Demonstration and Evaluation of Local 5G with GEO/LEO Backhaul: Implementing High Reliability and High Capacity

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1. Introduction

Satellite communications technology has advanced rapidly in recent years, including advances with Low Earth Orbit (LEO) constellations. This is leading to advances in the communications infrastructure being deployed by satellite communications operators, such as multi-orbit configurations.

On the other hand, Local 5G is getting organized domestically in Japan, making it possible to build independent 5G Networks within particular geographic areas or facilities. 5G is capable of high-speed, high-capacity and low-latency communications as well as large numbers of simultaneous connections, so it is highly anticipated for use in a wide range of fields, such as manufacturing, agriculture, disaster response and remote medicine.

By integrating satellite communications technology and 5G communications technology, we hope to create new value and contribute to solving societal issues. In commissioned research conducted by NICT, titled "Research and Development of Satellite-Terrestrial Integration Technology in Beyond 5G (No. 21901)," a network environment combining dynamic routing with Quality of Service (QoS) control was built, utilizing satellite communications as the Local 5G backhaul, with multiple orbits having different communications characteristics. This showed the effectiveness of dynamic control based on channel conditions. The demonstration confirmed that both stable communications and increased throughput can be achieved by combining LEO satellites for high-capacity data transport with Geostationary Earth Orbit (GEO) satellites for guaranteeing stable bandwidth.

This article introduces anticipated use cases, the 5G control technologies, and an overview of the demonstration and results. This is followed by discussion of how the results will be used and business prospects for the future.

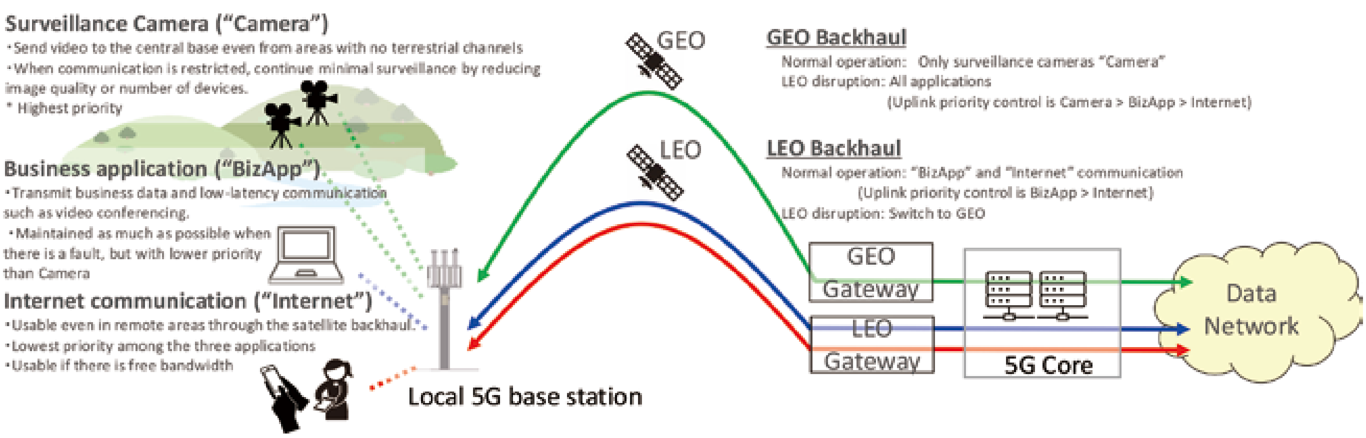
2. Local 5G and multi-orbit satellite communications use cases

A use case for multi-orbit satellite communications as the backhaul of Local 5G systems is in deployment of Local 5G base stations in regions where installation of fixed or mobile networks is difficult, such as on islands or in the mountains. The use case and applications (Camera, BizApp and Internet) are shown in Figure 1. GEO satellites and LEO satellites were used as the Local 5G backhaul for these use cases. With an understanding of the communications characteristics of both GEO and LEO satellites, we studied methods for utilizing the strengths of both types of satellite. Characteristics of each type of satellite communications are given below.

GEO satellites

GEO satellites have a stationary orbit at an altitude of approximately 36,000 km and their position relative to the earth's surface does not change, so it is easy to maintain line-of-site between an earth station and the satellite. A single satellite can provide communications over a wide area, so there is a wide range of choices for locating earth station equipment, and it can achieve stable transmission capacity and round-trip time (RTT).

Figure 1: Use case overview



LEO satellite

LEO satellites orbit at altitudes between hundreds and thousands of kilometers, and their position relative to the earth's surface is always changing. They are relatively small, and many are used to form mega-constellations that enable the whole system to achieve high capacity. Earth stations must track the satellites and perform handover between satellites as necessary. They are able to implement communication that is relatively high-speed and low latency.

Three types of application were envisioned for this use case. Among the three types, surveillance cameras, which require the highest level of communication priority and stability, always use the GEO satellite backhaul. The business application and internet communications are lower priority than the surveillance camera video, but require low latency and high capacity, so they normally use the LEO satellite backhaul. Interruptions in LEO satellite communication were anticipated (e.g. temporary interruption due to insufficient number of operating satellites, longer interruptions due to infrastructure faults, etc.), and GEO satellites were used to maintain the minimum communication when the LEO satellite communications were interrupted. Communication was switched back as soon as the LEO satellites recovered. QoS control was applied to adjust bandwidth for each application dynamically, even when channels were switched and traffic became concentrated on GEO satellite links. This control enabled communication continuity and stability to be maintained.

3. 5G Control technologies

Advanced technologies in 5G were used to implement the use cases described in Section 2. The main technologies: "dynamic routing" and "QoS control" are described below.

■ Dynamic routing

Dynamic routing involves many technologies for each domain (i.e.: access network and core network) and for each protocol layer. In this article, we describe the method for dynamic routing using protocols specified for the 5G core network. The Session Management Function (SMF) handles configuring and managing communication routes. In the User Plane Function (UPF), which handles packet routing and transport, transport rules are delivered using the Packet Forwarding Control Protocol (PFCP). In gNodeB (gNB: base stations) communications configuration is delivered using the Next Generation Application Protocol (NGAP) through the Access and Mobility Management Function (AMF). These functions are performed when a Protocol Data Unit (PDU) session is established, but the same control is also performed when a fault such as a communications interruption is detected, which makes automatic route switching possible.

■ QoS control

5G QoS control is done in units of QoS Flow, of which there are two types: Guaranteed Bit Rate (GBR) QoS Flows, which provide a guaranteed bit rate, and Non-GBR QoS Flows, which do not. 3GPP standardized multiple Quality of Service class identifier (5QI) values, defining QoS characteristics such as latency, packet loss, and priority level for each 5QI. A GBR QoS Flow controls bit rates in terms of a Guaranteed Flow Bit Rate (GFBR) and a Maximum Flow Bit Rate (MFBR).

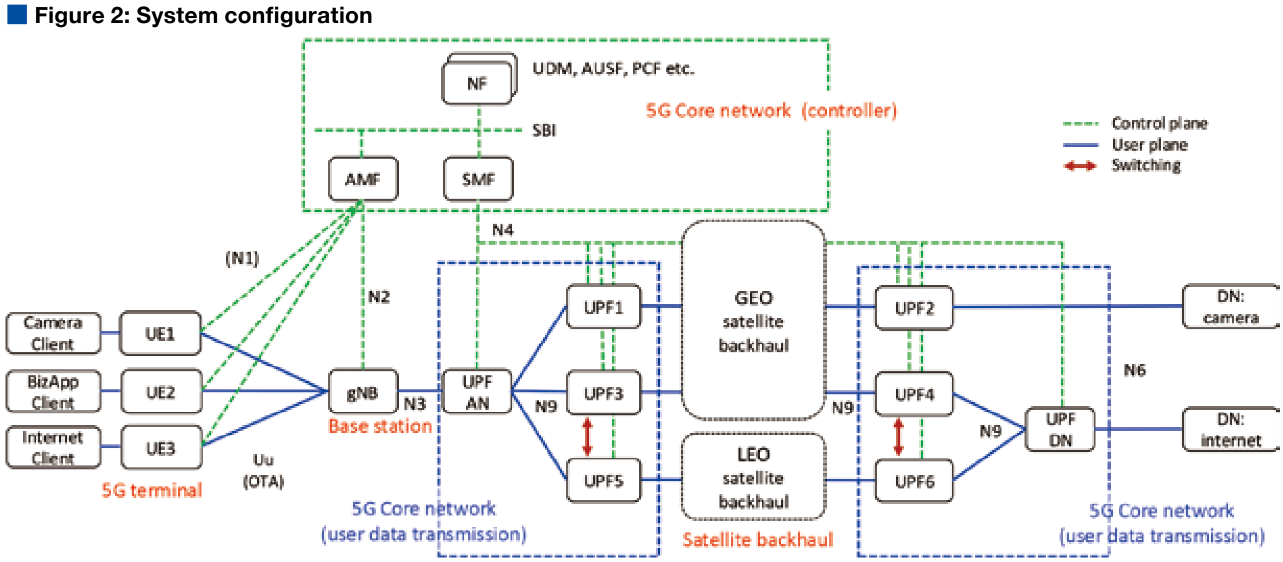
In this demonstration QoS control was performed by setting the priority level, GBR or Non-GBR, and GFBR/MFBR values for each application according to the network environment.

4. Test overview

Here we describe the demonstration performed using GEO and LEO multi-orbit satellite communications as the backhaul for Local 5G, based on the use case described in Section 2.

A summary of the system architecture is shown in Figure 2. The 5G core network UPF used in this demonstration had not

■ **Figure 2: System configuration**



■ Table 1: QoS design (normal operation)

Application	5QI	Priority Level	GBR	GFBR (Mbps)	MFBR (Mbps)	Backhaul
Camera	4	50	GBR	15	29	GEO
BizApp	6	60	Non-GBR	--	--	LEO
Internet	9	90	Non-GBR	--	--	LEO

■ Table 2: QoS design (when LEO interrupted)

Application	5QI	Priority Level	GBR	GFBR (Mbps)	MFBR (Mbps)	Backhaul
Camera	4	50	GBR	15	15	GEO
BizApp	4	50	GBR	8	10	GEO
Internet	4	50	GBR	3	4	GEO

implemented QoS control functions, so QoS evaluation for down-link communication was not possible. However, the gNB did implement QoS control functions for up-link communications, so QoS control was applied to the Local 5G radio segments (Radio Access Network, RAN).

For GEO backhaul channels, we built an environment emulating the 30 Mbps up-link throughput, while the LEO backhaul channels used real Starlink connections. Note that the GEO emulation environment was validated in preliminary testing with real GEO channels, confirming that there was no practical difference for indices such as throughput, jitter and RTT.

In this use case, we designed two QoS configurations: normal operation and when the LEO channel is interrupted; and enabled switching between them. The QoS designs for the demonstration are shown Table 1 and Table 2.

During normal operation, only the 5G control signals and Camera, which are high priority and require a stable connection, use the GEO channels. When a LEO channel is interrupted, BizApp and Internet also use the GEO channel. According to the QoS design, the upper limit for Camera is halved, maintaining the minimum quality it requires, while enabling BizApp and Internet to continue.

5. Test results and discussion

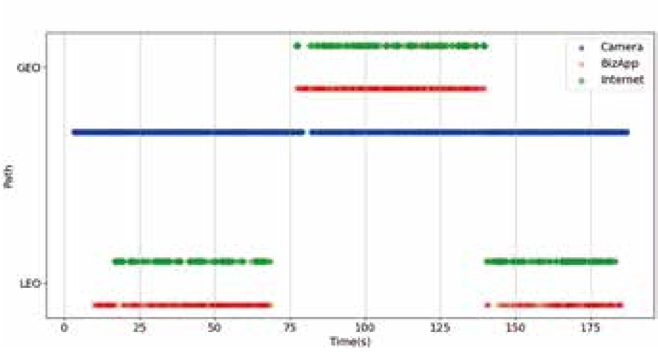
Route switching results

Figure 3 shows results of which backhaul each application is using, GEO satellite or LEO satellite, over time.

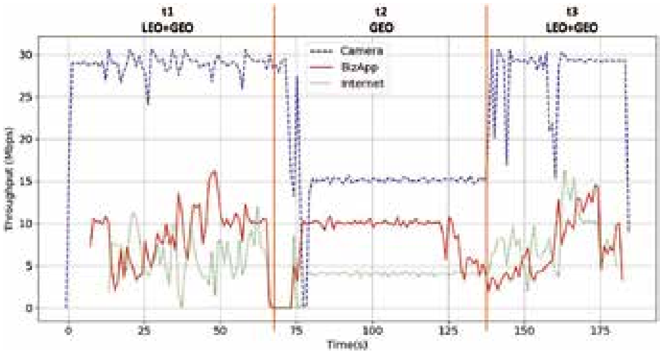
Camera (● symbol) uses the GEO satellite for communication all of the time, as designed. The ● symbol in a fixed position across the entire timeline shows continuous and stable communication.

The BizApp (× symbol) and Internet (◆ symbol) applications were designed to communicate by LEO satellite channel under normal operation. The × and ◆ symbols in the figure show the GEO satellite being used only when the LEO channel is interrupted, indicating that communication continuity is maintained by using the LEO satellites when they are available, and using the GEO satellite when they are not.

■ Figure 3: Backhaul classification



■ Figure 4: UDP throughput fluctuation



QoS control results

We measured the up-link throughput from User Equipment (UE) to the server on the Data Network (DN), and verified effectiveness of the QoS control. Results of UDP throughput measurements are shown in Figure 4. In the graph, the vertical axis shows throughput and the horizontal axis shows elapsed time. The horizontal axis can be divided into three main time periods:

t1. Using both GEO and LEO channels simultaneously

t2. Using only GEO channels (when LEO channels are not available)

t3. Using both GEO and LEO channels simultaneously (after LEO channels have recovered)

During the t1 and t3 segments, GEO and LEO channels are both being used, achieving high overall throughput. Camera uses GEO channel exclusively, so it does not compete for resources. On the other hand, although "BizApp" was higher priority than "Internet", priority control had no apparent effect on throughput. This is because the up-link bandwidth on the LEO channel is narrower than between gNB and UE, so QoS control on the backhaul is essential. Throughput on the LEO channel also fluctuates more, so the trade-off between guaranteed bandwidth and wide-band utilization must be considered in QoS control at the IP layer and higher.

In the t2 segment, throughput was stable, and bandwidth restrictions were shown to be operating appropriately for the three applications when using the GEO channels. Resource competition was minimized between the applications and communication quality was shown to be maintained for each application.

Note that interruption did occur for three to five seconds when switching channels. The switching time includes detecting the interruption, recovery and changing the route, and this can be adjusted by configuring the interval and frequency of detection.

6. Conclusion and future prospects

In this research, we studied a new use case using multi-orbit satellite communications for a Local 5G backhaul and showed that it is possible to increase throughput and achieve stable communications by using 5G QoS control and dynamic routing according to the network environment. These results suggest that multi-orbit satellite linked with 5G communications can provide high-speed, stable communications infrastructure in areas where terrestrial infrastructure is insufficient or during disaster.

A result of this demonstration is that satellite channels can be used in a service providing backhaul for Local 5G networks, but also that satellite communications can be applied in 5G NTN services expanded to the RAN segment in 5G (see Figure 5).

SKY Perfect JSAT Corporation is also considering applications for Universal NTN. Universal NTN is a multilayer network based on 3GPP standard technology, combining geostationary satellites, non-geostationary satellites, high-altitude platform (HAPS) and other technologies. This will function as communications infrastructure where terrestrial networks do not reach, such as at sea, in the mountains and during disaster and aim to implement a "Society without dead zones"[1].

Realizing Universal NTN will involve many issues beyond flexible routing and QoS control technologies used in this demonstration, such as improving performance of NTN infrastructure, network connection technology (ISL technology), development of multi-access/multi-band terminals and integrated control systems. For now, we will continue linking SKY Perfect JSAT Corporation's satellite infrastructure and terrestrial communications systems using the results of this demonstration, and expand functionality in stages, as 3GPP extension specifications spread. From the state of NTN standardization and external trends, we expect to implement multi-layered networks composed of multiple NTN infrastructures and terrestrial communications systems by around 2030. SKY Perfect JSAT Corporation plans to take leadership with these technologies and business models and create the future of sustainable communications infrastructure.

Acknowledgements

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References

[1] Hiroyuki Yagihashi, "Non-Terrestrial Network (NTN) Trends and SKY Perfect JSAT Corp. Initiatives —Toward a world with no dead zones—", ITU Journal Vol. 55 No.8 (2025.8)

Figure 5: Using results of this demonstration and business prospects