A Method of Access Node Change in Multi-Radio Multi-Connectivity

Sunmi Jun
Telecommunications and Media Research Laboratory
Electronics and Telecommunications Research Institute
Daejeon, Republic of Korea
starlet@etri.re.kr

Yong Seouk Choi
Telecommunications and Media Research Laboratory
Electronics and Telecommunications Research Institute
Daejeon, Republic of Korea
choiys@etri.re.kr

Heesang Chung
Telecommunications and Media Research Laboratory
Electronics and Telecommunications Research Institute
Daejeon, Republic of Korea
hschung@etri.re.kr

***Abstract*—3GPP introduces multi-radio dual-connectivity technology using FR1 and FR2. It is a method of using enhanced Mobile Broad Band (eMBB) in the high-frequency band while supporting the reliability of the connection. 6G tries to provide Tbps-level datarate by using sub-terahertz (0.1~0.3 terahertz) or higher bands, but it needs to solve the issues such as the extremely sensitive NLOS path loss characteristics. For this purpose, extremely fine beamforming technology based on a large-scale antenna array is required, and in this paper, we will introduce a method of reducing path loss rate and supporting end-to-end low latency using multi-radio multi-connectivity (MR-MC) technology.**

Keywords—multi-radio multi-connectivity, multi-radio dual-connectivity, Sub-terahertz communication, low latency SCG change, 6G system, 5G system, 3GPP standardization.

I. INTRODUCTION

5G has laid the groundwork for the development of low latency tactile access networks, with new frequency bands in mmWave and a complete redesign of the core network. However, future 6G services will require a radical development of data-centric and automated processes, and to support them, additional performance requirements such as Tbps data rates, hundreds of microseconds of latency, and large connectivity (10^7 /km^2) will be required [1].

To this end, many researchers have become interested in 6G wireless technologies, one of which is operating in the sub-THz band. The sub-Thz band can suffer from extremely high path losses compared to the mmWave band, and to compensate for this, huge antenna arrays and a higher degree of directional antennas will be used than before. Compared to mmWave, the higher directivity suppresses inter-cell interference, but it also results in more frequent and severe brokage. For example, user mobility caused by walking or driving, as well as the transient shaking and rotation of the device in the user's hand, can cause pathloss and result in beam search [2]. The pursuit of extremely fine-grained directivity requires very fine-grained beams, and the beam search procedure requires the re-establishment of active links. Depending on brokerage and micromobility, users will experience service interruptions and the user experience of low-latency services will deteriorate.

Multi-Radio Multi-Connectivity (MR-MC) is a technology that makes simultaneous connections between multiple radios such as FR1, FR2 and sub-THz. In this paper, we propose to utilize MR-MC technology to avoid session outages due to such path impairments. Originally, multi-connectivity technology has been standardized by the 3rd Generation Partnership Project (3GPP), and a user equipment (UE) can simultaneously connect LTE in 4G and NR in 5G to provide data transmission. This technology was intended to support rapid system migration from 4G to 5G, but in the future, it may be considered for low latency, high reliability, and broadband transmission in high frequency bands.

The structure of this paper is as follows. Chapter 2 introduces 6G service requirements, 3GPP standardization, and related papers. In Chapter 3, we proposed an MR-MC architecture that performs a fast access node change. Chapter 4 introduces the MR-MC simulation results and concludes in Chapter 5.

II. RELATED WORKS

A. 6G Use cases and Service requirements

5G services will require eMBB throughput of 0.1 to 10 Gbps, URLLC air-link latency of 1 ms, and reliability of up to 99.9999%. 6G services will require higher performance throughput of 10Gbps to 1Tbps, air-link latency of 0.4ms, end-to-end latency of 2-4ms, and reliability up to 99.9999%.

According to the service application type, the details are as follows. The emergence of AR/VR applications will deplete the 5G spectrum with a system capacity of 20Gbps, requiring a system capacity of more than 1 Tbps. Additionally, AR/VR cannot be compressed to meet the requirements for delaying real-time user interaction in immersive environments. Therefore, per-user data must be gigabit-per-second.

With the increasing human tendency to connect remotely, 3D holographic telepresence services have emerged. 3D holographic displays are uncompressed holograms and require specifications of colors, full parallax, and 30 fps, which requires 4.32 Tbps data rate. The latency requirements of this service are sub-millisecond and will require thousands of synchronized view angles compared to AR/VR. In addition, in order to provide a more realistic and immersive remote experience, information from the five senses of the human being must be digitized and transmitted through the network, which also leads to an increase in data.

Telemedicine and telesurgery are increasing the demand for healthcare services without the constraints of time and space. To realize this, continuous connection availability, 99.99999% reliability, sub-millisecond ultra-low latency, and mobility support are essential, along with real-time feedback [1][3].

B. Related works for Multi-Connectivity in Thz band

In this section, we introduce some of the papers related to THz communication. In the THz band, not only the blockers but also the slight shaking or rotation of UE in the user's hand causes frequent beam searching procedures or handovers and degrades performance. The use of multi-connectivity in high-density THZ BS deployments can demonstrate improvements service interruption due to blockage or micromobility[2]. In supporting simultaneous connectivity in the THz and mmWave bands, the probability of session outage varies depending on the policy of selecting the base station and the multi-connectivity strategy. For applications that are sensitive to session outage time, it is recommended to choose multi-connectivity that avoidance outage, but for applications that are not sensitive to session outage time, a coverage extension strategy that tolerates outage to some extent is more advantageous [4]. The THz channel was characterized as a 3D propagation channel to characterize the reduction of usable bandwidth due to the effect of molecular absorption loss in an indoor THz communication. Subsequent performance evaluations of two multi-connectivity strategies, 1) closest line-of-sight AP Multi-Connectivity (C-MC) and 2) Reactive Multi-Connectivity (R-MC), showed a significant performance advantage over single connectivity, and a comparison between multi-connectivity strategies also showed C-MC to be better than R-MC [5]. In the evaluation of the multi-connectivity performance of the THz band, the increase in the number of APs shows that the number of APs is more advantageous, and there is no significant difference between the optimal number of multi-connectivity, n>3 or more, and connections above a certain threshold [6]. In order to compensate for the service outage problem caused by blockers, it is necessary to increase the degree of multi-connectivity as well as to reduce handover overhead [7].

C. 3GPP MR-MC Standardization Work

3GPP defines MR-MC as a technology that makes simultaneous connections between multiple radios. It has been conducting research on dual-connectivity between FR1 and FR2. In Rel-17, the functions of Conditional PSChell change (CPC) and Conditional PSCell addtion (CPA) have been added for efficient secondary cell[9]management [9]. Rel-18 standardization is currently in progress, and selective activation of cell groups for enabling subsequent CPC/CPA after SCG change is in progress to reduce signaling overhead due to cell change in the case of frequent SCG changes. In addition, L1/L2 mobility enhancements that can be changed by L1/L2 signaling are currently being worked on to improve latency overhead by serving cell change by L3 measurements and L3 signaling. Finally, a mechanism that can configure Conditional Handover (CHO) and MR-DC simultaneously is [12][11].

III. A PROPOSED MR-MC ARCHITECTURE

A. Fast secondary node change method

This chapter proposes a method for fast secondary node change to reduce signaling overhead. In an environment where FR1, FR2, and THz bands are provided, the UE is connected to the most stable link (mainly FR1 or FR2) as MN, and in THz radio, it is connected by SN. Frequent changes occur between SNs, and performance degradation is also caused by signaling overhead. To solve this problem, MN manages multiple SNs as a group, not a single SN. Among them, one node that is currently connected is called Active SN, and a node that has no wireless link but can potentially be connected is called Inactive SN. There can be multiple inactive SNs, and although the RRC state is RRC_Inactive, the connection is established in advance with the N2 and N3 interfaces responsible for connection to the core network, and the PDU session is modified. The Xn interface for communication with MN is also set up. Later, when the active SN is changed from SN1 to SNn, only the radio link is set up, and the N2, N3, and Xn interfaces are preset, so signaling overhead can be reduced. The proposed MR-MC architecture is shown in Fig. 1 and the detailed procedure is illustrated in Fig. 2.

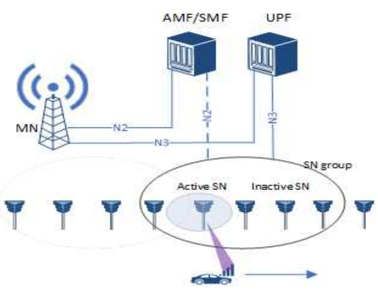

Fig. 1. Access Node group management in MR-MC

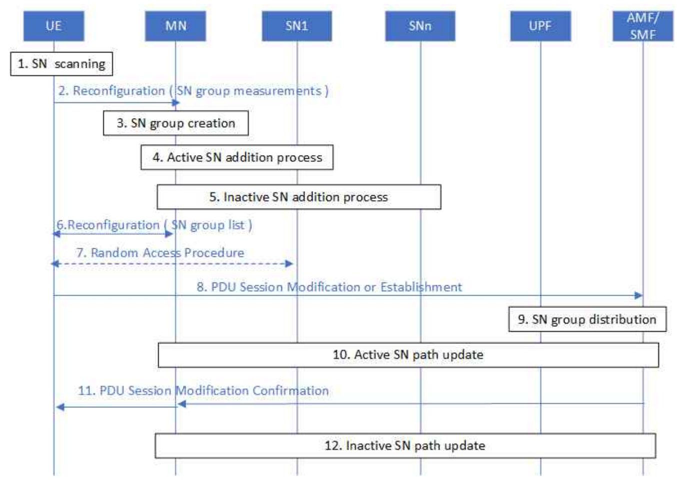

Fig. 2. Fast secondary node change method in MR-MC

IV. SIMULATION

The architecture and method proposed in Chapter 3 were simulated with Matlab. Multiple FR1, FR2, and Sub-Thz band base stations were deployed together in one space. It is assumed that the UE moves randomly at a speed within 5 meters per hour. Fig.3 are the average serving rate of each access node when the UE performs multi-connectivity in the same frequency band. Fig.4 is the average serving rate of the access node when the UE connects one connectivity for each band. The performance of the Sub-THz band is much higher than that of other bands, which shows that the performance is better when multi-connectivity is performed in the same band than in the multi-radio.

When selecting an access node based on the expected serving rate considering SINR, the signal delay of traffic routing/switching was considered. When an access node is changed in the same band, only the delay of the change between the access nodes is considered, and it is assumed that no delay occurs between the access node and the core network. Based on the specifications of [8-10], the signaling overhead required for changing the access node was estimated, and the signaling latency of the N2 interface and the Xn interface was referred to [12-16]. An example of signaling overhead is shown in Fig. 5. An example of signaling overhead is shown in Fig. 5. T1 is the signaling overhead between access nodes, and the latency required for one signaling varies from 1~30ms depending on the backhaul technology. T2 is the signaling overhead between the access node and the core network, and the signaling latency is in the range of 6 ~ 15ms. Fig. 6 shows the signaling overhead when multi-connectivity is performed in multi-radios including the Sub-THz band. In addition, higher bands show a spike in signaling overhead due to frequent access node changes. The proposed method of Fig. 2 simplifies the signaling procedure, and can also be expected to reduce signaling overhead.

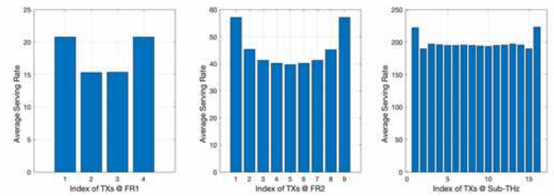

Fig. 3. Average serving rate for the same radio three connectivities

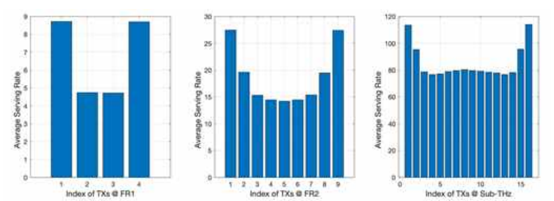

Fig. 4. Average serving rate for three connectivities for each frequency

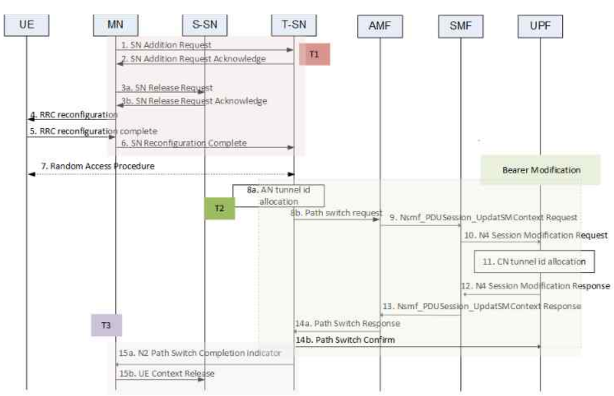

Fig. 5. An example of signaling overhead in MR-DC(3GPP TS 37.340)

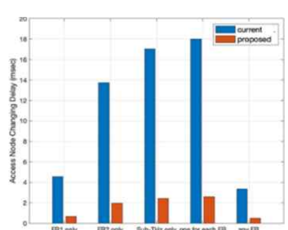

Fig. 6. Access Node Changing Delay in MR-MR

V. CONCLLUSIONS

The Sub-Thz band has very high NLOS path loss characteristics, which makes it difficult to meet the service requirements of 6G such as ultra broadband, high reliability, and low latency at the same time. In this paper, we propose MR-MC technology that extends the existing MR-DC technology that connects FR1 (Sub-6GHz) and FR2 (mmWave) at the same time and additionally connects the S ub-Thz. In order to compensate for the side effects caused by frequent Radio Link Failure (RLF), reliable connectivity through MC can be established and signaling overhead due to access node changes can be reduced to satisfy low latency requirements.

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