Development of extreme coverage communication system extended by non-terrestrial network: End-to-end route management scheme based on QoS of user equipment

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SUMMARY Non-terrestrial networks (NTNs) are being considered as a means of extending the coverage of 5G and 6G cellular networks to anywhere on the planet. Even with NTNs, it is still necessary to satisfy the quality of service (QoS) required of user equipment (UE). This paper presents a routing management scheme, which controls the end-to-end route between a 5G base station and 5G core network on the basis of the QoS of UE, to meet the required QoS for NTN. Simulation results show that our scheme can improve the QoS satisfaction rate of web conferencing and sensing by about 30% and 13%, respectively, compared with the conventional scheme that does not consider the QoS of UE.

keywords: *Non-terrestrial network (NTN), Multi-layer network, Satellite, HAPS, Routing, QoS*

1. Introduction

Next-generation mobile communication systems such as Beyond 5G and 6G have been attracting the attention of mobile carriers and research institutes around the world [1–5]. For 6G mobile communication services, cellular network coverage will need to be greatly extended to areas where the mobile ground network cannot reach such as the ocean, mountainous area, and sky [1]. Non-terrestrial networks (NTNs) are expected as a means to realize the extreme coverage extension. In an NTN, a satellite or high altitude platform station (HAPS) network is used to form service areas on the ground and sky from space.

The structure of the NTN we are advocating for is a multi-layer network that consists of a geostationary (GEO) satellite, low Earth orbit (LEO) satellite, and HAPS network [6]. The satellites and aircrafts of each network are connected by a wireless link. There are several advantages of a multi-layer satellite network. First, the traffic of the terrestrial terminals can be efficiently accommodated by controlling the connection to the optimal network depending on the state of network congestion and user equipment (UE) capability. Second, communication can be continued by routing management even if the link between satellites or between a satellite and a base station on the ground is broken due to satellite failure or heavy rain because the multi-layer network has multiple routes to the ground network. As a result, the multi-layer network ensures high availability.

Furthermore, next-generation mobile communication systems are expected to be expanded to various use cases such as healthcare, XR, and autonomous driving support. The requirements differ for each use case. To provide such services, the quality of services (QoS) of the UE must be sufficient for each service. The QoS must be satisfied end-to-end, at least between the UE and a 5G core network (5GC). In a 5G mobile system, a QoS class identifier (QCI) such as 5QI is defined [7]. The packet in traffic is classified into QoS classes. The QCI mechanism is used for traffic management, such as scheduling and admission control, to ensure QoS.

Even in an NTN, the QoS must be satisfied end-to-end between the UE and 5GC. However, in a multi-layer network, the bandwidth and delay time of the inter-satellite link greatly differ depending on the altitude of satellite etc. For example, when low latency is required for QoS, if the traffic flows via a route with long delay, it may not be possible to satisfy the QoS. Therefore, it is necessary to set an end-to-end route that satisfies QoS requirements.

To tackle this problem, we propose an end-to-end routing management scheme which manages an end-to-end route between a 5G base station (gNB) and 5GC on the basis of the QoS required of the UE. We verified that our proposed scheme can improve the QoS satisfaction rate in the multi-layer network based on the HAPS and GEO networks.

The rest of this paper is organized as follows. The concept of a multi-layer network for NTNs is explained in Section 2. In Section 3, we introduce our end-to-end route management scheme for multi-layer network. Simulation results are presented in Section 4, and Section 5 concludes this paper with a brief summary.

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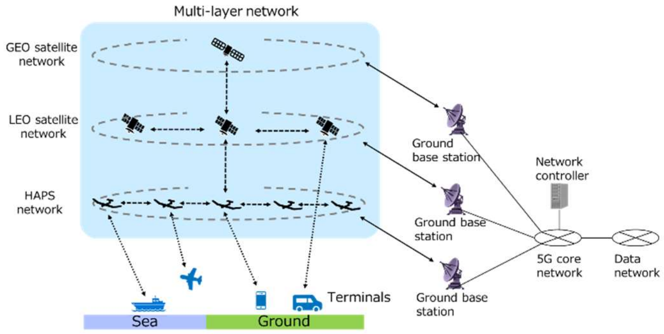

Fig. 1 Multi-layer network for NTN.

2. Multi-layer network for NTN

Figure 1 shows an overview of the multi-layer network for an NTN. It consists of a GEO satellite, LEO satellite, and HAPS network. The GEO and LEO satellites in the GEO/LEO network and the aircrafts in the HAPS network are connected by a wireless link such as radio or free-space optics (FSO). These satellites and aircrafts form a service area that covers the surface of the earth and the sky. UE on the ground connect to the satellite/HAPS networks, and the traffic generated by UEs are transferred to 5G core network (5GC) via ground base station. The network controller controls the link connection between the satellites and aircrafts to build the optimum network topology on the basis of the position of the satellites/aircrafts, the state of the wireless link between satellites/aircrafts, and the ground base station. This improves the availability of the NTN. For example, a high frequency such as the Ka band and Q band is required to widen the bandwidth of a feeder link. However, the link may be broken due to heavy rain because the attenuation loss of radio wave increases as the frequency increases. Therefore, the network controller controls the link connection on the basis of the link connection status and the rain conditions so that the network does not disconnect.

The network controller also controls the traffic routing. In the multi-layer network, the bandwidth and delay time of the inter-satellite/aircraft link greatly differ depending on the altitude of the satellite and other factors, so it is important that the traffic routing ensures the QoS of UE. In the next section, we introduce our end-to-end routing management scheme which manages an end-to-end route between the gNB and 5GC on the basis of the QoS of UE.

3. End-to-end routing management scheme for multi-layer satellite network

In this paper, we assume an NTN with satellites and HAPS aircrafts, which implement a regenerative payload. The aircrafts in the HAPS network have gNB. The aircrafts form service areas on the ground and in the sky, and then UE connects to the gNB implemented on the aircrafts. The traffic generated by UE in the service area is transferred to the 5GC through the satellite/HAPS and ground base station.

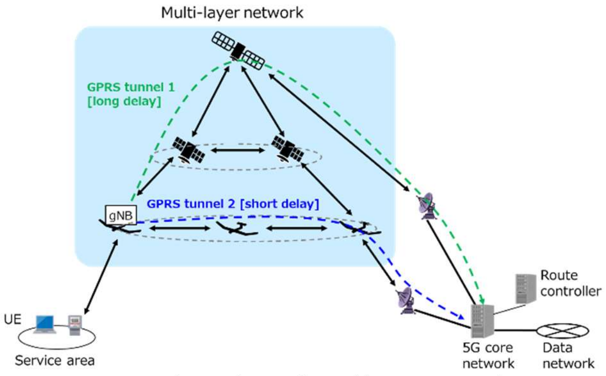

Fig. 2 End-to-end route formed by GPRS tunnel.

In a 5G mobile network, the route between the gNB and 5GC is connected by General Packet Radio Services (GPRS) tunnel with GPRS Tunneling Protocol (GTP). Figure 2 shows an image of the end-to-end route formed by the GPRS tunnel in the multi-layer structure. The multi-layer network contains routes between the gNB and 5GC. Furthermore, as mentioned in Section 2, the bandwidth and delay time of the inter-satellite link greatly differ depending on the altitude of satellite and other factors. For example, when using the route via the GEO satellite, the transmission delay between the gNB and 5GC is 240 ms or more because of the propagation delay resulting from 36,000-km transmission. The route via the GEO satellite is not suitable for services such as URLLC which require low latency.

Our proposed end-to-end routing management scheme manages an end-to-end route between the gNB and 5GC on the basis of the QoS of UE [8]. In the scheme, an end-to-end route that satisfies the QoS is searched for and selected on the basis of the required QoS such as data rate and delay. Figure 3 shows the flowchart of the proposed scheme. First, the route controller acquires the UE QoS information. Then the route controller searches for an end-to-end route that satisfies the required QoS using bandwidth and delay information for each link. For all possible routes, it determines whether the QoS is satisfied in terms of the bandwidth, bandwidth utilization, and delay time of the satellite/aircraft link existing between the gNB and 5GC. If such a route does not exist, the route controller will search again later after waiting for communication resources to become available. If a guaranteed data rate is required, the route controller controls the scheduling of the packet transmission for the satellite/aircraft on the selected route. Finally, the route controller forms a GPRS tunnel between the gNB and 5GC on the selected route.

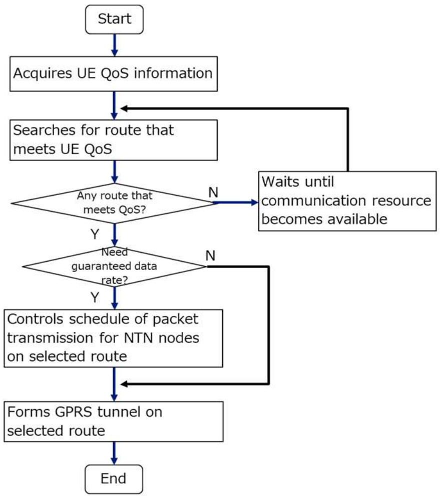

Fig. 3 Flowchart of proposed scheme.

Table 1 Simulation parameters

Link capacity between HAPS and ground base station [Mbit/s]	1000
Link capacity between GEO satellite and ground base station [Mbit/s]	400
Link capacity between HAPS [Mbit/s]	1000
Link capacity between HAPS and GEO satellite [Mbit/s]	400
Required delay time of web conference [ms]	200
Required delay time of sensing [ms]	1000
Ratio of sensing and web conference traffic	50%-50%

4. Simulation results

We evaluated our proposed scheme by computer simulation. The simulation parameters are listed in Table 1, and the model is depicted in Fig. 4. The multi-layer network used for this evaluation consists of four HAPS aircrafts and a GEO satellite. The HAPS aircrafts are connected in series, and all HAPS aircrafts and GEO satellite are connected. The UE in the HAPS service area connect to the gNB mounted in the HAPS aircrafts. Then the UE traffic, which was generated by a uniform distribution in this simulation, are transferred to the 5GC through the GPRS tunnel. The GPRS tunnel for each HAPS aircraft is basically formed over each feeder link. In this simulation, we assumed that the feeder link of HAPS1 was broken by heavy rain, and GPRS tunnel was formed between gNB and 5GC with other routes. There are two candidate routes, one is the route via GEO satellite network (route1) and the other is the route via HAPS network (route2). The latter is a route via one of the HAPS2, HAPS3 and HAPS4 feeder link, and we assumed that the traffic corresponding to the surplus transmission capacity of each feeder link can flow.

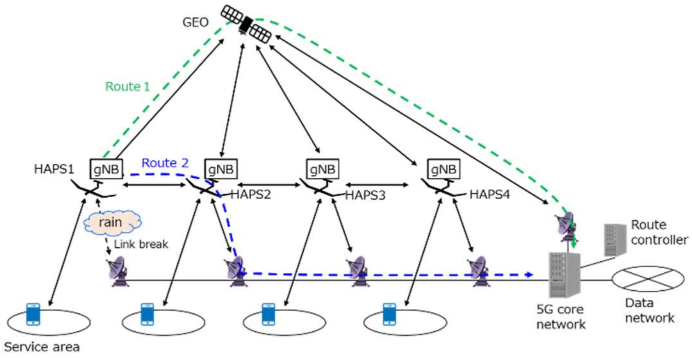

Fig. 4 Simulation model.

In the proposed scheme, a route that satisfies UE QoS is selected from two routes for the GPRS tunnels via the GEO satellite network or HAPS network. In the conventional scheme that does not use UE QoS information, the route via the HAPS network is preferentially selected as long as there is surplus transmission capacity is available in HAPS network. We assumed two types of services, web conferencing and sensing. The required delay time was used as the UE QoS.

Figure 5 and 6 show the QoS satisfaction rate of the web conference and sensing services, respectively, when the amount of traffic per cell changes. The proposed scheme yielded a higher QoS satisfaction rate than that of the conventional scheme. The proposed scheme improved the satisfaction rate of web conferencing and sensing by about 30% and 13%, respectively, at 900 Mbit/s of traffic per cell. This is because the route via the GEO satellite is not suitable for web conferences, which require low latency, so the route via the other HAPS aircrafts is preferentially selected in the proposed scheme. Similarly, in the proposed scheme, the route via GEO satellite is preferentially selected for sensing.

5. Conclusion

In this paper, we proposed an end-to-end route management scheme for a multi-layer satellite network. The proposed scheme manages an end-to-end route formed by the GPRS tunnel between the gNB and 5GC on the basis of the QoS of UE. The simulation results demonstrate that our proposed scheme can improve the QoS satisfaction rate in the multi-layer network based on the HAPS and GEO networks. We determined that the proposed scheme improves the QoS satisfaction rate of web conferencing and sensing by about 30% and 13%, respectively, at 900 Mbit/s of generated traffic.

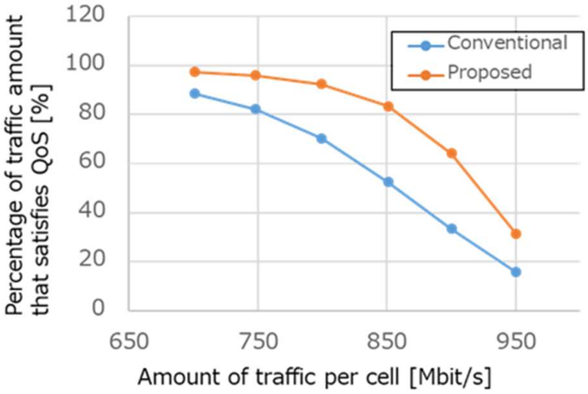

Fig. 5 QoS satisfaction rate of web conferencing.

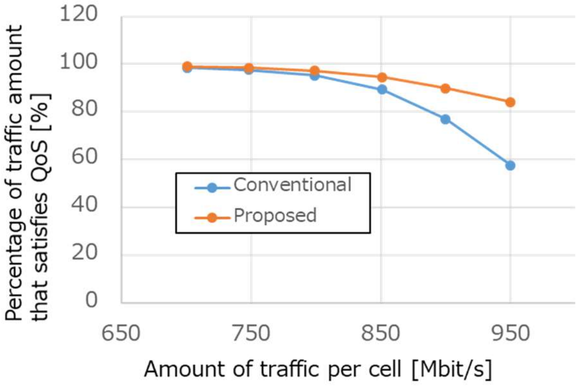

Fig. 6 QoS satisfaction rate of sensing.

Acknowledgments

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