Survey on Protocol Achitectures for Cellular-based Low Earth Orbit Satellite Communications

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***Abstract*— This paper presents protocol architectures for cellular-based low earth orbit (LEO) satellite communications which have been being discussed in the 3GPP standardization groups. This paper also addresses one-way delay and functional considerations according to the protocol architectures. Due to the comparative analysis, it is able to be carefully concluded that the regenerative payload satellite with mobile core functions is the most adequate for 6G satellite communications in spite of several research issues.**

Keywords*— *6G satellite communications, LEO, Satellite protocol architectures

I. Introduction

Recently, investment and research on the provision of mobile communication services through LEO satellites have been actively conducted due to advantages such as low launch costs and short transmission delays. In particular, satellite communication companies such as Starlink and OneWeb are taking the lead in LEO satellite communication businesses. With this trend, 3GPP has also been actively discussing the standardization of non-terrestrial network (NTN) to provide mobile communication services through satellites [1].

The goal of 6G satellite communications is to provide broadband mobile communication services to all users in the world through LEO satellites. Unfortunately, at the 3GPP NTN release 17 and 18 standardization, only a transparent payload satellite has been considered. Since the satellite performs only radio frequency transformation between service link and feeder link, a service range covered by the LEO satellites can be very limited. Thus, the transparent payload satellite can be unsuitable for the goal of the 6G satellite communications. Actually, an inter-satellite link (ISL) is essentially required to extend the service range of LEO satellites. For multi-hop inter-satellite communications through the ISL, it is also needed to address whether a LEO satellite is a relay station or not. If the LEO satellite is a relay station, we may consider to apply the mobile integrated access and backhaul (IAB) architecture which has been discussed in the 3GPP to the LEO satellite. However, there may be several research issues at the mobile IAB architecture such as the ISL based on the wireless optical communication, the long end-to-end latency through ground core network, and the high traffic congestion near the ground core network, and so on. For these reasons, it can be essential to study the protocol architecture of LEO satellites to cover the world by using LEO satellites.

In section II, we describe several protocol architectures of LEO satellites considered in the 3GPP. In section III, we present a comparative analysis table of the described protocol architectures in terms of control plane and user plane, and discuss a protocol architecture of LEO satellites suitable for the 6G satellite communications.

II. Protocol Architectures of LEO Satellites in 3GPP

Before describing protocol architectures of LEO satellites, we would like to explain components of the LEO satellite communication networks. As shown in Fig. 1, the LEO satellite communication network can consist of ground and air terminals, LEO satellite, and ground station. The terminals communicate with LEO satellites through the service link and LEO satellites are connected with the ground station through the feeder link. With the service and feeder link, the inter-satellite communications are performed through the ISL.

For the NTN discussion, the 3GPP standardization groups have described three protocol architectures of LEO satellites such as a transparent payload satellite, a regenerative payload satellite with the partial gNB function, and a regenerative payload satellite with the full gNB function [2].

As described in section I, the transparent payload satellite has a limitation as the short coverage range. However, because of the implementation simplicity, it has been dealt with a basic protocol architecture of the LEO satellite in the 3GPP NTN release 17 and 18 standardizations. Since the gNB is on the ground, the service and feeder link are Uu interface specified in the 3GPP standards.

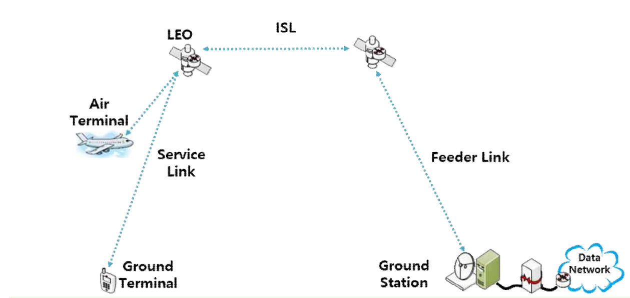

Fig. 1. LEO Satellite Communication Networks

For the regenerative payload with the partial gNB functions as depicted in the Fig. 2, LEO satellites can include the partial gNB functions such as physical (PHY), medium access control (MAC), and radio link control (RLC) specified in the 3GPP standards. In the 3GPP, this architecture is generally called as a gNB-distribute units (DU). The ground station can have other gNB functions, such as protocol data convergence protocol (PDCP), service data adaptation protocol (SDAP) are included in the ground station, and radio resource control (RRC). This architecture is also called as a gNB-control units (CU). Since a gNB-CU can be connected with various gNB-DUs through the F1 interface, a ground station can also communicate with various LEO satellites. However, at this architecture, layer 1 and 2 for the feeder link may not be under the 3GPP scope. By this architecture, since the packet scheduler is located at LEO satellites, the latency of the radio resource scheduling can be deteriorated compared to the transparent payload satellite. Moreover, the retransmission delay performed at the MAC and the RLC can be also reduced. However, it may be needed to consider several issues for this architecture. Whenever a UE moves between satellites, the inter-DU mobility can occur. When a satellite moves between ground stations (gNB-CU), a research of the F1AP mobility provision may be required because the F1AP mobility may not be provided in the current 3GPP standards. Like the transparent payload satellite, the service range can be limited because the ISL interface is not defined in this architecture.

For the regenerative payload satellite with the full gNB as shown in Fig. 3, LEO satellites have the full gNB functions. In this architecture, since the RRC is located at the satellite, the latency of the RRC procedure can be reduced compared to the previously described architectures. However, this architecture has several research issues due to the fast mobility of the LEO satellite. This leads to the high frequent inter-satellite handover performed by a lot of users. When we consider the speed of the LEO satellite is about 7.5 km/s, the large number of the inter-satellite handover can have an effect on the service quality and the system performance. Moreover, it is needed to investigate mobility provision issues for the XnAP and NGAP when we consider the dynamic satellite network topology. This means that the necessary information may be transmitted and received through the XnAP and NGAP when the connected neighbor satellite and ground station are changed. The ISL can be used for the XnAP at this architecture, however the service range of this architecture may be also limited. This is because the data traffic has to be preferentially transmitted to the ground core networks.

With these three architectures, a new protocol architecture for LEO satellites are recently discussing in the 3GPP service and system aspects 1 (SA1) working group [3,4]. In this group, two service scenarios for the satellite communications have been proposed and agreed such as the store and forward scenario and the UE-to-UE communication through a satellite without going to ground stations. For these scenarios, it is needed to apply the mobile core functions to LEO satellites as depicted in Fig. 4, because the UE registration and the packet data unit (PDU) session establishment procedures have to be completed without going to ground mobile core networks. In addition, since the data traffic can be stored or locally routed at the satellite, the user plane function (UPF) has to be located at the satellite. Unfortunately, at this architecture, there are also several research issues due to the mobility of the mobile core functions with LEO satellites. Since the anchor UPF is able to continuously move away from the connected UE as the LEO satellite moves, it may be necessary to investigate the mobility provision technologies of the anchor UPF. In addition, the information of the registered UEs may be delivered to the neighbor satellite when the serving satellite moves away. These mobility issues of the mobile core functions are needed to be carefully handled. This is because there may be a lot of procedures and considerations by the deployment scenarios of various mobile core function sets between the LEO satellites and the ground stations.

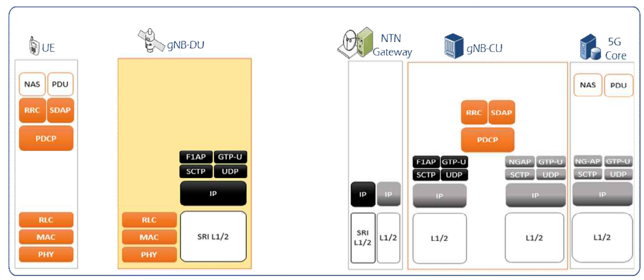

Fig. 2. Protocol Architecture of a Regenerative Payload Satellite with the Partial gNB Function

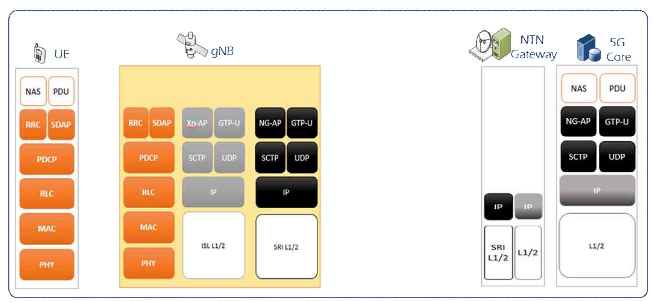

Fig. 3. Protocol Architecture of a Regenerative Payload Satellite with the Full gNB Function

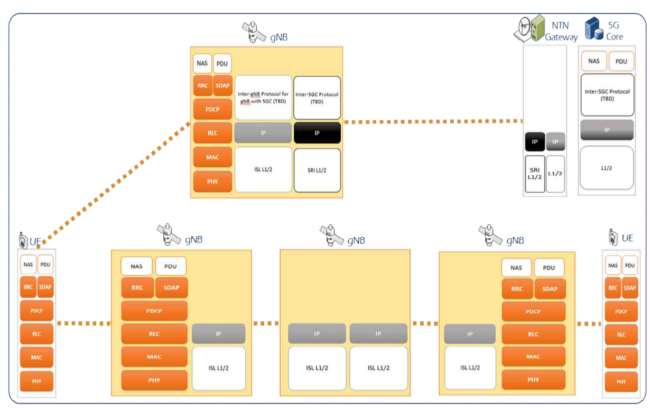

Fig. 4. Protocol Architecture of a Regenerative Payload Satellite with the Mobile Core Function

Table 1. Summarization of the Described Protocol Architecture of LEO Satellites

Protocol Architecture	Service Range	Control Plane				User Plane		
		One Way Path of Control Procedures		Mobility Aspect of LEO Satellite		One Way Path of Retransmission		One Way Path of End-to-End Service (UEs in a Satellite)
Transparent Payload	Limited	MAC Level	Service Link plus Feeder Link	UE	Inter-Cell/Beam Mobility	HARQ	Service Link plus Feeder Link	(Service Link plus Feeder Link) x 2
		RRC Level	Service Link plus Feeder Link			RLC	Service Link plus Feeder Link	
		NAS Level	Service Link plus Feeder Link					
Regenerative Payload with Split gNB	Limited	MAC Level	Service Link	UE	Inter-DU Mobility	HARQ	Service Link	(Service Link plus Feeder Link) x 2
		RRC Level	Service Link plus Feeder Link	Satellite	F1AP Mobility	RLC	Service Link	
		NAS Level	Service Link plus Feeder Link					
Regenerative Payload with Full gNB	Limited	MAC Level	Service Link	UE	Inter-Satellite Mobility	HARQ	Service Link	(Service Link plus Feeder Link) x 2
		RRC Level	Service Link	Satellite	XnAP and NGAP Mobility	RLC	Service Link	
		NAS Level	Service Link plus Feeder Link					
Regenerative Payload with Mobile Core	All over the World	MAC Level	Service Link	UE	Inter-Core Mobility	HARQ	Service Link	Service Link x 2
		RRC Level	Service Link	Satellite	Inter-Satellite Multi-hop	RLC	Service Link	
		NAS Level	Service Link					

III. Protocol Architecure of LEO Satellites for 6G Satellite Communications

In this section, we would like to summarize various features of the protocol architectures of LEO satellites described in section II, and discuss which protocol architecture is the most suitable for the 6G satellite communications. Table 1 presents various features of the protocol architectures in terms of the control plane and user plane. In particular, we describe the one-way path for procedures for the control plane, retransmissions, and end-to-end services to consider the latency according to the architectures. Here, in the table 1, we assume that the end-to-end service scenario is for UE-to-UE communications through a LEO satellite without going to the ground station.

Since the goal of the 6G satellite communications is to provide broadband mobile communication services to all users in the world through LEO satellites, only the regenerative payload satellite with mobile core functions can support it in terms of the service range. Moreover, the regenerative payload satellite architecture with mobile core functions can provide the shortest latency in terms of the control plane, retransmissions, and the end-to-end services. Especially, when we consider the latency of the end-to-end services that UEs are connected with different LEO satellites, the latency of the architecture can be significantly reduced compared to other protocol architectures.

IV. Conclusion

In this paper, we have described four protocol architectures of LEO satellites which have been being discussed in the 3GPP standardization groups and presented a summarization table of the various features of the protocol architectures. In addition, we have carefully concluded that the protocol architecture of LEO satellites with the mobile core functions is the most suitable for the 6G satellite communications in spite of the various research issues for the mobility of the mobile core functions. Consequently, it is essential to study the research issues of the mobility of the mobile core functions include in the LEO satellites for the 6G satellite communications.

Acknowledgment

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References

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