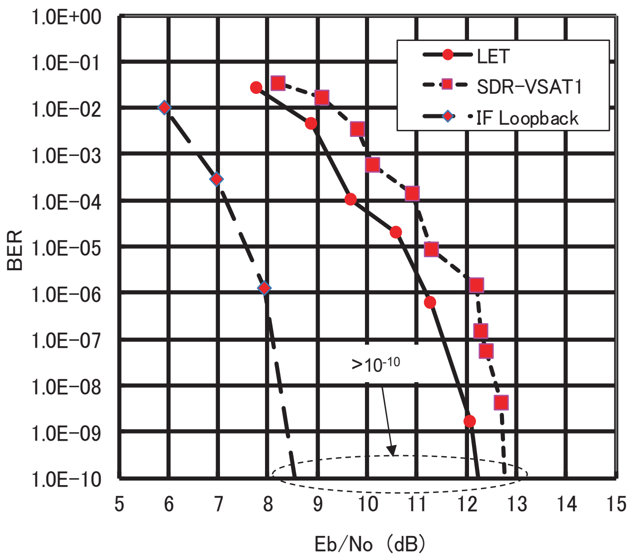

Fig. 13 BER result for 1244 Mbit/s transmission test

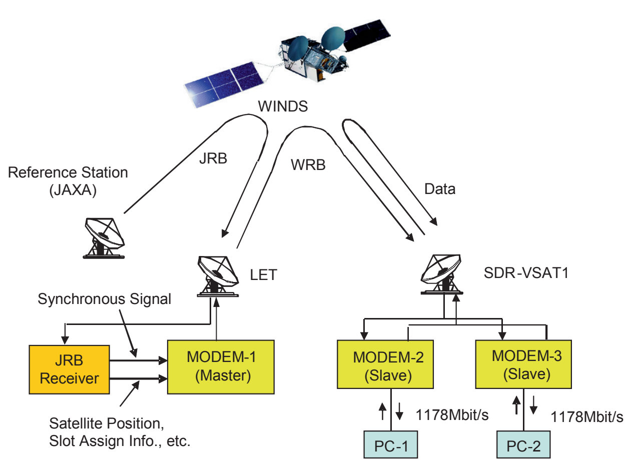

Fig. 14 Configuration of 1244 Mbit/s TDMA communication experiment

(2) Kanto Beam transmission experiment at 1,244 Mbit/s TDMA

As shown in Fig. 14, a modem was added to the configuration shown in Fig. 1 to perform an experiment at 1,244 Mbit/sTDMA. Both modem1 and modem2 were connected with SDR-VSAT1 and they operated simultaneously. The slot allocation of TDMA for the iperf experiment is shown in Fig. 15. Slot1 is the route from modem2 to modem1, and slot2 is the route from modem3 to modem2. The results of the iperf experiment at UDP are summarized in Table 8. As shown in the results, although the volume of the transmitted data rate was less than 1,244 Mbit/s due to the overhead of iperf, it was confirmed that data was transmitted without packet error at bidirectional 1,178 (one way 589 ×2) Mbit/s. In Table 9, the result of the iperf experiment for TCP is for the case of packet error rate of UDP at less than 0.01%. The bandwidth was improved from 50 Mbit/s to 200–300 Mbit/s when the window size was expanded from 4 MB to 64 MHz by hybla. Thus, the bandwidth may be improved by expanding the window size.

3.3 3D, 4K HDTV application transmission experiment [12] [13]

The transmission experiment of a three-dimensional (3D) 4K HDTV video between Kanto-Kinki Beam by 1 wave TDMA transmission mode at 622 Mbit/s was performed. The configuration of the demonstration performed at the NICT Keihanna Fair held in November 2010 is shown in Fig. 16. It was performed as a memorial event of the 1,300th year anniversary of the establishment of the old capital Nara Heijo-kyo held in Nara Prefecture. NICT

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	RB	WRB	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
2			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
3			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
4			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
5			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
6			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
7			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
8			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
9			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
10			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
11			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
12			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
13			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
14			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
15			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2

1:SDR-VSAT1 (MODEM2)>SDR-VSAT1 (MODEM3)
2:SDR-VSAT1 (MODEM3)>SDR-VSAT1 (MODEM2)

Fig. 15 TDMA slot allocation for 1244 Mbit/s transmission test

Table 8 iperf test UDP

SDR-VSAT1⇔SDR-VSAT1	Eb/No	589 Mbps	Remarks
Modem-2⇒Modem-3	13dB-14dB	Loss 0%	9 slots in frame
Modem-3⇒Modem-2	13dB-14dB	Loss 0%	9 slots in frame

Kashima Space Technology Center (Kashima City, Ibaraki Pref.) is the location of LET and Keihanna Plaza are connected by broadband network for research and development of JGN2 plus. Slot allocation of TDMA transmission from Kanto (LET) is 1 slot column (about 30 Mbit/s) and that from Kinki (SDR-VSAT1) is 13 slot column (about 400 Mbit/s). We confirmed that packet error was 0% for the case from SDR-VSAT1 to LET at 400 Mbit/s, and from LET to SDR-VSAT1 at 30 Mbit/s. The video taken by a three-dimensional (3D) 4K–HDTV camera was compressed to 200–300 Mbps via 8 channels of a multi-channel picture transmission system. Then 3D, 4K HDTV video was received with LET via a satellite line of 400 Mbit/s. From LET to the event site, the data was transmitted via a ground network system (JGN2 plus/VLAN), that led to a successful and high-quality display.

Table 9 hybla TCP throughput

time(sec)	Window size(Mbyte)	Bandwidth(Mbps)
180	4	50
180	32	206
		264
		210
		244
180	64	213
		226
		176
		274

4 Summary

The development of WINDS was completed and it was launched successfully. Today, many kinds of experiments are performed. NICT has developed a dual high rate burst modem of 622/1,244 Mbit/s that is installed in SDR-VSAT1, 2 and LET for high-speed network experiments.

We confirmed that the BER characteristic in a bent-pipe transponder was less than 10^{-10} for the case of Eb/No of 10dB at 622 Mbit/s. Also, we confirmed that the BER characteristic was less than 10^{-10} for the case of Eb/No of 13dB at 1,244 Mbit/s. As a result, compared with the BER characteristic at IF, there was deterioration of about 2dB at 622 Mbit/s, and about 4 dB at 1,244 Mbit/s. Also, a data transmission experiment using Ka band 1 carrier at 1,244 Mbit/s was successful (the fastest in the world, as was 2010). The 622/1,244 Mbit/sTDMA transmission in the WINDS vent pipe mode succeeded. Traffic burst was successfully sent to the TDMA slot using the WRB frame pulse synchronized with the JRB frame pulse. Bidirectional transmission at both 300 Mbit/s and 589 Mbit/s was confirmed in the experiment of Iperf-UDP. Also, we confirmed 622 Mbit/s for full slot unidirectional transmission. Bandwidth of 200–300 Mbit/s for 622/1,244 Mbit/s was achieved using hybla TCP. Also, as an application test, a 3D 4K HDTV video transmission experiment was performed and succeeded using the TDMA transmission mode in the 622 Mbit/s 1 wave TDMA mode between the Kanto-Kinki beam.

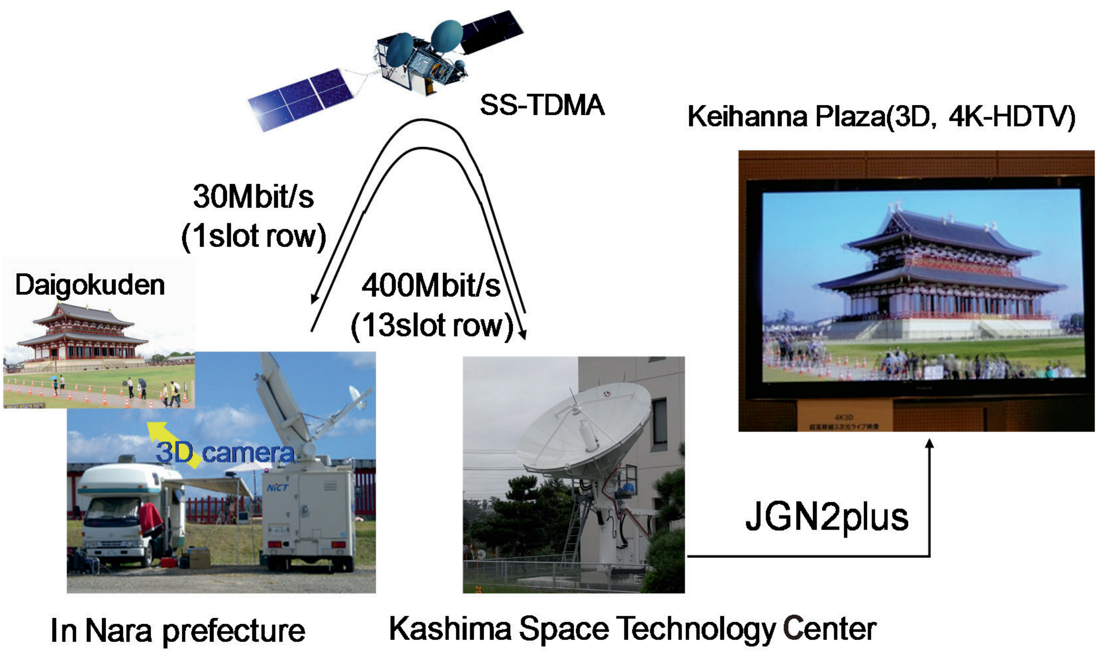

Fig. 16 3D 4K-HDTV application experiment

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