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Recent Japanese R&D in Satellite Communications

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SUMMARY Current trend in telecommunications is "broadband" and "ubiquitous." To achieve this goal, satellite communications systems are expected to play an important role in cooperation with terrestrial communications systems. Along with the advancement of optical fiber transmission systems, the role of satellite communications was dramatically changed from long distance transmission to various applications utilizing unique features of satellite communications. This paper overviews recent Japanese R&D in satellite communications.

key words: *satellite communications, R&D, Japan*

1. Introduction

History of Japanese satellite communications started at KDD's Ibaraki space communications experimental station which was opened on 20th November, 1963. Just 3 days after its opening, the famous TV relay experiment between Japan and USA brought the TV news of President John F. Kennedy assassination case in Dallas to Japan. This experiment made the people all over the world know the potential and usefulness of satellite communications.

20 years later, Japanese first domestic commercial communications satellite, CS-2a (Communications Satellite-2a) was launched in February, 1983, after 5-year long CS experiments using the experimental communications satellite, CS (named Sakura) launched in 1977. Using CS-2a, domestic commercial satellite communications services started in May, 1983 in Japan. Since then, a lot of R&D efforts have been made to enhance the performance, to reduce the cost, and to extend the application areas of satellite communications [1]–[3].

As satellite communications use a relay station in space, satellite communications have unique features, e.g. high reliability against natural disasters, wide service coverage, multicasting capability and quick set-up of a transmission link. Especially, the cost per bit/s of satellite communications systems is independent of the distance of the transmission link, while that of terrestrial transmission systems is in proportion to the distance. Thus, satellite communications were used for international communications, i.e. "long distance transmission" for a long time. However, as the cost per bit/s/km of optical fiber transmission systems was significantly reduced over the past 20 years, the role of satellite communications was dramatically changed. Nowadays, satellite communications are being used for various applications, e.g. emergency communications in case of natural disasters, nomadic communications such as satellite news gathering, backup link for high reliability networks, cost effective wide area coverage and rapid deployment of new services such as VSAT (Very Small Aperture Terminal) networks for Internet services and mobile satellite communications.

This year is the tenth anniversary of Japan and Korea's Joint Conference on Satellite Communications (JC-SAT). JC-SAT started in 2000 to exchange the ideas and to discuss satellite communications between Japanese and Korean researchers and engineers. 275 papers were presented in total in the past JC-SAT conferences from 2000 to 2008. Figure 1 shows the technical areas of the papers presented in the past JC-SAT conferences. Although Fig. 1 does not indicate clear trend, the number of the papers regarding fixed broadband satellite communications has been decreasing and that on mobile satellite communications and navigations has been increasing. In addition, many papers on "new systems and applications" have been constantly presented. This survey implies that satellite communications R&D is moving from "fixed" to "mobile" just like terrestrial wireless systems and many researchers have been trying new applications of satellite communications. Note that satellite broadcasting is still a very attractive application area, though it is not described in this paper due to the limitation of pages.

Current trend in telecommunications is "broadband" and "ubiquitous." Satellite communications systems are also expected to play an important role to achieve this goal in cooperation with terrestrial communications systems, as indicated by the above survey. Thus, it would be worth looking back on recent ten years of R&D in Japan when we consider the future of satellite communications. With this motivation, this paper overviews Japanese R&D in satellite communications, namely R&D performed by NICT (National Institute of Information and Communications Technology),

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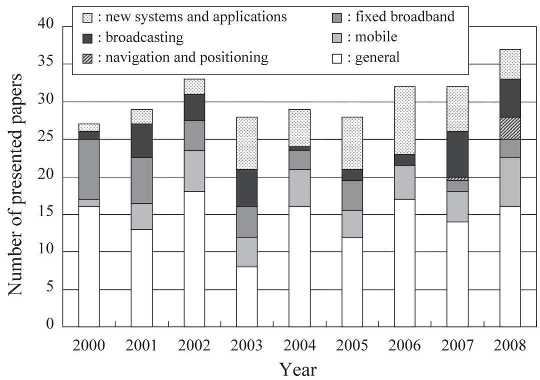


Fig. 1 Technical areas of the papers presented in the past JC-SAT conferences from 2000 to 2008.

NTT (Nippon Telegraph and Telephone Corp.) group and KDDI.

This paper is organized as follows: Section 2 describes R&D in NICT regarding national R&D projects such as ETS-VIII (Engineering Test Satellite VIII), WINDS (Wideband Inter-Networking engineering test and Demonstration Satellite), QZSS (Quasi-Zenith Satellite System), STICS (Satellite/Terrestrial Integrated mobile Communication System) and optical satellite communications. On the other hand, NTT and KDDI have been conducting satellite communications R&D as telecommunications carriers. Section 3 describes R&D in NTT group regarding both fixed and mobile domestic satellite communication and the advanced technologies for future satellite communications. Section 4 describes R&D in KDDI such as an intersystem frequency sharing between ESVs (Earth Station onboard Vessels) and terrestrial FS (Fixed Service) stations to support broadband mobile satellite services for vessels near coastlines, and the advanced technologies for future mobile and ubiquitous services. Then, this paper is concluded.

2. R&D in NICT

2.1 Mobile Satellite Communications

One of the most promising and challenging areas of future satellite communications is mobile communications since true ubiquity, i.e. anytime and anywhere, can be economically realized only by the combination of terrestrial systems and satellite systems. R&D in this area includes the ETS-VIII, the STICS and the QZSS.

2.1.1 ETS-VIII

The purpose of the ETS-VIII project is to develop key technologies for personal and mobile satellite communications by handheld terminals, so that the ETS- VIII was developed for proof of concept. The ETS-VIII was developed by NICT and JAXA (Japan Aerospace Exploration Agency). Its main feature is large deployable onboard antennas with a mechanical dimension of 19 m × 17 m (an electrical aperture diameter is 13 m) to enable mobile communications with handheld terminals. Figure 2 shows the outlook of the ETS-VIII, which was launched in December, 2006, and was successful in unfolding the large deployable antennas on orbit. The major specifications are shown in Table 1. The ETS-VIII was designed to cover Japan's main islands with six beams in the S-band, and three beams can be used simultaneously. Since the ETS-VIII has the large deployable antennas for high EIRP and high G/T, handheld terminals can be used for voice satellite communications. The photo of the prototype handheld terminal is shown in Fig. 3 [4]. Its size is 58 mm (Width) × 37.5 mm (Depth) × 170 mm (Height), and it weighs 266 g except batteries. The output power of the transmitting amplifier is 1 watt. A position information terminal has also been developed. It has a GPS receiver and a transmitter to send the position information via the ETS-VIII. Its weight is as light as 30 g except batteries.

The transformation of the large deployable antenna on orbit has been verified through one-day long antenna measurements [5]. The communication performance of the ETS-VIII including the packet switch and the baseband

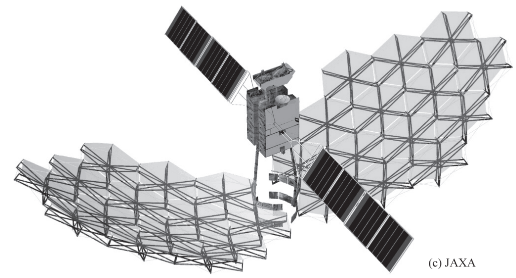


Fig. 2 Outlook of the ETS-VIII.

Table 1 Major specifications of the ETS-VIII.

Frequency	S band (Up: 2.6 GHz / Down: 2.5 GHz) for mobile link
Antenna	13 m mesh deployable reflectors for mobile link
Tx power	400 W for S band
Onboard switch	(1) Baseband switch for personal communications (5.6 kbit/s and 32 kbit/s) (2) Packet switch for broadband mobile communications (1024 kbit/s)
EIRP	55 dBW
G/T	14 dB/K

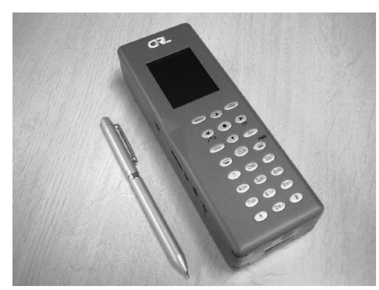


Fig. 3 Photo of the proto-type handheld terminal for the ETS-VIII.

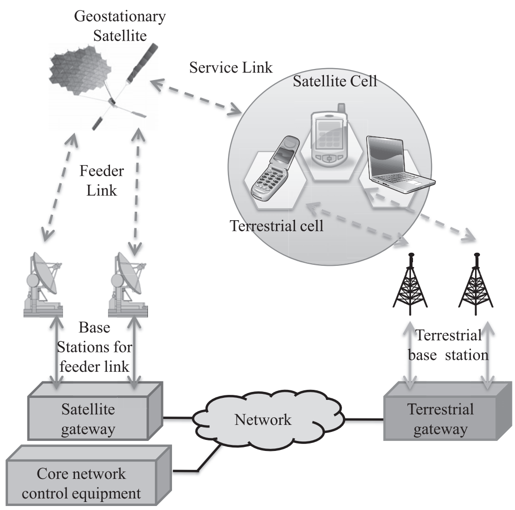


Fig. 4 Concept of the STICS.

switch has been checked-out, and confirmed to satisfy the specifications in space, except the low noise amplifiers. In order to recover the receiving function of the ETS-VIII, an S-band medium-size antenna with a diameter of 1m on the ETS-VIII is used with terrestrial transponders amplifying and forwarding the signal of handheld terminals and position information terminals [6].

2.1.2 STICS

Satellite/terrestrial integrated mobile communications system with an Ancillary Terrestrial Component (ATC) was recently realized by SkyTerr. The ATC-based satellite communications system has a potential to provide ubiquitous wireless service coverage using a handheld terminal with dual mode of satellite and terrestrial communications functions.

The STICS project for future mobile satellite communications started in 2008, assuming a satellite with a 30 m-class large deployable antenna by using the results of the ETS-VIII. The STICS is a satellite/terrestrial integrated mobile communications system which covers Japan and exclusive economic zones (EEZs) with approximately 100 high-gain multi-beams and shares the same frequencies assigned to the satellite component of IMT-2000 for both satellite communications and terrestrial communications. Figure 4 shows the concept of the STICS [7]. It consists of a terrestrial mobile network including many base stations and a satellite mobile network and a core network to connect the satellite mobile network to the terrestrial mobile networks, the Public Switched Telephone Networks (PSTN) and the Internet. The STICS will enable dual mode communications, where a common mobile terminal will be used in both terrestrial and satellite networks. The main features of the STICS are as follows:

(1) The satellite mobile communications network makes the communications infrastructure safe and secure even when the terrestrial infrastructure fails due to disasters.
(2) A dual mode mobile terminal having the same size and weight as a terrestrial cellular phone can be used by using an onboard large-scale antenna (30 m class).
(3) The inter-system interference between the satellite system and the terrestrial system is mitigated by the simultaneous management of the control information on the frequency assignment, transmitting power, and beam forming in the terrestrial and satellite systems.

2.1.3 QZSS

Regarding satellite positioning, Europe and China have their plans of their original positioning satellites. Japan aims at improving positioning precision by complementing the GPS with the QZSS. The QZSS will consist of three satellites to improve the visibility of the satellites from the ground users greatly in mid-latitude areas such as Japan.

Government sector is working for navigation and positioning mission to complement the modernized GPS. The first QZSS satellite is scheduled to be launched in 2010 followed by the field experiments of satellite positioning technologies. The current orbit design assumes three satellites to be placed on almost 43 degree inclined geosynchronous orbit planes with ascending node intervals of 120 degrees. The orbits have an eccentricity of nearly 0.1 with its apogee above Japan to weight its availability over Japan. The trajectory of the orbit is shown in Fig. 5.

JAXA will develop the total system for positioning, including the onboard L-band navigation equipment, the master control stations, and around 10 monitoring stations in and out of Japan [8]. NICT will develop timing system in the QZSS including onboard time transfer subsystem and the ground system such as time management station and related software [9].

2.1.4 Broadband Satellite Communications

The WINDS has been developed to solve the digital divide problems in Japan and Asia Pacific regions, and to realize ultra-high-speed satellite communications networks using the Ka band. It was jointly developed by JAXA and NICT. NICT developed Advanced Baseband Switch (ABS) that routes the ATM cells on the satellite in the regenerative communication mode [10].

Recently, the satellite Internet services such as iPSTAR and WildBlue are increasing gradually to solve the last one mile problem for the Internet. Currently, many satellites used for the satellite Internet services are operated as the bent-pipe type transponders with multi spot beam antennas. In this case, the satellites are operated as just a transmission link. On the other hand, WINDS and Spaceway3 have the onboard baseband switch matrix for flexible routing of communications traffic. The WINDS and Spaceway3 have the onboard layer 2 switching function and have achieved the maximum transmission rate of 155 Mbit/s and 96 Mbit/s respectively.

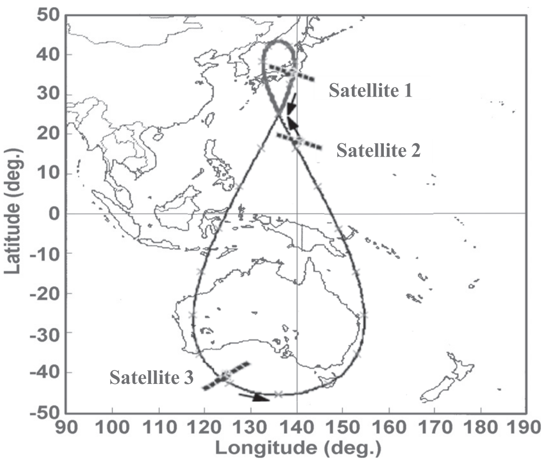


Fig. 5 Trajectory of the orbit for the QZSS.

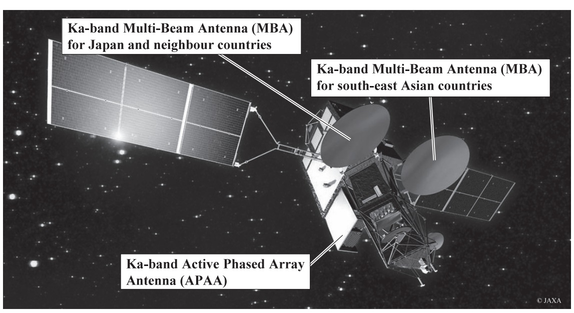


Fig. 6 Outlook of the WINDS.

In the case of the bent-pipe type satellite, only onboard space switch on a physical layer needs to be considered. However, if the higher layer switching function is installed in the satellite, it is necessary to consider the system architecture and required functions on each layer (1 to 3). It is simple to install the IP router in the satellite for IP networking. However, the transmission efficiency of the satellite link extremely decreases if the packet transmission such as simple Aloha is used for medium access control. As the WINDS system employs TDMA (Time Division Multiple Access) for layer 2 functions, higher transmission efficiency of the satellite link can be maintained. The WINDS system employs Multi-Carrier-TDMA on the uplink and the TDM on the downlink using the reference burst signal sent from the satellite. In the WINDS system, both way communications up to 155 Mbit/s between the VSAT stations are available without using the hub station with the large antenna [11]. In the WINDS system, a bent-pipe type transponder mode with 1.1 GHz bandwidth is also available. 1.2 Gbit/s/622 Mbit/s Satellite-Switched-TDMA system was developed for the bent-pipe mode [12].

Figure 6 shows the outlook of the WINDS. The WINDS has two fixed multi-beam antennas (MBA) and one active phased array antenna (APAA). One MBA covers Japan, Seoul, Beijing and Shanghai, and another MBA covers seven cities in South-East Asia. APAA can be electronically controlled to cover Asia Pacific regions. The coverage of the WINDS is shown in Fig. 7. The major specifications of the WINDS are shown in Table 2. The WINDS was launched in February, 2008. The initial mission checkout was completed and the satellite functions were confirmed.

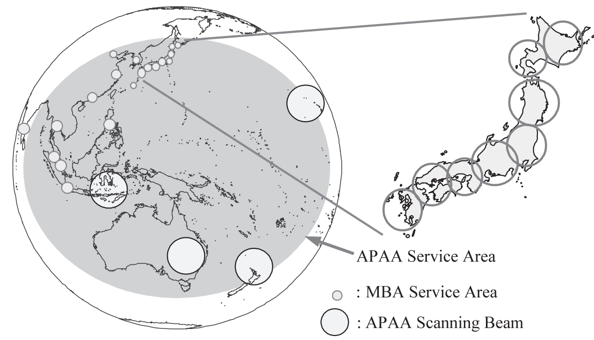


Fig. 7 Coverage of the WINDS.

Table 2 Major specifications of the WINDS.

Frequency	Up: 28.05 GHz / Down: 18.25 GHz (BW: 1.1 GHz)
Antenna	MBA: Two dishes of 2.4 m diameter APAA: 128-element phased array
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 mode by ABS and Bent-pipe mode

2.2 Optical Satellite Communications

The Ka band is used for data transmission from an observation satellite to a data relay satellite in Japan. Currently, its transmission rate is around 300 Mbit/s and higher data transmission of several Gbit/s will be required in future, according to the increasing number of onboard sensors and high resolution sensors. Thus, 10-Gbit/s class optical satellite communications are being studied.

The first satellite-ground laser communications with the ETS-VI succeeded in 1994. The first bi-directional space laser communications between NICT optical ground station and Optical Inter-orbit Communication Engineering Test Satellite (OICETS) was successful in 2006 in cooperation with JAXA. The uplink rate was 2 Mbit/s and the downlink rate was 50 Mbit/s [13] using an atmospheric influence suppression technique on the propagating light. In 2008, another OICETS-ground laser demonstration was conducted with JAXA by using a newly developed fast steering mirror in the optical transmission system. The experimental results revealed the operation characteristics of the fast steering mirror. Besides, the laser transmission trials with TerraSAR-X of German Aerospace Agency were carried out successfully in the end of 2008. Currently, an optical receiver and an optical amplifier for space use are being developed, where a coherent detection is planned.

3. R&D in NTT Group

In the early 1990s, NTT offered domestic satellite communications services that mainly supported emergency traffic, disaster-affected areas and rural areas [14]. DYANET (DYnamic channel Assigning and routing satellite aided digital NETworks) [15] was also used in the backbone network to carry terrestrial overflow traffic. Such systems and services were dedicated for PSTN and/or narrowband ISDN (Integrated Services Digital Network). On the other hand, the rapid adoption of the Internet in the late 1990 s created strong demands for broadband, multimedia and interactive satellite communications services. In 2000 s, mobility and ubiquity also became crucial factors as the terrestrial mobile services became widespread. NTT group focused on satellite communications R&D to meet such demands. This chapter presents NTT's major R&D results.

3.1 Challenges toward Broadband, Multimedia and Interactive Services

The first satellite intranet/internet system developed by NTT laboratories combined satellite and terrestrial channels as shown in Fig. 8 [16]. To reduce the cost of the satellite receiver, the satellite channel was designed based on the DVB (Digital Video Broadcasting) standard. The developed system offered asymmetric packet transfer services of up to 1 Mbit/s in the downlink. Using the developed system, the commercial satellite intranet/internet services called "Mega Wave-pro" and "Mega Wave" started in 1998 and 1999, respectively.

Although these services offered broadband downlink channels, the uplink channels were poor and tied to terrestrial networks. Meanwhile, satellite communications networks have the inherent ability to offer multicast services such as contents delivery or enterprise intranets that comprise multiple access points. To accommodate these applications only by satellite, the direct multicast satellite communications system was developed to realize a full-mesh type network [17]. It also supported multimedia services with high frequency utilization efficiency.

The system configuration is shown in Fig. 9, where each UES (User Earth Station) transmits/receives multiple signals to/from different UESs simultaneously in an FDMA (Frequency Division Multiple Access) mode. Although FDMA has an advantage over TDMA from the RF equipment viewpoint, it requires a large number of modems to support multiple transmission links. The group modem is a key component in solving this problem. The features of the developed group modem are; (1) the number of carriers and the bandwidth of each carrier are variable; (2) it allocates the required bandwidth over dispersed frequency bands so that continuous frequency bands are not required as illustrated in Fig. 10. These features are achieved by combining a seamless multi-rate filter bank with the timeshared processing modem [18]. The outlook of the developed group

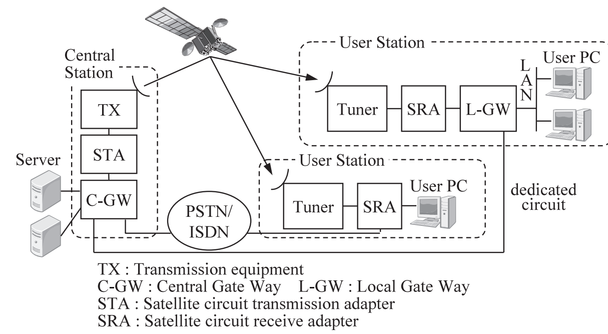


Fig. 8 Configuration of the satellite intra/internet system.

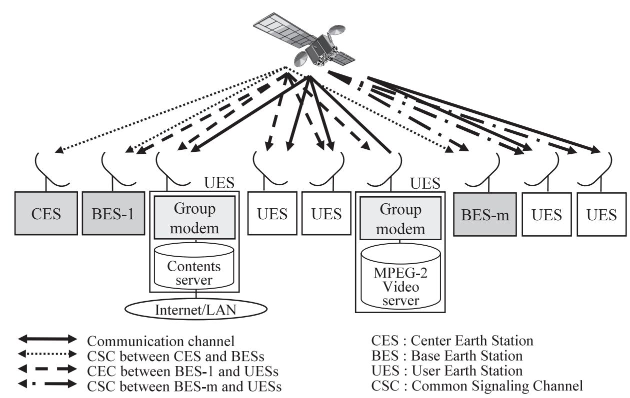


Fig. 9 Configuration of direct multicast satellite communications system.

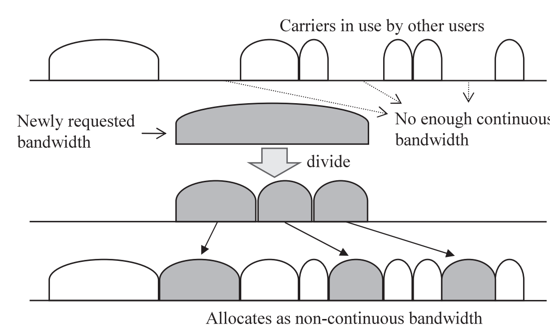


Fig. 10 Multi-carrier decomposition in the group modem.

modem is shown in Fig. 11 and an example of its output spectrum is shown in Fig. 12. The direct multicast satellite communications system was put into commercial use for the maritime broadband communication service named "Ku-Globe" by NTT Communications Corp. in 2007 [19].

Lifeline services also need to satisfy the broadband demands, and extremely high reliability is required. Thus, a new common satellite communications infrastructure, that accommodates isolated island communications services and disaster-affected area emergency services, has been developed to offer broadband and multimedia service lifelines [20]. Configuration of the developed system is shown in Fig. 13. To reduce deployment and operational costs, this system exploits a common platform and shares satellite

Depth/Width/Height = 550/482/88 [mm]

Fig. 11 Outlook of the developed group modem.

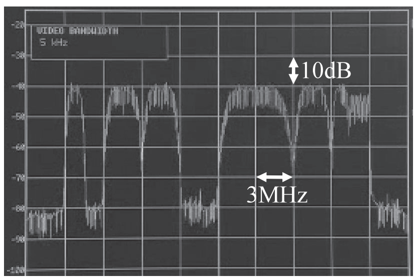


Fig. 12 Output spectrum of the group modem.

transponders among the two services. Key features of the developed system are as follows.

(1) Transponder resource sharing

To achieve high reliability for the isolated island communications services, the developed system has redundant paths, i.e., satellite A as a primary path and satellite B as a backup path. Meanwhile, the disaster-affected area emergency services utilize satellite B. Namely, satellite B is shared by the two services. When the primary path for the isolated island service fails, some of satellite B's resources are used for the isolated island service on a priority basis. This concept is effective to reduce the total number of satellite transponders needed.

(2) Group modem

The group modem described in 4.1.2 is used to accommodate multiple channels with different bandwidths.

(3) VoIP transmission technology

As the disaster-affected area emergency services need a unified, flexible and simplified interface for both voice and data, the developed system employs VoIP technology. To meet voice quality requirements, the system parameters such as voice codecs and bit rates have been carefully optimized. The developed system has been in commercial operation by NTT East and NTT West Corp. since 2005.

3.2 Pursuing Mobility and Ubiquity

First S-band mobile satellite system was introduced by NTT DoCoMo in 1996 [24]. In 1999, DoCoMo initiated new satellite development to augment the fidelity and reliability of the system. Since N-STAR-a and its sister satellite N-STAR-b, which were launched in 1995 and 1996, respectively, were designed to operate in tandem to cover the full operating bandwidth spectrum, a backup satellite was needed. The new satellite named N-STAR-c was designed to ensure compatibility with existing systems and enhance the capability to meet future demands. The developed new satellite uses a large unfurlable mesh antenna, for power-concentrating shaped beams to increase the maximum EIRP. The satellite system also uses a multi-port amplifier to distribute arbitrary power to any beam. The enhanced power enables smaller portable terminals and higher data throughputs. An artist's illustration of the N-STAR c satellite is shown in Fig. 14.

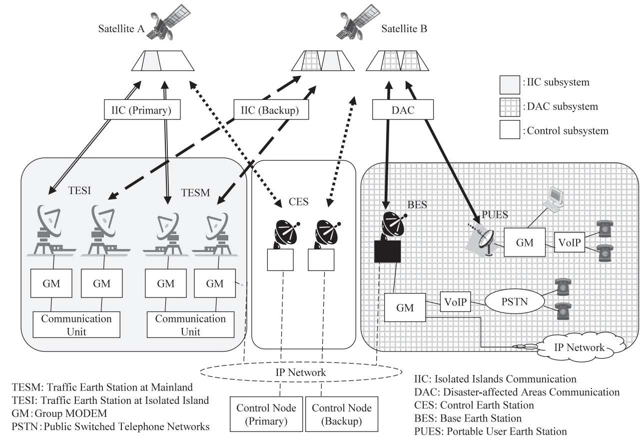


Fig. 13 Configuration of the satellite communications system for isolated islands and disaster-affected areas.

Fig. 14 Rendering of the N-STAR c. ((c) Orbital Science Corp.)

Just before the retirement of N-STAR a & b, N-STAR d was launched with the JSAT (Japan Satellite Corp.) mission. System specifications of N-STAR d are shown in Table 3 together with those of N-STAR a, b & c. The mission design of N-STAR d was inherited from N-STAR c, and satellite EIRP was further enhanced and full bandwidth selective mode was implemented to enhance capacity assignment flexibility to handle dense traffic in one beam. This lopsided situation, where all channels are used within one beam, can happen in mobile and maritime communications. One of the design challenges in N-STAR was extremely wide dynamic range of transmitting power. The combination of a high-power transmitter and a high sensitivity receiver increases the possibility of PIM (Passive Inter-Modulation), which significantly degrades communication performance. Multi-level verifications from unit to system levels were conducted to exclude any potential PIM sources. Challenge regarding

Table 3 System specifications of N-STARs.

	N-STAR d	N-STAR c	N-STAR a& b
Beams (area)	4 beams (Including sea area around , 200 nautical miles)		
Polarization	S-trans.: Right-hand Circular		
	S-receive.: Right-hand Circular		
G/T (C to S)	13		1
(S to C)	10		3
EIRP (C to S)	62	59	52
(S to C)	40	49	36
Frequency band	15/12MHz 30MHz	15/12MHz	15/12MHz

S: Service link S-band frequency, C: Feeder link C-band frequency

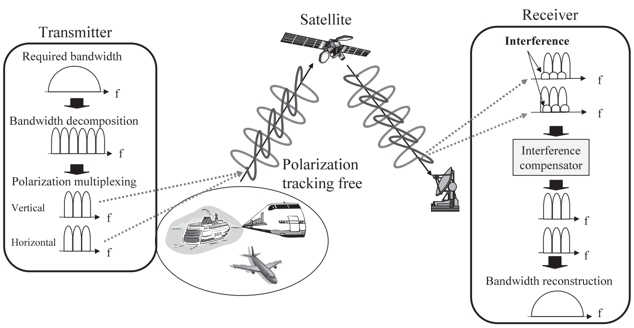


Fig. 15 VPFDM transmission.

the unfurling mesh antenna was to verify its quality on the ground to ensure the integrity when deployed in orbit.

3.3 R&D for Future Satellite Communications Systems

Terrestrial broadband infrastructures such as photonic networks and LTE/IMT-Advanced mobile networks are certainly creating the broadband ubiquitous era in near future. However, satellite communications are inevitable to offer broadband services to passengers in platforms such as ships, trains, and airplanes, which are not covered by terrestrial communications networks. NTT laboratories are currently focusing on such application fields. An example is a polarization tracking free satellite communications system that employs VPFDM (Variable Polarization Frequency Division Multiplexing) transmission as shown in Fig. 15 [21]. Since this system does not need polarization tracking, mobile terminals can adopt simple and/or low profile antennas. Other R&D activities include a broadband and scalable mobile satellite communications system [22] and a hyper multipoint data gathering satellite communications system [23] both of which extremely enhance ubiquity of the satellite communications.

4. R&D in KDDI

4.1 Inter-System Frequency Sharing

VSAT services by ESVs are being introduced for broadband maritime services. For ESVs, minimum operational distances from coastlines are specified in ITU Radio Regulations (RR) as 300 km in the 6 GHz band and as 125 km in the 14 GHz band to protect Fixed Services (FS) from interference by ESVs.

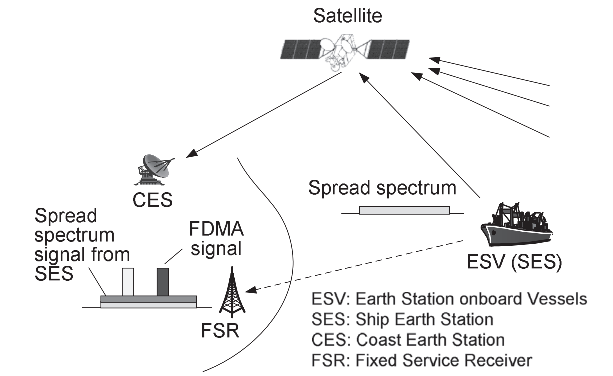
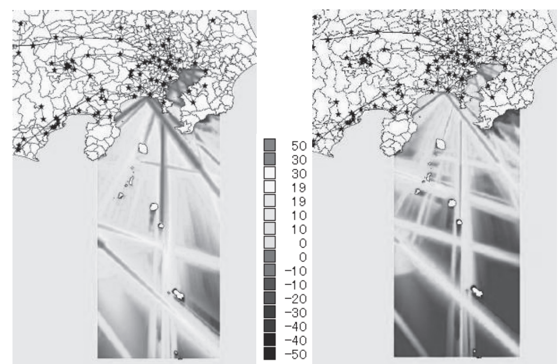


Fig. 16 Interference geometry between ESVs using spread spectrum signals and FS receivers (FSRs).



(a) With ESVs adopting a conventional signal. (b) With ESVs adopting a spread spectrum signal.

Fig. 17 Simulated maximum levels of I/Ns at FSRs located in Japan (shown with black dots in the map) from an ESV located at each point in the sea.

The interference geometry between ESVs and FS receivers (FSRs) is shown in Fig. 16. It was shown that the interference limit specified by ITU RR can be met by adopting spread spectrum (SS) techniques at ESVs [25]. Examples of simulation results in the 6 GHz band are shown in Fig. 17, indicating maximum levels of I/Ns at FSRs located in Japan (shown with black dots in the map) from an ESV located at each point on the sea. Figure 17(a) shows the results when SS techniques are not adopted, whereas Fig. 17(b) shows the results when EVSs adopt SS techniques. In "warmer" colored (e.g. red) ESVs locations, interference levels for FSRs exceed the I/N (Interference to Noise ratio) threshold of 19 dB. The interference is remarkably mitigated as shown in Fig. 17(b) compared with Fig. 17(a), and SS techniques enable ESVs operation within the specified separation distances from coast lines, i.e. 300 km in the 6 GHz band.

Another sharing study between downlinks of Fixed Satellite Services (FSS) and IMT-Advanced for future mobile services in the 4 GHz band was conducted. Interference reduction techniques using adaptive-array (AA) antennas were studied by field experiments [26], [27]. The interference geometry is shown in Fig. 18, and the interference

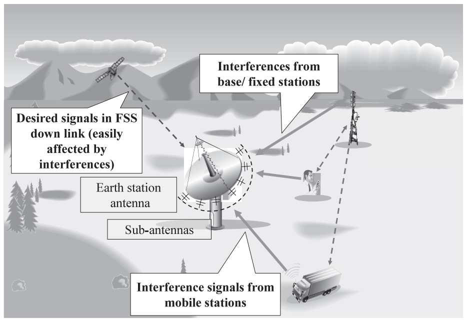


Fig. 18 Interference geometry between downlinks of Fixed Satellite Services (FSS) and future mobile services.

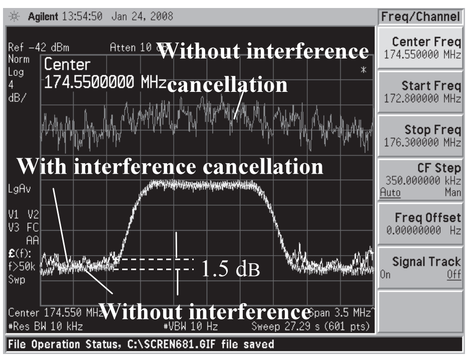


Fig. 19 Interference levels measured at the earth station in the field trial.

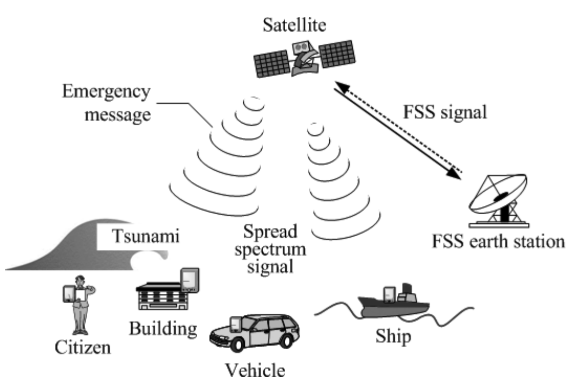


Fig. 20 Co-channel sharing scenario with a low speed wideband spread spectrum signal superimposed on conventional FDMA FSS signals.

measured at the earth station is shown in Fig. 19. The desired signal is totally masked by the interference from IMT-Advanced (the pink trace), however the field trial results show it can be recovered after the interference cancellation using AA antennas (the yellow trace).

4.2 Intra-System Frequency Sharing

Co-channel sharing scenario shown in Fig. 20 was studied. It was assumed that the small terminals receive low data rate but broadband spread spectrum signals superimposed on conventional FDMA FSS signals and both are transmitted from FSS stations. The study results show that the data rate of several tens kbit/s is guaranteed for small terminals with a semi-omni directional antenna with 5 dBi gain. This may be used for emergency alert messaging services, such as earthquake or tsunami warning. The study results have been standardized as Recommendation ITU-R S.1779 ("Characteristics of fixed satellite service systems using wideband spreading signals").

5. Conclusions

This paper has overviewed Japanese R&D in satellite communications over recent ten years, namely R&D activities in NICT, NTT group and KDDI. NICT has been involved in many national R&D satellite projects such as the ETS-VIII, the WINDS, the QZSS, and the STICS for fixed broadband and mobile satellite communications. On the other hand, NTT group focuses R&D for the domestic satellite communications systems including mobile satellite communications and the advanced technologies. KDDI focuses the frequency sharing and techniques, aiming at broadband satellite services for aircraft and vessels.

As indicated by the R&D activities described in this paper, satellite communications are evolving toward "broadband" and "ubiquitous" along with terrestrial networks. The key for the future satellite communications will be "integration of satellite and terrestrial" to realize true "ubiquitous" networks since satellite communications is still one of the most economical ways to provide telecommunications services, both fixed and mobile, in less populated areas, and terrestrial systems are suitable to densely populated area. This system and network level satellite communications R&D should be strengthen in addition to each element of technologies such as antenna, RF component and modem. R&D for efficient utilization of frequency spectrum is also important to achieve the goal of "broadband." Satellite communications will continue to play an important role in the ubiquitous network society by supplementing the terrestrial networks, taking advantage of the unique features of satellite communications.

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