2 Overview of the Wideband InterNetworking Engineering Test and Demonstration Satellite Project

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Wideband InterNetworking engineering test and Demonstration Satellite (WINDS) is an experimental satellite aiming at research and development of broadband satellite communications system which takes part in construction of worldwide broadband networks. Its origin is the Gigabit Satellite R&D started in Communications Research Laboratory (CRL, one of former bodies of NICT) in 1992, and fundamental technologies such as Ka-band active phased array antenna, satellite onboard modem and high speed baseband switch were developed in the project. Full scale experimental satellite project as WINDS started in 2001 and the satellite will be launched in early 2008. This paper describes the overview of WINDS project such as circumstances, key technologies and experimental plan.

Keywords
Satellite communications, Broadband, Phased array antenna, Onboard switch,
Ultra high data rate modulation / demodulation

1 Introduction

The explosive growth of the Internet and broadband networks in the 1990s led to dramatic changes in how information is distributed in all aspects of daily life. Until this period, data communications were rarely used in homes, limited to certain applications such as BBS (Bulletin Board System). However, during this period, fix-charged ISDN connections and ADSL/FTTH applications expanded into the home, leading to significant growth in broadband networks and full-time access to the Internet. As a result, daily data information traffic is now increasing exponentially. On the other hand, in mountainous areas and islands with geographic conditions disadvantageous to the construction of information infrastructures, and with correspondingly small market prospects, the penetration of broadband networks and the Internet tends to lag behind in these areas, giving rise to the so-called digital divide. In addition, when large-scale disasters occur, telecommunications infrastructures on the ground often fail to operate. In these cases, satellite communications play an important role. Moreover, to support large-capacity information distribution, it is necessary to implement broadband satellite communications systems. We can also expect the development of more convenient services taking advantage of the characteristics of satellite communications, such as wide coverage, multicast capability, and flexibility in connection setup. An experimental Wideband InterNetworking engineering test and Demonstration Satellite (WINDS) is currently under joint development by the National Institute of Information and Communications Technology (NICT) and the Japan Aerospace Exploration

Agency (JAXA), aiming at developing and demonstrating technologies for ultra-high-speed satellite communications systems to complement the existing broadband network infrastructure.

Figure 1 is a schematic diagram of WINDS applications. The realization of ultra-high-speed satellite communications systems is expected to increase the usability of satellite communications, particularly in ensuring communications in disasters, providing broadband communications in mountainous areas and islands, in temporary expansion of network facilities, and in multicast-based services.

2 Background of development

In response to the spread of broadband telecommunications networks, researchers and engineers have been developing technologies for higher data rate satellite communications systems since the 1990s. The US launched the Advanced Communications Technology Satellite (ACTS) in 1993, developed a satellite communications system that provided 696-Mbps bent-pipe mode and 110-Mbps regenerative mode, and demonstrated operation of the satellite through transcontinental supercomputer network experiments and other applications. In 1994 Japan launched the Engineering Test Satellite Ⅵ (also known as Kiku-6 or ETS-Ⅵ). A Ka-band transponder with bandwidth of 200 MHz was developed and installed on the satellite; this technology was then incorporated into N-STAR, NTT's commercial communications satellite launched in 1995. A 155-Mbps high-definition video transmission experiment was planned for ETS-Ⅵ but was not performed, as the satellite was not successfully delivered into geostationary orbit. Later, this experiment was performed using the transponder installed on N-STAR. In 1997, Japan and the US were connected at 45 Mbps using Intelsat and ACTS, and a remote post-production experiment was performed with high-definition images. If we are to realize a high-data-rate satellite communications system equivalent to or higher than ACTS, we must develop new technologies. Accordingly, NICT established the concept of the "Gigabit Satellite" and began studying the feasibility of such a concept in fiscal 1992.

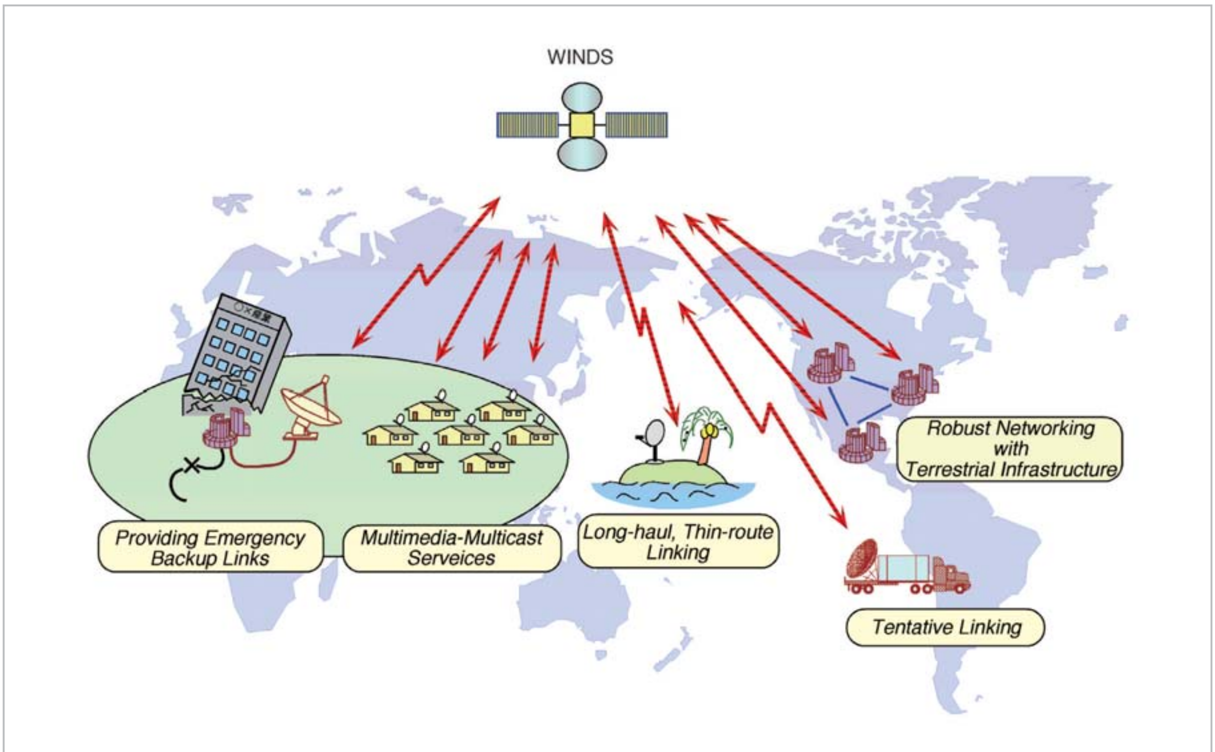

Fig.1 Schematic diagram of WINDS applications

Gigabit Satellite

The Gigabit Satellite development concept[1] describes the implementation of a satellite system designed to provide both ultra-high-speed transmission and wide coverage. The design incorporates the use of the Ka band (28-GHz band for uplink and 18-GHz band for downlink), which can provide a wide bandwidth of 1 GHz or more. Ultra-high-data-rate transmission requires a high-gain spot-beam antenna. Securing wide coverage at the same time requires an extremely large number of multi-spot beams or several scannable spot beams. After studying this concept, we gained perspective in fabricating an active phased-array spot-beam antenna (referred to simply as a scanning spot-beam antenna, or SSBA). To enable gigabit-class communication with an earth-station antenna featuring a diameter of 5 m, we need to construct an active phased-array antenna consisting of approximately 1,000 elements. Although technical issues remain in the structure and in the eliminating of heat, we have concluded that the antenna is feasible if we make certain assumptions about future prospects for the development of solid state amplifier devices. We have designed the SSBA as an antenna that can freely scan up to four beams for different directions, thus requiring a function to interconnect the spots. We considered two methods to effect onboard beam interconnection: the bent-pipe method, which switches the signal route in the IF band, and a regenerative method based on the ATM cell switching, which provides more advanced, more flexible switching functions. Although the bent-pipe method requires switching scheduling in accordance with beam interconnection requests from the earth station, this method allows for the implementation of ultra-high-speed communications utilizing the transponder's entire bandwidth. The regenerative method, on the other hand, imposes restrictions particularly on the speed of operation of the modulation/demodulation device to be installed on the satellite, and thus it is difficult to provide ultra-high-speed communication of a type that uses the entire transponder bandwidth. Nevertheless, as the regenerative mode allows for demodulation of the uplink packet and determining of the downlink beam, it can provide advanced, flexible beam interconnection as well as the functions of a router.

Based on these study results and presuming that an experimental satellite would be launched around fiscal 2002, we developed the fundamental technologies and subsystem prototypes from fiscal 1996 to fiscal 2000. Figure 2 provides an illustration of the concept behind the Gigabit Satellite. Specifically, we have developed a breadboard model (BBM) of a 64-element SSBA subunit (the constituent unit of a large-scale SSBA), an onboard modulator/demodulator, and an ATM switch. Figure 3 shows the external appearance of the developed transmission SSBA subunit BBM. These research and development results are succeeded in the development of WINDS.

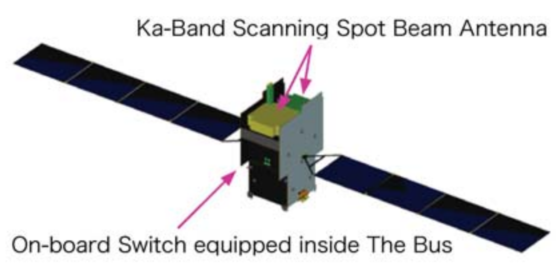

Fig.2 *Concept Behind Gigabit Satellite*

Fig.3 *64-element transmission SSBA subunit*

Wideband InterNetworking Engineering test and Demonstration Satellite (WINDS)

In fiscal 2000, the Space Activities Commission approved an initiative referred to as "space infrastructure development research for the implementation of an ultra-high-speed Internet society", and full-scale development of WINDS subsequently began as a joint project with the Japan Aerospace Exploration Agency (JAXA).

The WINDS system was designed based on the Gigabit Satellite described above, taking into consideration both development efficiency and known requests for application experiments. Specific details are described in Section **3** and later. An overview follows below.

(1) WINDS provides fixed spot beams to areas with high demand for experiments: nine locations in Japan and 10 locations overseas. To enable use of the satellite with smaller earth stations, WINDS is equipped with a fixed multi-beam antenna (MBA) with a diameter of 2.4 m.

(2) For the transmitter connected to the MBA, WINDS uses a multi-port amplifier (MPA) that provides flexible power distribution to realize advantages in its compensation for attenuation due to rain.

(3) In terms of the many issues surrounding the development of the SSBA, we plan to develop a down-scaled 128-element active phased-array antenna (APAA) to install aboard WINDS.

(4) To implement the regenerative beam interconnection function, WINDS is equipped with a switching router based on ATM cell switching (called an ATM Baseband Switch, or ABS) equivalent to three 155-Mbps lines.

(5) To implement the bent-pipe beam-interconnection function, WINDS is equipped with a microwave switch matrix.

Among these items, NICT is in charge of developing ABS for the proto-flight model (PFM), and JAXA is in charge of developing APAA for the engineering model (EM) and developing the PFM, based on the results of development of the Gigabit Satellite. JAXA is also in charge of developing other onboard devices and the satellite bus. The satellite bus is designed based on the COMETS bus to increase development efficiency and to reduce risk.

We have decided to develop four types of experimental earth stations: a 45-cm-diameter Ultra-Small-Aperture Terminal (USAT) for 155-Mbps reception and 1.5/6-Mbps transmission, a 1.5-m diameter High-Data-Rate Very Small Aperture Terminal (HDR-VSAT) for 155-Mbps reception and 51/155-Mbps transmission, a 2.4-m-diameter Super-high Data Rate Very Small Aperture Terminal (SDR-VSAT) for 622-Mbps reception and transmission, and a 5-m-diameter Large Earth Terminal (LET) for 622-Mbps/1.2-Gbps reception and transmission. The smaller two earth stations support broadband communications while taking up less space, and it is believed that these stations will prove effective in promoting a range of applications. The larger two earth stations are intended for implementation of ultra-high-speed satellite networks. Among these earth stations, JAXA is in charge of developing USAT and VSAT, and NICT is in charge of developing SDR-VSAT and LET.

3 Elemental technologies in research and development

3.1 Elemental technologies in research and development of subsystems aboard WINDS

(a) Onboard Switching Router

The Onboard Switching Router implements the routing function on the satellite and simultaneously provides multiplexing in downlink. Thus, this router serves as an important technology enabling highly efficient use of transmission power. For this reason, many satellites planned in the late 1990s adopted similar technologies. For example, HotBird 6/7 of Europe are equipped with a DVB-S multiplexing device known as Skyplex. Spaceway of the US is equipped with a packet switch (16-Mbps uplink and 106-Mbps downlink) based on a proprietary protocol.

WINDS is equipped with a switch based on the ATM cell-switching function and implements three 155-Mbps lines for the switching function, as the world's fastest onboard switching router. To support earth stations of varying scales and levels of performance, we developed an onboard demodulator that can handle a wide variety of transmission rates, from 1.5 Mbps to 155 Mbps. Software can be updated, allowing for fixing of bugs that may arise, or added even after launch. As a particularly significant characteristic, the switch structure allows for the subsequent addition of a label-switching function.

The technical issue in developing the ABS is implementing fast modulation/demodulation and switching using radiation-hardened devices that can be installed on a satellite. In particular, the onboard demodulator needs to handle many transmission rates, as stated above, but needs to be as lightweight as possible. This will require significant development in circuit structure and signal-processing methods.

(b) Active Phased Array Antenna (APAA)[3]

APAA technology is essential in covering a wide area and in implementing high-gain spot beams at the same time. Previously, a 19-element S-band APAA was developed for the ETS-Ⅵ satellite. Outside of Japan, France's CNES developed a Ku-band APAA for Stentor, while the US developed a Ka-band receiving APAA for Spaceway. However, the WINDS project incorporates the first development, and demonstration in space, of a transmitting and receiving APAA featuring bandwidth of 1.1 GHz in the Ka band.

For the Gigabit Satellite, we assumed a large-scale APAA consisting of 1,000 or more elements and built a 64-element subunit. In developing WINDS, we are mainly aiming at technical demonstrations in orbit; accordingly, we decided to develop two 128-element APAA for transmission and reception, respectively. The technical issues in an APAA with many elements lie in the structure of the heat sink as well as the support structure. These issues are significantly influenced by the improvement in the added power efficiency of the solid-state power amplifier (SSPA) transmission element. The challenge is to develop a highly efficient SSPA based on the required overall transmitted power, the required number of elements, and an appropriate level diagram. Here, the APAA provides common amplification for multiple channels and can implement flexible power distribution per channel. Thus, it is important to discuss the added power efficiency at the system level as well as at the device level. The prototype SSBA subunit in the Gigabit Satellite recorded an added power efficiency of 55% or more for the transmission amplification device and an added power efficiency of 18% or more as an SSPA module.

(c) Multi-Port Amplifier (MPA)[3]

Compensation for rain attenuation — a problem to be resolved in the Ka band-can be implemented flexibly and efficiently with a multiport transmission amplifier consisting of two or more traveling wave tubes (TWT) and two or more input and output ports. WINDS combines a fixed multi-beam antenna (MBA) with MPA to distribute more power to spots with greater attenuation from rain, and thus can provide consistent communication quality. Previously, an S-band MPA was developed for the ETS-Ⅵ satellite, but there has been no such development to date in the Ka band. An MPA requires a divider/combiner circuit between the input/output ports and the TWTs. This circuit is constructed of waveguides in the Ka band, and a significant technical issue arises in the implementation of the extremely high phase control precision required.

3.2 Elemental technologies in research and development for earth stations

(a) Ultra-high-speed modulator/demodulator

WINDS provides ultra-high-data-rate transmission using the entire 1.1-GHz bandwidth in bent-pipe transponder mode. To best take advantage of this characteristic, we resolved to develop a 622-Mbps and 1.2-Gbps ultra-high-data-rate modulator/demodulator for an experimental earth station. Adding an error-correcting code requires an additional 10–20% increase in the transmission rate. In past satellite communications, the 696-Mbps rate achieved by ACTS as described above is the highest transmission rate; thus a transmission rate of 1.2 Gbps will be the world's fastest. The development issues lie in the signal-processing technologies, including error-correction demodulation processing that will ensure transmission quality at low C/N_0 while limiting the occupied bandwidth to within 1.1 GHz[4].

(b) Network synchronization

WINDS has an onboard switching function and can provide flexible beam interconnection. On the other hand, an earth station must transmit packets with timing that supports a spot beam containing the earth station. Accordingly, WINDS adopts an access method based on time division multiple access (TDMA) and transmits a reference burst at the head of the TDMA frame for synchronization. The earth station needs to receive this reference burst for TDMA synchronization and to acquire the network information for access control. This network synchronization function is required for all earth stations, from LET to USAT. The only remaining development issue is to implement this function using the simplest and least expensive circuit and software configurations possible.

4 Development schedule and planned experiments

4.1 Development schedule

The development of WINDS began in April 2001 with a preliminary design, in collaboration with JAXA. We started work on a basic design in January 2002, with completion of the preliminary design review (PDR) in March 2003. We proceeded to detailed design in March 2003, and a critical design review (CDR) for the satellite system was completed in March 2006. We moved to the maintenance design stage in March 2006.

4.2 Planned experiments

The demonstration experiments planned after the launch of WINDS can be classified into fundamental and application experiments. NICT and JAXA, the organizations developing the satellite, are positioned to perform the fundamental experiments, with the aim of confirming performance of the developed devices and demonstrating the effectiveness of the WINDS communications network system.

After an initial checkout to be performed directly after the launch of WINDS, only fundamental experiments are to be performed for a period of approximately seven months, to verify that stable experimental environments may be provided to application-experiment users and to demonstrate the effectiveness of the WINDS communications network system. From seven months to two years after launch, fundamental experiments will have priority over application experiments in terms of scheduling; however, both types of experiments will be performed in parallel with as many application experiments as possible. After two years from launch through the end of the mission, application experiments will have priority.

A range of fundamental experiments are planned: NICT will perform experiments to verify the performance of the onboard devices, experiments to verify the performance of the earth stations, basic transmission experiments, high-data-rate satellite-network experiments, and network application experiments. JAXA will perform experiments to verify the performance of the onboard devices, disaster operations experiments, multicast communication experiments, and data-delivery experiments with respect to observation data.

NICT and JAXA will perform some of the experiments jointly, including experiments to verify the performance of onboard devices such as the APAA and the regenerative transponder, rain-attenuation compensation experiments, and high-speed satellite-network experiments.

Application experiments are to be performed by organizations other than NICT and

JAXA. The Ministry of Internal Affairs and Communications (MIC) solicited application experiments from February 1, 2007 through March 30, 2007, and received 53 proposals. Based on deliberations at the Satellite Application Experiment Promotion Conference (Chair: Prof. Fumio Takahata, Waseda University) held in May 30, 2007, MIC adopted all proposals. These proposals include 26 from Japan, 11 from Thailand, three from Indonesia, and three from Malaysia. More than 15 nations will take part in the project. Diverse types of experiments are planned. Some experiments are related to communication techniques (such as experiments on propagation characteristics), methods of rain attenuation compensation, and communication control. Other experiments relate to distance education, telemedicine services, disaster communications, and other application demonstrations. To help facilitate the smooth execution of these experiments, the WINDS Application Experiment Consortium was established on July 26, 2007.

5 Conclusions

WINDS began in 1992 with the concept of the Gigabit Satellite. Following research and development of fundamental technologies, building of prototypes, and testing, the full-scale project began in fiscal 2001, embodied in the WINDS experimental satellite, in collaboration with JAXA.

Research and development of satellite communications technologies involves developing cutting-edge elemental technologies, incorporating these technologies in system design, and satisfying the specifications and restrictions governing onboard devices, including considerations of weight and mass. As a result, development is generally a long term process, posing the risk that the novelty and importance of the relevant technologies may recede during this period. As for the WINDS project, 15 years have passed since the Gigabit Satellite concept was born. Nevertheless, the broadband satellite communications that WINDS was designed to establish continue to involve the world's most advanced technologies. At the same time, research and development of similar technologies have recently begun in many countries. Thus, when WINDS is launched into its proposed geostationary orbit and accomplishes the planned demonstration experiments, we will be positioned to lead technological development in this field and to make a significant worldwide contribution. We fully intend to pursue this project vigorously to meet these ambitious expectations.

The development of WINDS is currently continuing in the final stage toward launch in fiscal 2007. Here at the end of this article, I would like to note that this project has been successfully executed to date thanks to the efforts and enthusiasm of numerous people, many of whom have been involved in the project since its inception.

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