A Broadband Satellite Communication Technology for a Safe and Secure Society

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1. Introduction

Frequent, high-definition observation of global-scale climate changes is important to reduce the impacts of natural disasters on people's lives. Recently, the combination of technological innovation in the space industry with information communication technologies in other industries has led to expectations for new businesses for mapping various types of information on geographic spaces to acquire new information. In such systems, a large volume of data needs to be transmitted between satellites and ground stations in near real-time. This paper describes the latest trend in technologies to increase the data capacity for earth observation satellites and communication satellites. The paper also outlines the combination of communications and observation as a vision of the future.

2. Trend in Earth Observation Satellites and Future Technologies

2.1 Trend

In recent years, in addition to more accurate sensors to be installed on earth observation satellites, constellations of multiple satellites circling in low earth orbit are expected to make earth observation possible in near real-time. Such systems require high-speed datalinks to transmit observation data quickly to ground stations.

There are two types of datalink for earth observation satellites: one via data relay satellites located in geostationary orbit and the other in which data is directly transmitted to ground stations from the satellites in low earth orbit. The propagation loss on direct transmission paths is smaller than via geostationary orbit, and high-speed transmission is possible. Conventionally, direct transmission has used the X-band (8-GHz band), but the bandwidth becomes restricting as the transmission rate is increased. Therefore, the Ka-band (26-GHz band) for which the bandwidth (1.5 GHz) is four times that of the X-band has been studied. In addition, the Q-band (39-GHz band) that can use 3 GHz of bandwidth might improve the transmission rate.

2.2 Future technologies

Using high-frequency bands such as the Ka-band and Q-band will increase the antenna gain and usable bandwidth, and thus improve the rate of data transmission from earth observation satellites to ground stations. However, attenuation due to the atmosphere, such as rain, will also increase: when the elevation angle is low, in particular, waves travel further through the atmosphere, so the influence is large. Site diversity technologies in which multiple ground stations are used effectively improve the availability in rain. However, when the frequency band is switched to the Ka-band and Q-band from the X-band, the area of the beam transmitted from the satellite becomes smaller due to the increased frequency, so the signal to noise power ratio (SNR) in reception changes based on the positional relationship between the satellite and ground station, which is a problem. In addition, for the Q-band, earth observation satellites have been assigned as secondary users, so their interference to primary users (e.g., terrestrial networks) must be smaller than the specified value.

To solve such problems, a technique to control beams transmitted from earth observation satellites adaptively is effective.[1] This technique improves the reception SNR of the satellite systems and keeps the interference to terrestrial networks smaller than the specified value through adaptive control. Figure 1 illustrates an outline of this technique. First, as shown in Fig. 1(a), the satellite changes the orientation of the transmitting antenna to select site diversity or single-station reception dynamically. Next, as shown in Fig. 1(b), it changes the antenna's rotation angle such that the reception SNR becomes maximum by making the pattern of the transmitting antenna asymmetrical like an oval antenna. Lastly, as shown in Fig. 1(c), when a

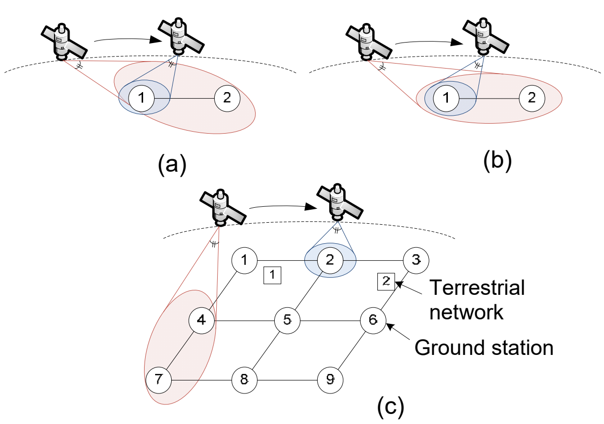

Fig. 1 An example of beam control

terrestrial network is located near the target ground station, it selects another ground station to reduce the interference. When a terrestrial network is near the target ground station, the satellite controls the beam radiation position using a weighting factor to improve either the availability or degradation of SNR preferentially. This technique improves the availability of the terrestrial networks and concurrently reduces the degradation of the SNR of the earth observation satellite system as shown in Fig. 2.

In addition, the transmittable time with a ground station is limited within the visible range where the ground station can be seen from the satellite, so observation data may need to wait to be sent if some data could not be sent within the transmittable time. To resolve this problem, the multi-carrier multi-hop communication technique shown in Fig. 3 works well. The technique improves the data transmission probability for each transmission opportunity in earth observation satellite constellations.[2] A satellite using this technique has a channelizer and multiple transmitters. The transmitters perform encoding and modulation based on the quality of paths. The channelizer demultiplexes signals input from the transmitters to sub-channels and uses the switch to multiplex its own signals with signals from other satellites for sending to the inter-satellite-link or direct transmission path. Figure 4 illustrates an example of transfer using this technique. The control station calculates the transmittable capacity for each of the satellites that can communicate with ground stations. It then selects multiple ground stations to which the earth observation satellites will send all data that they possess and determine the inter-satellite-link path to send the data to the target ground stations (routing information).

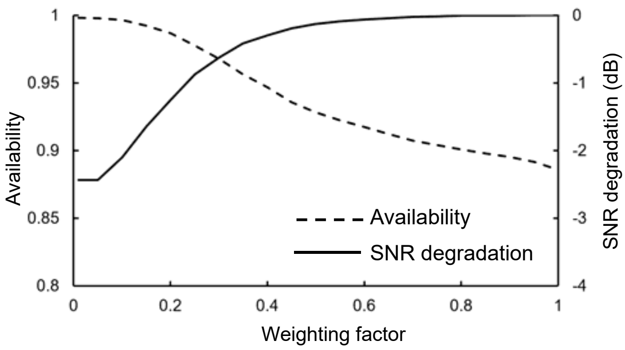

Fig. 2 Availability of terrestrial networks and SNR degradation of satellite link

3. Trend in Communication Satellites and Future Technologies

3.1 Trend

For communication satellites, the high throughput satellite (HTS) has been used to reduce the bit cost of a single satellite. In HTS, multiple short-range beams reuse frequencies to increase the relay capacity. Figure 5 illustrates the configuration of an HTS system. A terminal is located in each of multiple beams radiated from the satellite and communicates with the gateway via the satellite. A modern HTS system has tens of beams to span cover the coverage area, achieving a channel capacity of approx. 100 Gbit/s by the entire system. As the frequency plan, the user link consists of the four-color frequency reuse scheme (two frequencies and two polarized waves). However, when multiple beams are used to span the coverage area, frequencies for the feeder link run out. As a solution, multiple gateways are provided at geographically separate locations to reuse the frequencies of the feeder link to increase the number of beams for the user link.

3.2 Future technologies

Currently, many HTS systems are bent-pipe repeaters in which the frequency of each beam and the connection between the beams are fixed. On the other hand, digital channelizers and beam hopping are effective for improving the frequency efficiency, by assigning frequencies or time flexibly based on changes in communication demand. As the speed of devices

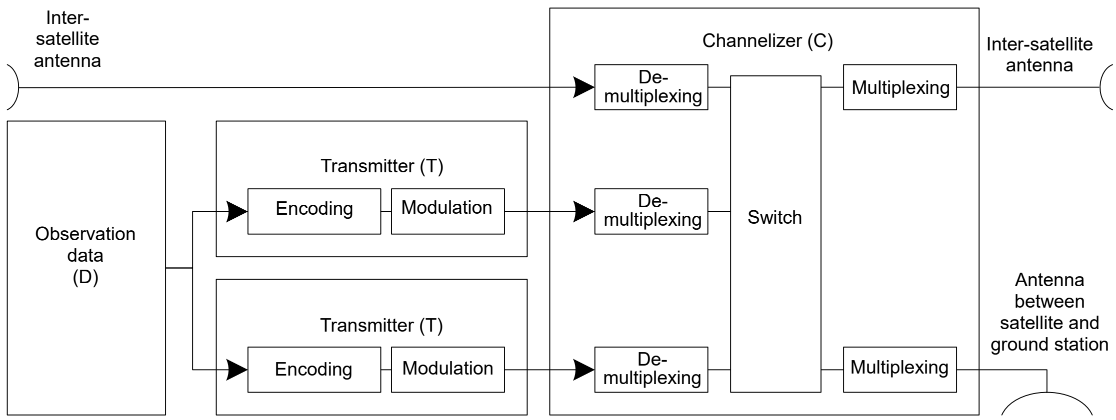

Fig. 3 Satellite function block for multi-carrier and multi-hop relaying

installed on satellites becomes higher, digital channelizers and beam hopping are expected to be applied to broadband systems (e.g., Ka-band systems). Mitsubishi Electric Corporation has developed a digital channelizer including de-multiplexing and multiplexing circuits that process up to 640 MHz per beam.

Conventionally, when a digital channelizer is used to concentrate frequencies to a specific beam, it is done within the bandwidth assigned to the user link. Meanwhile, for the Ka-band, the frequency bands assigned to the user link and feeder link are continuous. Therefore, as shown in Fig. 6, by changing the ratio of the bands between the user link and feeder link, the bandwidth of the user link can be significantly increased.[3] This technique allows the feeder link and user link to be assigned to the same frequency repeatedly by selecting a gateway that does not interfere much with the beam to which the frequency should be intensively assigned when traffic is concentrated to a specific beam, which can increase the transmission capacity as shown in Fig. 7.

In addition, for conventional beam hopping, the movable ranges (clusters) of the beams transmitted from satellites are independent, so when traffic is unbalanced between the clusters, the frequency efficiency deteriorates. To solve this problem, the overlapping clustering beam-hopping technique is effective. In this technique, the domains of the clusters overlap with each other and the beam is radiated from a different cluster to an area to which the traffic is concentrated. This

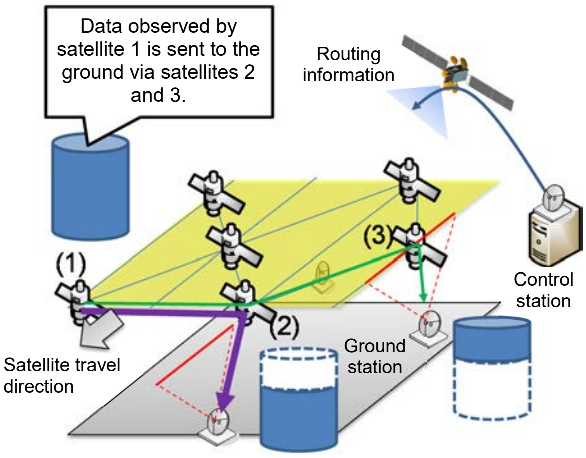

Fig 4 An example of data transfer

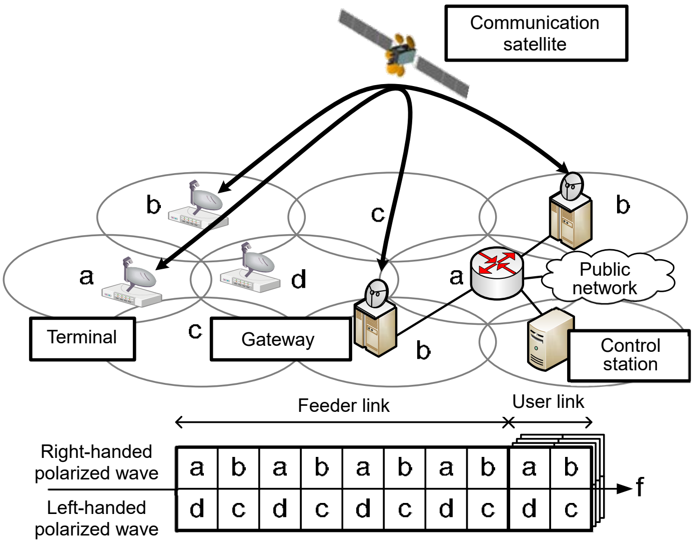

Fig 5 System architecture of HTS

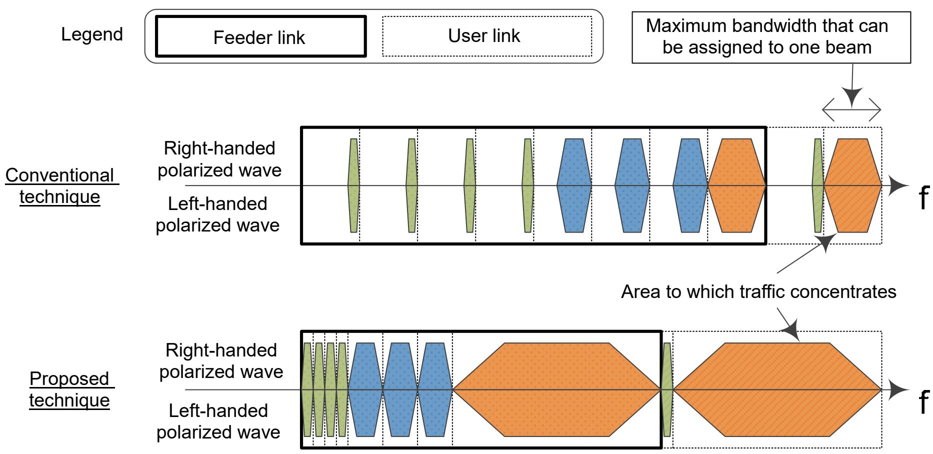

Fig 6 Comparison of frequency plan

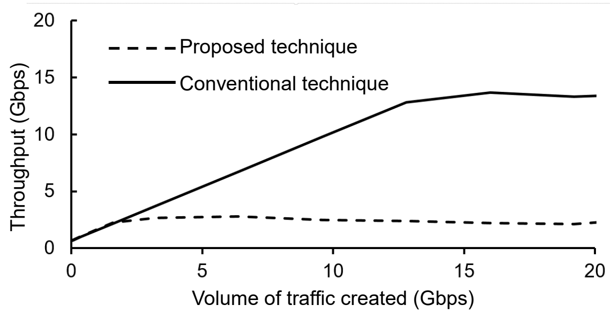

Fig 7 Throughput performance in congested area

achieved by a single system; it is important to establish scalable and flexible systems suitable for each user.

5. Conclusion

This paper described the trend in earth observation and communication satellites that support safety and security, as well as future technologies that control methods of sending data from satellites to ground stations and exchanging data between satellites based on their positional relationship and volume of data left unsent adaptively to increase the transmission capacity.

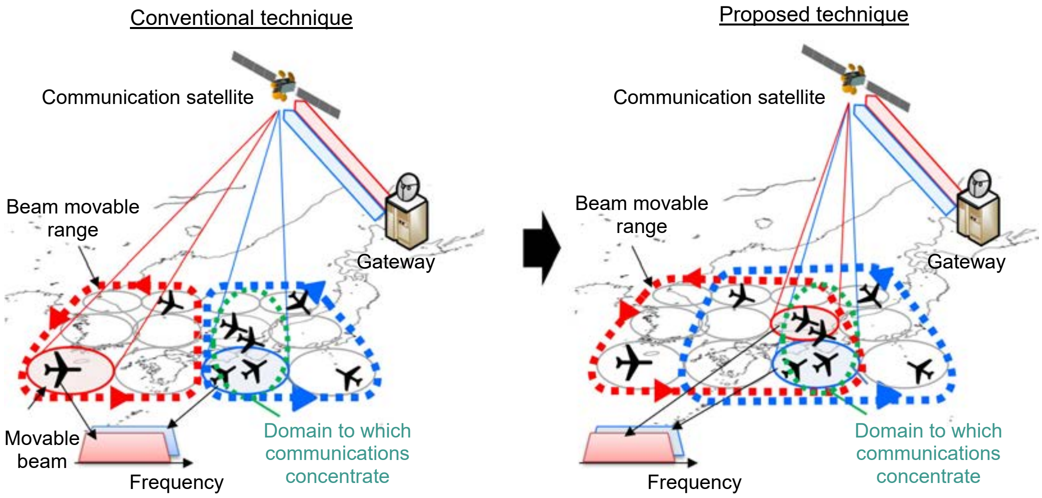

Fig 8 Overview of the overlapping clustering beam-hopping technique

technique can improve the transmission capacity to approximately 1.5 times that of the conventional technique.[4]

4. Combination of Observation and Communications

To reduce the impact of natural disasters on people's lives, it is important to understand the situation quickly and take action promptly. It is effective to establish real-time observation systems to understand the situation: hybrid networks in which HTS systems are combined with inter-satellite transmission that was described in the preceding part and that is used to achieve low-delay transmission are effective. Earth observation satellite systems and satellite communication systems both require higher speed, immediacy, and accommodation of multiple users. Effective ways to achieve this are broadband transmission using the Ka-band, improvement of the frequency efficiency using multiple beams, and improvement of the flexibility by satellite digital payload. Thus, both types of systems have similarities, from the configuration of the networks to single components, so systems in which observation and communications are combined using integrated networks may be established in the future. However, these services cannot be

The paper also showed the similarities between earth observation satellite and communication satellite technologies, and expectations for services that combine both types of technologies.

6. References

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