Next-generation Broadband Mobile Satellite Communication System in the Ubiquitous Network Era

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Abstract

After investigating the potential market for satellite communications in around 2010 that will have advantages over future terrestrial communication networks, we concluded that there will be a large demand for broadband communications services for passengers in vehicles such as long-haul trains, sea-going vessels, and airplanes. In this article, we describe a next-generation broadband scalable mobile satellite communication system for Japan that can offer economical broadband Internet service for passengers in such vehicles. We describe possible services, estimate the potential market, and discuss the requirements for such services to flourish. Finally, we discuss enabling technologies required for the system.

1. Introduction

The recent explosive increase in data communication over the Internet has generated strong demand for high-speed access lines. According to the Japanese Ministry of Public Management, Home Affairs, Posts and Telecommunication, the telecommunication market in Japan has two distinctive features [1]. As of March 2005, DSL (digital subscriber line) access lines were offered in over 90% of municipalities in Japan and the number of subscribers exceeded fourteen million. The number of subscribers using optical fiber (fiber to the home (FTTH)) reached 2.85 million in March 2005. Most broadband users had always-on connections via DSL, CATV (cable TV), or FTTH. In addition, more than 86% of the 87 million cellular phone users subscribed to mobile Internet access. Around 2010, Japanese terrestrial cellular networks will enter the broadband 3G (third generation) or beyond 3G system (B3G) era [2]. Moreover, the hotspot services offered over wireless local area networks (LANs) are currently expanding rapidly. These trends suggest that the broadband network will become ubiquitous in Japan and that people will be able to access the Internet from wherever they are.

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However, at present in Japan, broadband Internet service is not available to passengers in airplanes, long-haul trains, or sea-going vessels. It is thought to be impossible to provide an economical service using terrestrial cellular networks. On the other hand, the global mobile satellite communication industry has been gradually moving toward the broadband era. Inmarsat provides a 64-kbit/s HSD (high-speed data) service (Inmarsat-A). It also provides a 144-kbit/s Regional BGAN (broadband global area network) service via the Thuraya spacecraft using the L band. A 432-kbit/s BGAN service, provided by Inmarsat-4 spacecrafts, commenced in 2005. Connexion by Boeing has started offering a broadband Internet service for business-class passengers on planes. This service uses the Ku band and was initially offered on routes between Europe and North America, then on routes between the Far East and North America, and finally on routes between Europe and the Far East [3]. The ESV (earth station on vessel) technical standard was decided at the World Radiocommunication Conference held in 2003 (WRC-03) [4]. ESV can provide two-way broadband communication for ships by using the Ku band and the C band. Based on the standard, there are many commercial satellite tracking antennas for ships available nowadays. In April 2002, we decided that mobile satellite communication services was one of the most promising markets and started to focus on R&D of satellite communication systems and key technologies for the services [5].

According to a report [6] by the Satellite Industry Association (SIA), mobile broadband services and broadband connectivity to aircraft were considered to be emerging services/applications. SIA also reported that the revenue from mobile satellite data services increased by 8% in 2005. Its analysis showed that services were driven by the growth in emergency response and military applications. It predicted that mobile broadband development would be driven by military, emergency, and in-flight services. Another report [7] by Northern Sky Research says that mobile broadband satellite services based on high-speed data will be a sustainable and viable business proposition over time though there are currently serious technological difficulties mainly related to the performance and affordability of antenna systems for mobile environments.

These circumstances led us to conclude that around 2010, satellite communication could have some advantages over future terrestrial communication networks. In this article, we describe a next-generation broadband scalable mobile satellite communication system for Japan and explain its requirements and key technologies that need to be developed.

2. Satellite communication services in Japan

2.1 Trend of Japanese telecommunications market

In Japan, the number of DSL subscribers exceeded fourteen million and the number of the subscribers using optical fiber reached 2.85 million in March 2005. As shown in **Fig. 1**, the Internet population was steadily increasing and had reached almost 80 million. Moreover, cellular phone users had exceeded 87 million, and more than 86%, almost 75 million, subscribed to the mobile Internet. The transmission speed of the mobile Internet was between 9.6 and 384 kbit/s. However, just like fixed broadband Internet users, mobile Internet users naturally want higher transmission speeds.

The trend of revenue for the leaders of the Japanese telecommunications industry is shown in **Fig. 2** broken down by type of service. The revenue is the sum of revenues for major telecommunication operators, who own their networks and offer services over them. The revenue for each service was calculated using data in their published annual reports [8]-[13]. The total revenue of operators had been almost constant and was 16 trillion yen (approximately US$ 139 billion) as of March 2005. Revenue from voice communications on cellular communication networks had remained almost constant for a few years though it had continued to increase up until 2001, while revenue from voice communication on fixed communication networks decreased. Revenue from data transmissions was increasing rapidly and so was revenue from data transmissions on cellular networks. Comparing the distribution ratios of services between 2000 and 2004, it is clear that the mobile data service was growing to occupy a certain amount of revenue.

Concerning future mobile computing, the Mobile Computing Promotion Consortium (MCPC) [14] in Japan has estimated the future Japanese market and number of users of mobile computers. As shown in **Fig. 3**, the market was expected to double from 1.9 to 3.7 trillion yen from 2002 to 2005, with a marked

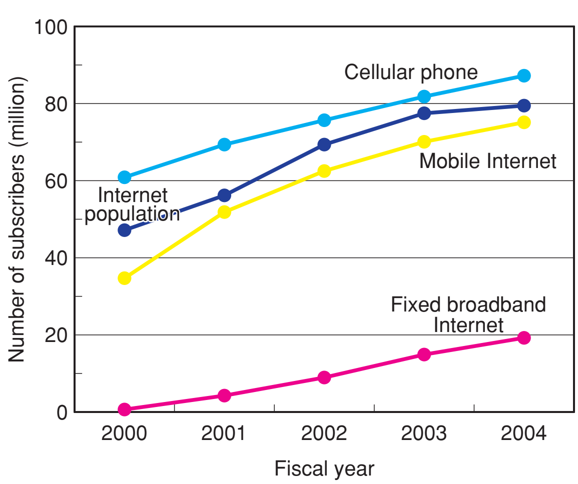

Fig. 1. Internet population and mobile Internet.

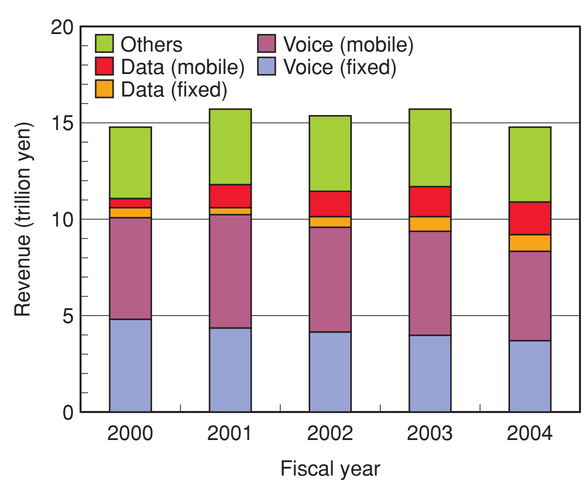

Fig. 2. Revenue for Japanese telecommunication services.

increase in mobile terminal revenues and a 60% increase in communication charge revenues. The number of users was projected to increase from 83 million in 2002 (fiscal year (FY) to 89 million in FY2005. This indicated that the traffic would increase and that users would desire higher transmission speeds.

These trends suggest that, in the near future, people will be able to access the Internet from wherever they are, i.e., the mobile Internet market will expand rapidly.

2.2 Satellite communication market

The revenue trend for major Japanese satellite communication operators is shown in **Fig. 4** [8], [15]. These operators had 13 satellites in 10 geostationary orbital slots. Their total revenue had increased well, mainly due to the revenue for entrusted CS (communication satellite) broadcasting. However, it was starting to fall. The telecommunication revenue had been almost constant with a slight increase in transmissions entrusted by telecommunication operators. In the long term, as broadband terrestrial access networks expand, the fixed satellite communication service is destined to shrink due to the limited capacity and high cost of the communications satellite itself, meaning that it cannot compete economically with terrestrial communications networks.

On the other hand, as shown in **Fig. 5**, the number of mobile satellite communication subscribers in Japan had been steadily increasing, and it reached 50,000 in March 2005. The services used the N-STAR mobile satellite communication system, the Orbcom system, and the Inmarsat system. Two-thirds of the subscribers belonged to the N-STAR system, which mainly offered voice communications and low-speed telemetry/packet communication. These services were offered to earth stations onboard vessels, airborne earth stations, and portable earth stations. From Figs. 4 and 5, we concluded that the revenue of fixed satellite communication services including broadcasting had started to shrink and that the number of mobile satellite service subscribers was rising.

2.3 Potential roles of satellite communications

Because broadband terrestrial communication networks were spreading rapidly and most mobile users could access the Internet, it was very important to investigate potential markets in which future satellite could have an advantage over future terrestrial communications networks. The potential roles of satellite commu-

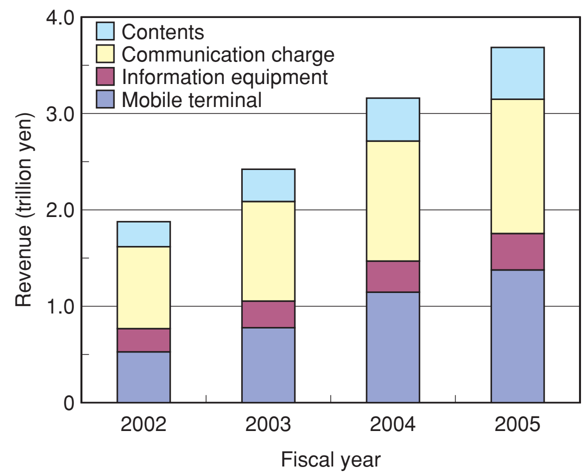

Fig. 3. Market projection by MCPC [14].

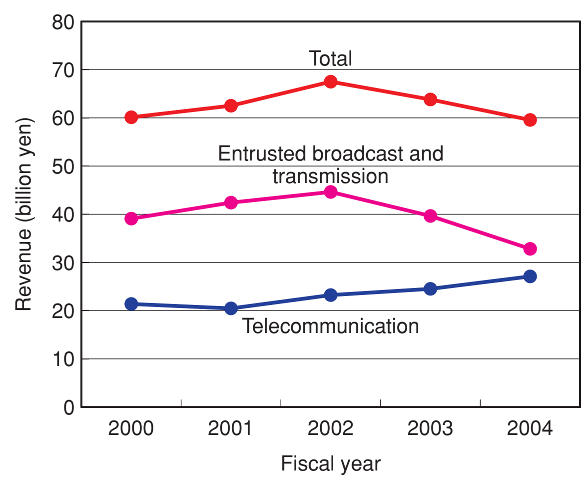

Fig. 4. Revenue of Japanese satellite operators.

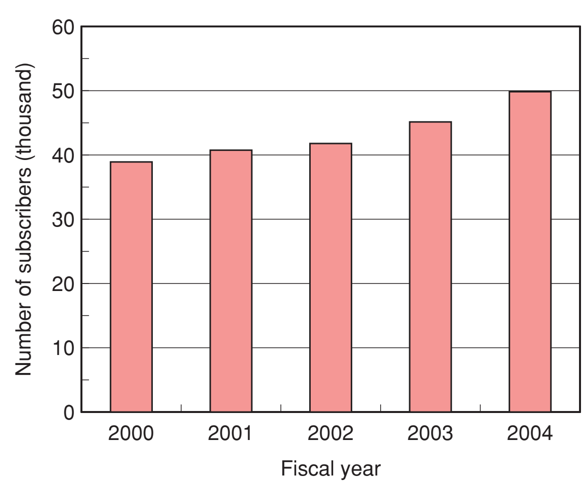

Fig. 5. Mobile satellite communication subscribers in Japan.

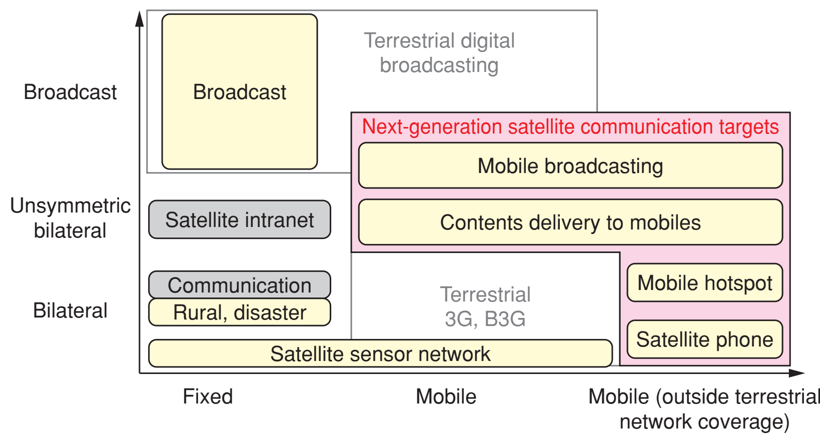

Fig. 6. Roles of satellite communication in Japan.

nications in around 2010 in Japan are shown in **Fig. 6**.

We concluded that the demand for fixed satellite communications services, except for broadcasting, was shrinking because the demand for satellite communication circuits on remote islands and for disaster relief was limited, and as terrestrial broadband access networks spread out from metropolitan areas, satellite access networks would not be able to compete with them in terms of transmission speed and price. One piece of evidence was that at the end of March 2005, NTT-SC, which had offered satellite broadband intranet service, was dissolved and merged into JSAT.

It was clear that a conventional mobile satellite communication system would not be able to compete with terrestrial 3G/B3G cellular networks in terms of transmission speed or price. However, we expected a large demand for broadband communications outside the terrestrial broadband cellular networks areas, where mobile broadband satellite service could be offered economically. Typical customers for the satellite services filling this gap would be passengers in long-haul trains, vessels, and airplanes. As long as satellites are the most efficient means for reaching rural and remote areas with a high-speed ubiquitous link, then economical broadband services can be offered to those vehicles by using a high-performance and cost-effective satellite.

According to Northern Sky Research, Internet access on trains generates a high level of public interest and presents an opportunity; the market size is considered to be large. Broadband services can be achieved through a combination of satellite-based schemes and WiFi*. The near-term market for satellite-WiFi deployments [16] is expected to be over 90,000 hotspots by 2007, although alternative wireless standards, such as WiMAX and 3G, might dominate the satellite market. Moreover, according to a report [17] from wireless LAN experts BWCS, train travelers will be spending US$420 million per year on in-transit LAN hotspot services by 2008. By then, 625 million people will use WiFi-enabled trains worldwide every year.

Finally, we should note that a multicasting satellite communications can still have a big advantage over terrestrial cellular networks [18]. Consequently, we believe that the next-generation mobile satellite communication system will mainly provide broadband and multicast services for passengers in vehicles.

3. Next-generation mobile satellite communication services and system

We believe that up to around 2010, satellites will still be the most efficient means of obtaining economical broadband services with high-speed ubiquitous links to vehicles and rural areas, when we consider the expansion of the terrestrial broadband access networks. By that time, fixed broadband services, such as ADSL (asymmetric digital subscriber line) and FTTH, will be available almost everywhere. Services provided by 3G cellular systems will have reached their saturation point and B3G will be beginning to emerge. However, terrestrial broadband networks, such as FTTH, 3G, and B3G will not to be able to physically or economically cover all of Japan, including the sea. In addition, as long as the system can offer services economically, it can also offer low-speed services economically. The following are services that we think could be offered using our pro-

* WiFi is a brand name owned by the WiFi Alliance, which promotes high-speed wireless LANs.

posed system, design conditions, and target performances.

3.1 Target applications and terminals

Next-generation mobile satellite communication services are schematically illustrated in **Fig. 7**. We envisage five kinds of services available in Japan and its exclusive economic sea zone: 3G/B3G and broadcast services for vehicles, namely, mobile hotspots, nomadic access, digital divide solutions, disaster relief, and satellite supervisory control and data acquisition (SCDA), which is a kind of satellite sensor network. These services, with different types of terminals, will be provided by a single satellite system. This means that mobile satellite communications systems should be configured to serve several segmented markets, while focusing on mobile hotspot services. If this is done, then the system will constitute part of the ubiquitous network. Some such terminals, which meet the speed requirements, are shown in **Fig. 8**. Current voice communication through satellites requires proprietary satellite terminals. Consequently, we think that only a fraction of the potential users will be able to subscribe to the satellite communications service.

Therefore, the customer base could be significantly increased if people had access to satellite services from their own terrestrial terminals when the terrestrial networks are not available. The service could be offered through a satellite radio base station and called a gap-filler service [19]. The concept is similar to the Ancillary Terrestrial Component (ATC) system.

In such systems, broadband traffic will mainly consist of hotspot services in airplanes, long-haul trains, and vessels and of nomadic access services. These services could also be offered to passengers who have their own terminals or personal computers (PCs). In these vehicles, satellite WiFi could be used to obtain economical broadband services. In a combined satellite-WiFi deployment, a satellite link would be used as the backbone link to the Internet and would feed the WiFi access point, which would serve end users having a WiFi access card. The recent spread of WiFi wireless access technology makes this ideal for supporting the bandwidth and low cost requirements of broadband access.

The nomadic access service will be useful when freelance broadcasters or government organizations need to send images of disasters or accidents or on-

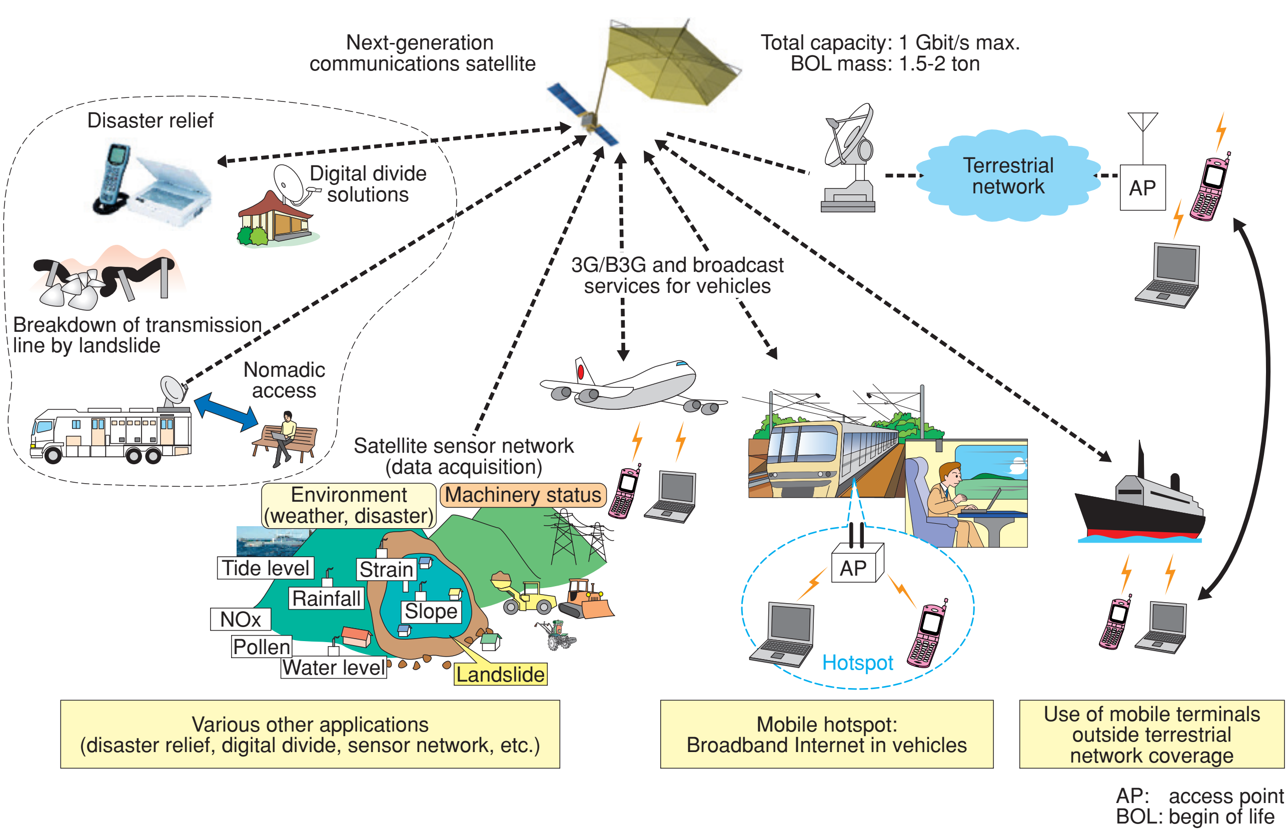

Fig. 7. Next-generation mobile satellite communication services.

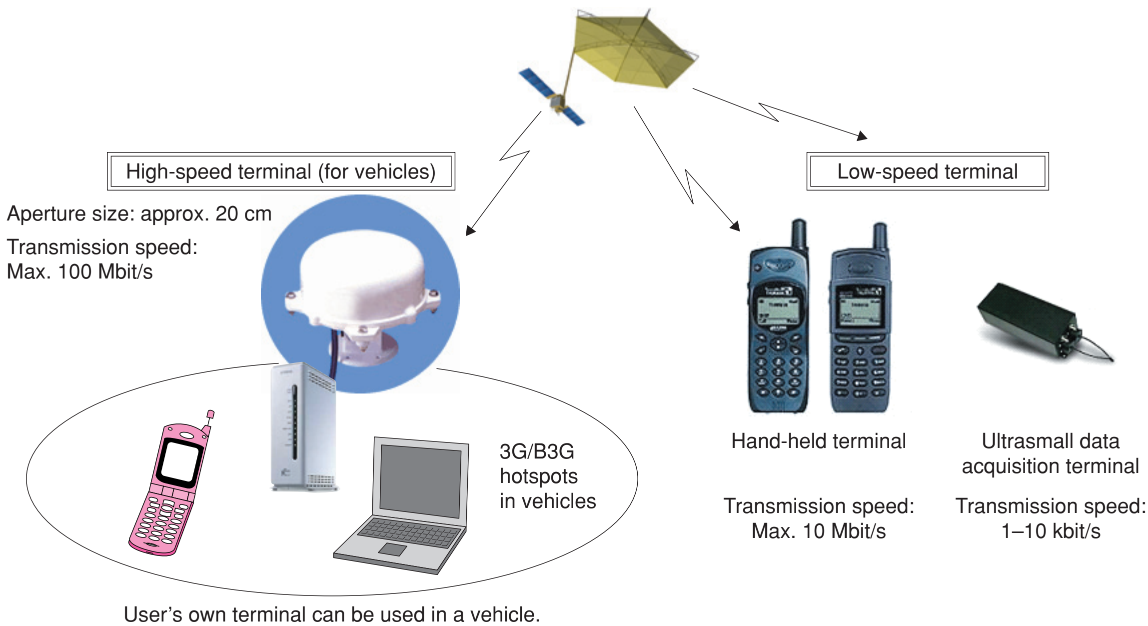

Fig. 8. Concept of Satellite terminals.

the-spot reports of events. The ubiquitous nature of handheld and portable terminals integrated with mobile satellite communication system will make them indispensable for disaster relief. Satellite sensor networks or satellite SCDA services will gather low-speed data from a large number of places, such as weather or seismic data measured over a wide area, and they will usually be located in large remote areas. Therefore, maintenance alone could be very expensive. In general, the amount of data will be fairly small. Some types of data must be transmitted in real time, 24 hours a day, whereas others only need to be sent periodically. From the perspective of offering these services to rural and remote areas, if the system can provide a speed equivalent to that of terrestrial networks, it might be possible to accommodate both broadband services and SCDA services.

For services to flourish, it is very important to match the satellite cost to the size of its potential market. The markets mainly consist of narrowband and broadband services. Narrowband services are primarily used for voice communication. If 1% of cellular phone users subscribe to a gap-filler service, then narrowband traffic could double to a total of 100 Mbit/s.

Broadband traffic in such a system, essentially data traffic, will consist of the hotspot service in airplanes, long-haul trains, and vessels and the nomadic access services. We estimated the broadband traffic of hotspot services in airplanes and high-speed trains (*shinkansen*). The service in these vehicles will also be offered to the customers having their own terminals like PCs. As mentioned in the previous section, satellite-WiFi can be used for economical broadband services in these vehicles. In a combined satellite-WiFi deployment, a satellite link is used as the backbone link to the Internet. The link is used to feed the WiFi access point, which ultimately serves end users that have a WiFi access card. Recent technology for widespread WiFi wireless access is a prime candidate to support the bandwidth and low cost requirements of a broadband access.

Counting the potential business travelers in Japan reveals that a total capacity of 600 Mbit/s would be required for such a broadband mobile hotspot service (**Fig. 9**). Moreover, our analysis showed that a further

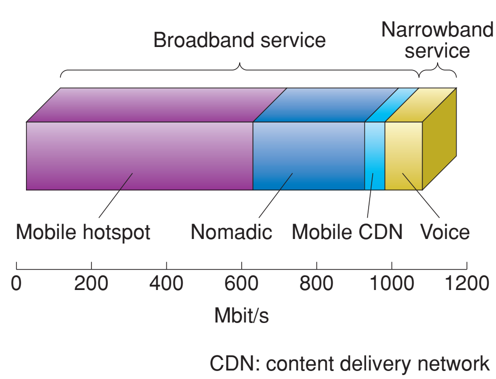

Fig. 9. Demand projection for next-generation mobile satellite communication service.

300 Mbit/s would be required for a nomadic access service. Even though the satellite SCADA service will gather low-speed data, it will do so from many places, so its total contribution could be large. Adding the narrow and broadband traffic together, we found that the total traffic demand would be 1 Gbit/s. Thus, the next-generation mobile satellite communication system should have at least this much broadband capacity.

3.2 System design conditions

Several system design conditions must be satisfied if future mobile satellite communication services are to flourish.

A. Transmission speed

By about 2010, people will be able to receive 3G or B3G terrestrial cellular communication services and they will expect services in vehicles to offer equivalent speeds. Therefore, future mobile satellite communication systems must achieve a maximum of 100 Mbit/s for the forward link, from the hub station through the satellite to the user, and 20 Mbit/s for the return link, from the user through the satellite to the hub station.

B. Satellite capacity

To effectively utilize the satellite capacity, there should be a good match between the demand and satellite capacity. We estimate that the satellite capacity will be about 1 Gbit/s by around 2010.

C. Scalability of transmission speed and traffic fluctuations

Since satellite services will cover everything from low-speed-data to broadband-data communications, the system needs to incorporate various types of terminals and be scalable to achieve speeds up to 100 Mbit/s, for which the dynamic bit rate range is 50 dB. Because this system deals with vehicles, traffic will fluctuate depending on the time and geographical location. This means that the demand will not be uniformly distributed in space and time. Some areas will have very little traffic while other regions will have heavy demands. Therefore, the system must offer the capacity according to the demand. This does not mean that the system should be designed to supply only the maximum required capacity, while leaving transponders unused. Rather, it must manage the satellite resources well, while meeting the demand and loading the transponder to capacity.

D. Support for users' terminals

To increase the customer base significantly, the system must offer the satellite services to users' own terrestrial terminals, such as cellular phones and PCs.

E. Scale of communications satellite

It is very important to provide services at affordable prices. Because communications satellites account for a major part of the total system costs, these costs must be minimized. Therefore, the potential cost reductions should be taken into account during the system design stage. In general, lighter, lower-power satellites cost less than heavy, high-power satellites. At the base level, we assume the scale of the present communications satellite used by Japanese mobile satellite operators. For this reason, the target payload power of a geostationary communications satellite is in the 2-kW class and the dry weight of the satellite is about 1 ton.

F. Frequencies

Currently, mobile satellite communication services are provided mainly over the L band or S band, but they have relatively narrow bandwidths. Another choice would be the Ku band, where secondary allocations are given to mobile satellite service (MSS) and aeronautical mobile satellite service (AMSS), and primary allocations are given for ESV. The Ku band has a wide bandwidth, but even so, the requirements for the primary ESV allocation to control interference in fixed service (FS) or fixed satellite service (FSS) are stringent. Therefore, the terminals will be more expensive than those for the L and S bands. For this reason, the ultimate target set for the primary MSS band, is the S band, which has a bandwidth of only 35 MHz.

3.3 Outline and target performance

Based on these requirements, it follows that a next-generation mobile satellite communication system will be broadband, scalable, and well-managed to enable fully loaded transponders on a 1-ton-class geostationary communications satellite to constitute part of a ubiquitous network so as to complement terrestrial networks. A large-capacity high-utilization satellite communication system will open up the potential market by greatly reducing costs.

To achieve a total communication capacity of 1 Gbit/s and access speed of up to 100 Mbit/s per user, we need to use a multibeam system that allows extremely high levels of frequency reuse. The target performance for such a multibeam satellite communication system is shown in **Table 1**. We are aiming for 30 times the capacity of current mobile communications satellites. Our investigation [19] found that the conflicting requirements for low power and large capacity could be met simultaneously by using a high-performance multibeam feeder and a light-

Table 1. Target performance of next-generation mobile satellite communication systems.

Frequency bands	Service link	S (bandwidth: 35 MHz)	
	Feeder link	C or Ka	
Transmission speed	Forward link	100 Mbit/s max.	
	Return link	20 Mbit/s max.	
Scalability	From 1 kbit/s to 100 Mbit/s		
Total capacity	1-Gbit/s class		
User terminals		Return	Forward
	Portable (< 5 W (RF))	< 20 Mbit/s	< 100 Mbit/s
	Handheld (< 1 W (RF))	< 0.5 Mbit/s	< 10 Mbit/s
	Utrasmall (< 0.1W(RF))	1–10 kbit/s	
Communications satellite	Power	2-kW class	
	Weight (dry)	1-ton class	
Service area	Japan and its exclusive economic sea zone		

RF: radio frequency

weight large reflector and that a 1-Gbit/s capacity for a 35-MHz bandwidth would require a 3-beam cluster model with over 70 beams, i.e., over 20 times reuse of the 35-MHz bandwidth. It also found that a satellite antenna with a gain of 43.5 dBi at EOC (edge of coverage) could provide 70 beams, which is equivalent to a 20-m aperture. An example of beam allocation over the service area is shown in **Fig. 10**.

4. Enabling technologies

Our approach is to greatly increase the system's communication capacity first and then utilize it as efficiently as possible. This system will require the development of enabling technologies for the communication system and high-performance onboard equipment. The former consists of a frequency reuse and resource allocation scheme and a multiplexing

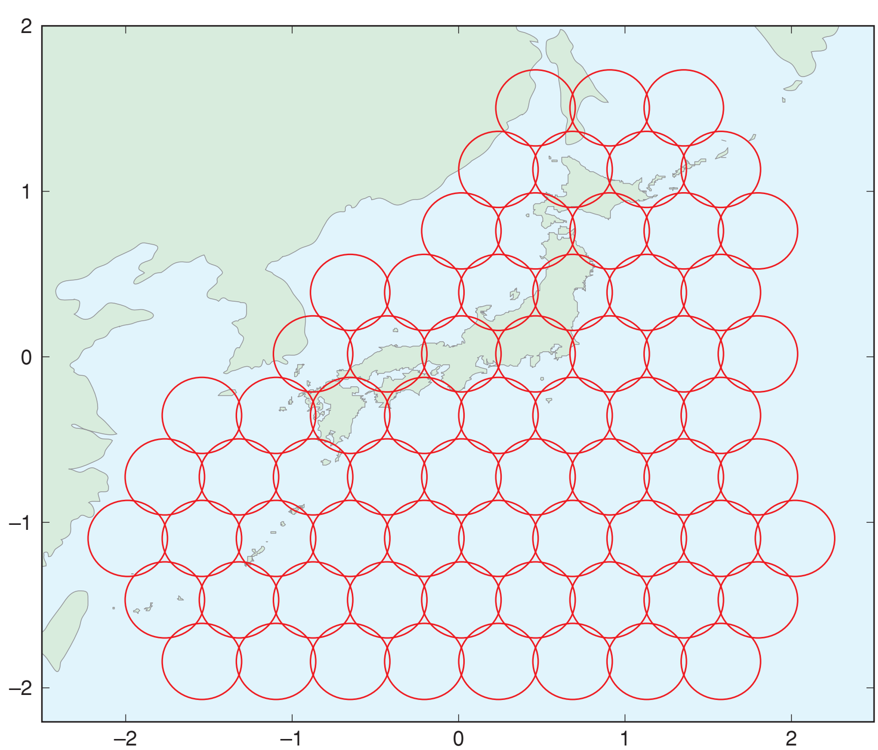

Fig. 10. Example of beam allocation.

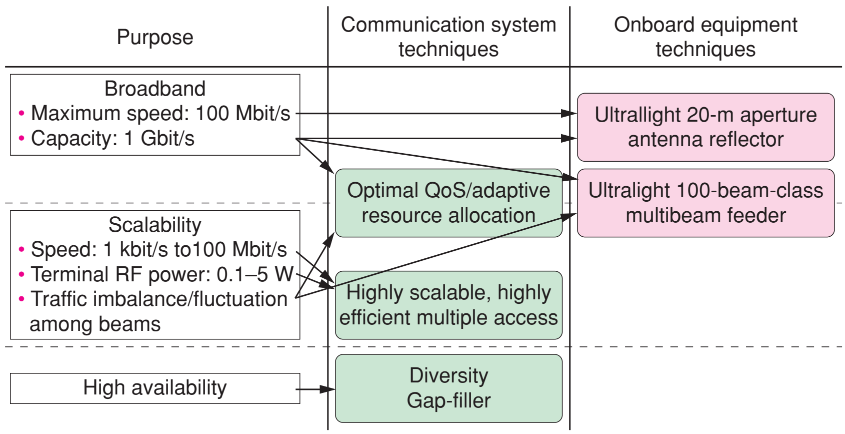

Fig. 11. Enabling technologies.

scheme. The latter consists of an ultralight large antenna reflector and an ultralight multibeam feeder. The relationship between the design conditions and technologies is shown in **Fig. 11** and explained below.

4.1 Communication system

According to our analyses, a transmission speed of about 84 Mbit/s for the forward link and 20 Mbit/s for the return link are feasible with the performances shown in **Table 2**. However, because our system must support a wide range of speeds, the satellite's power and frequency bandwidth might be wasted because of multicarrier backoff or guard-bands. Usually, the power required for terminals depends on blocking, interference, and the user's environment. For the same speed requirements, some users may need more power because of high interference, other users may not need as much power because there is less interference, while others could be assigned no power because they are completely shadowed. The uniformly distributed capacity obtained using multibeam satellite antennas will result in substantial unused throughput. As the traffic fluctuates, many areas will have very few users and other regions will have a heavy demand. To solve these problems, both a new onboard architecture and a new communication system must be developed to assign more capacity to the high-demand areas. While keeping the total capacity at 1 Gbit/s, as a means of absorbing the traffic fluctuation effects in each beam and still providing the required capacity for all beams, the system must also adaptively control the power, bandwidth, modulation, and coding rate for the beams as well as for individual users. Therefore, taking into account wasted bandwidth and power requirements, we must make good use of the total power and available frequency bandwidth. Besides, the required quality of service differs, depending on the type of application. To maintain the service quality or to avoid breaks in service requires control of such things as the bit error rate and time delay by using adaptive modulation coding. To improve availability, diversity and gap-filler technologies are useful. The former technology is most effective when applied in a moving train, where sections are periodically shadowed by the support structure for the overhead electrical wires. The latter can be applied to situations where entire vehicles are blocked by buildings, tunnels, and so on.

Table 2. Target payload performance.

Total power		2000 W
Total weight		400 kg
Total frequency bandwidth reused		(35 MHz ÷ 3) × 69
EIRP	Service link	Uniform beam 52 dBW
		Concentrated beam 65 dBW
	Feeder link	46 dBW
G/T	Service link	17 dB/K
	Feeder link	15 dB/K

EIRP: effective isotropic radiated power
G/T: gain/temperature, a measure of a satellite's receiving ability

4.2 Communications satellite

The baseline budgets on the power and weight were set to 2.8 kW and 1000 kg (dry mass), respectively, for communications satellites and 2.0 kW and 400 kg for the payload. There are many commercial heavy, high-power mobile communications satellites such as ACeS [20], [21] and Thuraya [22]. However, their capacities are far less than 1 Gbit/s. Based on the present technologies, the greater the required capacity is, the heavier a high-power communications satellite must be. This leads to a huge increase in service charges, thus reducing the advantage of the satellite system over terrestrial networks. Therefore, to achieve a 1-Gbit/s capacity on a 1-ton-class geostationary satellite, two lightweight onboard pieces of equipment must be developed: a lightweight feeder and transponder architecture, such as one that uses phased array feeders, and an ultralightweight deployable antenna reflector structure.

Large mesh reflector technology has progressed, and 13-m class reflectors are now available. However, even state-of-the-art technology may not satisfy the reflector budget weight. Thus, we need to develop a new type of ultralightweight reflector structure, whose weight per unit area is less than half that of current state-of-the-art reflectors. To enable the capacity of each beam to be changed so that it corresponds to its traffic, the onboard architecture must be able to change the power and frequency bandwidth in proportion to the traffic concentration in the specified area while limiting the total power and frequency bandwidth.

The performance of the envisioned communications satellite is shown in **Fig. 12** together with those of conventional mobile communications satellites including N-STARc [23]. For the purposes of comparison, the capacity was estimated for a handheld terminal. The figure shows that we need an extremely high-performance satellite.

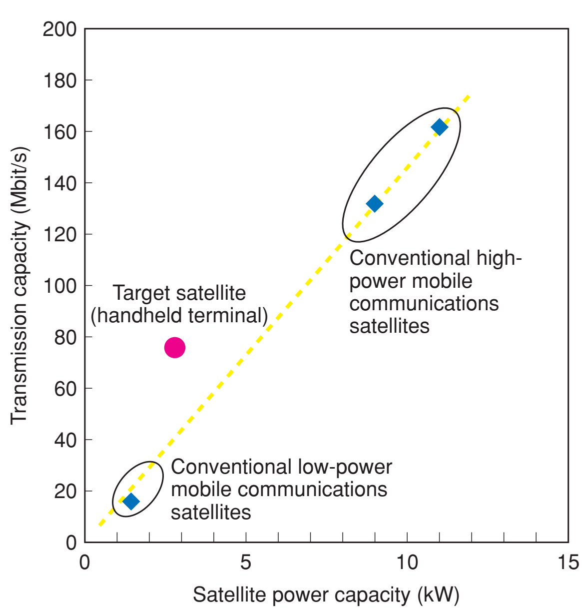

Fig. 12. Next-generation satellite performance.

5. Conclusion

Considering the expansion of terrestrial broadband access networks, we investigated the future roles and prospects in around 2010 for satellite communications in Japan. In this article, we described some services, mainly for users in vehicles in areas where the terrestrial networks cannot offer services economically. Then, we described a next-generation broadband scalable mobile satellite communication system that could offer these services at an affordable price based on the estimated demand. After that, we clarified the requirements for such services to flourish. Finally, we discussed the enabling technologies required for the communications system and the payload of the communications satellite.

Acknowledgments

We are grateful to Dr. Masahiro Umehira of Ibaraki University, former executive manager of NTT Network Innovation Laboratories, for his encouragement and guidance.

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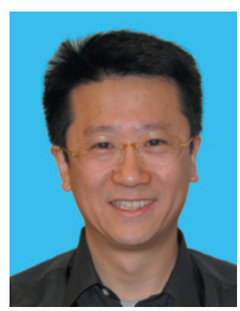

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