Mobile Relay Technology for 5G

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Introduction

Relay has been a promising technique for extending the coverage area of a cellular network without incurring additional cost for wired backhaul. With this merit, relay technology has been widely considered for developing and deploying cellular networks such as IEEE 802.16j WiMAX and 3GPP LTE-Advanced [1]. As a natural consequence, standardization for relay support is now being conducted in the 3GPP 5G NR work item called Integration of Access and Backhaul (IAB) in Rel-16, which enables cost-effective deployment of small cells through wireless backhauling [2]. In Rel-16 IAB, however, only fixed relays are considered. In order to meet diverse 5G requirements under various deployment scenarios, mobile relays can be useful to provide enhanced user experience to the onboard passengers in, for example, trains and buses. Hence, in this column, focusing on realistic 5G high-mobility deployment scenarios, we provide a brief background and motivation for mobile relay and investigate potential technical challenges to be overcome in the future 5G releases.

Background and Motivation for Mobile Relay

Considering a traditional two-hop relaying scheme, a relay can be used as a bridge between the backhaul link (i.e., the link between the gNodeB and relay) and the access link (i.e., the link between the relay and user equipment (UE)). From the gNodeB's perspective, the relay can be seen as a UE. In contrast, UEs regard the relay as the gNodeB. With the help of relay, it is expected that both backhaul and access links experience better channel propagation conditions compared to the direct link between the gNodeB and UE on condition that the relay is appropriately deployed.

Depending on the method of processing the received signal at the relay, typically two types of relaying methods can be considered: amplify-and-forward (AF) and decode-and-forward (DF) relaying. AF relays, sometimes referred to as repeaters, amplify the received signal from the source and forward it to the destination. The AF relays are implemented with low complexity but experience signal-to-noise (SNR) degradation at the destination due to noise amplification effect. DF relays first decode the received signal from the source and then forward the regenerated signal to the destination. Although there is no SNR degradation due to noise amplification in the DF relaying scheme, errors occurring at the relay are propagated to the destination. The DF relays also incur additional latency due to modulation/demodulation and encoding/decoding operations at the relay.

Traditionally, relays have been employed as a means of providing wireless backhaul links for small cells when wired backhaul is unavailable or cost-ineffective. Therefore, fixed relays have been a main concern for both research and industry sectors. However, in order to satisfy highly demanding user experience requirements in mobile environments such as trains and buses, the development and deployment of mobile relays are needed. By deploying onboard mobile relays at the vehicles (e.g., trains or buses), in-vehicle access for the in-vehicle UEs through wireless backhaul links can be efficiently provided. Several advantages of mobile relaying over the direct access of the UEs to the gNodeB have been identified: the reduction of high vehicle penetration loss up to 20–35 dB, the avoidance of the signaling storm problem due to group handover, etc. [3].

5G Deployment Scenarios for Mobile Relay

5G targets to achieve several ambitious use case-specific goals including large-volume data rate, ultra-high reliability, and very-low latency for various deployment scenarios such as indoor hotspot, urban, rural, and so on [4]. Among these identified deployment scenarios, the *high speed train* scenario targets to support wireless access to the passengers inside a high speed train moving at a speed up to 500 km/h as seen in Fig. 1 (top). The deployment of gNodeBs can be done so as to cover the train track area by forming a narrow beam along the track. The outside antenna of the onboard relay can be deployed at the top of the train carriage and the inside antenna can be installed inside the train carriages to provide access to the passenger UEs.

Another promising 5G use case employing mobile relay is the *tethering via vehicle*, which is one of the important 5G V2X use cases, as seen in Fig. 1 (bottom). Through the tethering via vehicle use case, a vehicle can provide network access to a driver, passengers, pedestrians, other vehicles, etc., thereby leading to reduced UE power consumption and increased throughput thanks to the reduced transmission distance [5]. The out-of-coverage vehicles due to blockage, for example, can have access to the network through the relay.

Technical Challenges

In order to fully take advantage of mobile relaying, several technical challenges need to be addressed, namely high frequency band, high mobility, duplexing, and handover.

High Frequency Band: Low frequency bands (i.e., below 6 GHz) are becoming more scarce as a consequence of the sharply increasing demand for wireless services. Hence, mmWave bands such as 28 GHz and 39 GHz can be promising candidates for the backhaul link. In such higher frequency bands, propagation characteristics are quite different from the lower frequency counterparts. More specifically, the high frequency radio wave propagates more straightforwardly and hence is more sensitive to the blockage, requiring more advanced beamforming techniques such as fast beam switching and multi-beam transmission.

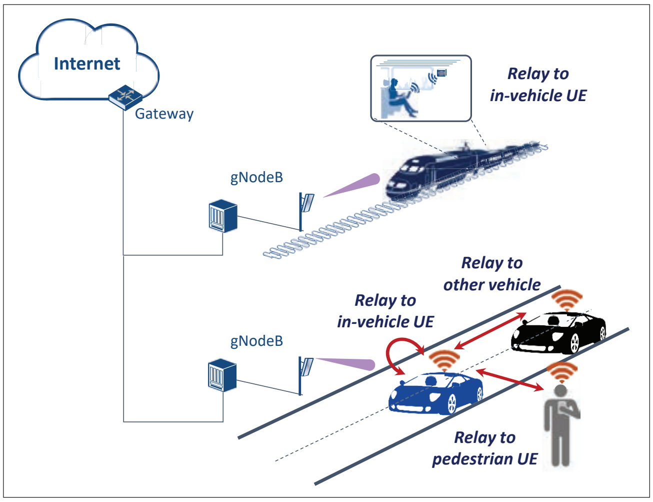

FIGURE 1. Deployment scenarios for mobile relay: high speed train (top) and tethering via vehicle (bottom).

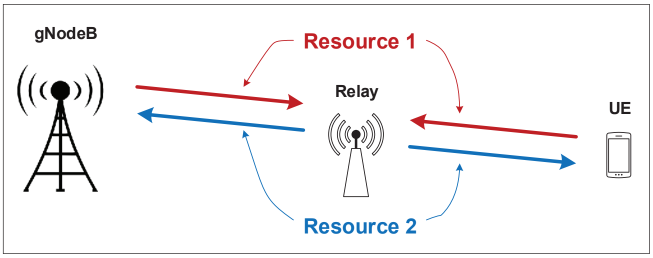

FIGURE 1. A possible resource allocation scheme for the duplexing of backhaul and access links.

High Mobility: In order to support very high mobility up to 500 km/h (e.g., high speed train), impacts from the Doppler shift/spread should be mitigated, requiring more advanced designs in frame structure, reference signal, and channel estimation/tracking, all of which should be robust to high Doppler. For doing so, the time units for transmission (e.g., symbol/slot/frame) should be shorter enough to adapt to the rapid channel variations. The periods for estimating, tracking, and reporting of the channel state should also be shortened.

Duplexing: The radio resource duplexing between downlink and uplink for the backhaul and access links can be done either in the frequency or time domain. The most conservative way of duplexing here is to allocate separate resources (i.e., frequency or time) to the downlink/uplink of backhaul and access links. In this situation, no interference is expected but the spectral efficiency is significantly reduced. At the other extreme, so-called "full-duplex relaying" allows the reuse of the same resource both for the backhaul and access links both in the downlink and uplink directions. Higher spectral efficiency can be achieved at the expense of the complex interference mitigation procedures including self-interference cancellation. Between the two extremes, as seen in Fig. 2, a more balanced resource allocation method for duplexing can be considered, which allocates the same resource, namely Resource 1, to the two receiving links at the relay, and the other same resource, namely Resource 2, to the two links coming out of the relay. By doing so, resource reuse between backhaul and access link is possible without a complex self-interference cancellation operation.

Handover: A main concern regarding handover is the handover frequency. With the speed of 500 km/h for a high speed train, the handover operation occurs every 7.2 seconds when assuming the inter-gNodeB distance of 1km. The way of solving this problem can be either minimizing the number of handover operations by, for example, a single frequency network (SFN), or by conducting handover operation more quickly. Several handover schemes are identified to reduce or even eliminate the handover interruption time. Among them, the *make-before-break* scheme can maintain connection while acquiring synchronization with the target gNodeB. The *RACH-less handover* enables to reduce the time for the random access procedure during the handover. If a mobile relay has a *dual-connectivity* capability, it can be simultaneously connected both with the source and target gNodeBs, achieving 0ms interruption handover.

Concluding Remarks

In this column, we summarized the current status and future prospects of the mobile relay technology toward the direction of 5G. Based on the brief description of the motivation and feasible deployment scenarios, we have discussed several key technical challenges when developing and deploying a mobile relay system in the aspects of frequency band, mobility, duplexing, and handover. It is expected that a mobile relay can be an efficient and cost effective deployment option in future 5G releases.

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Biographies

Gosan Noh received his B.S. and Ph.D. degrees in electrical and electronic engineering from Yonsei University, Seoul, Korea, in 2007 and 2012, respectively. From March 2012 to February 2013, he was a postdoctoral researcher at the School of Electrical and Electronic Engineering, Yonsei University. Since March 2013, he has been with the Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea, where he is a senior researcher. He has contributed to several areas of telecommunications including cognitive radio, spectrum sharing, millimeter-wave transmission, and high mobility applications. He has published 45+ scientific papers in journals and conferences. He has also been involved in 3GPP 5G NR standardization as ETRI's delegate to the 3GPP RAN1 working group since 2016.

Heesang Chung received the bachelor's degree in physics from KAIST, Korea in 1993 and the Ph. D. degree in physics from Chungnam National University, Korea in 1999. Since 1999 he has been with the Electronics and Telecommunications Research Institute, Korea. He was involved in research projects on optical communications from 1999 to 2005. He moved on to the Wireless Communications Department of ETRI in 2005. He was involved in research projects on LTE and LTE-Advanced from 2006 to 2010. His recent research interests are 5G and millimeter-wave based mobile communications including mobile wireless backhauls for public transportation.

Ilgyu Kim received his B.S. and M.S. degrees in electronics engineering from the University of Seoul, Republic of Korea, in 1993 and 1995, respectively, and his Ph.D. degree in information communications engineering from KAIST 2009. He worked for Shinsegi Telecom from 1994 to 1999, where he took part in the optimization of the IS-95 CDMA radio network and the international standardization of W-CDMA. Since 2000, He has been with the Electronics and Telecommunications Research Institute, where he was involved in the standardization and development of WCDMA, HSPA and LTE. He was in charge of the development of the LTE UE modem chip set and MHN system. Since 2019, he has been the assistant vice president of ETRI and managing director of the Future Mobile Communication Research Division. Currently, his main research interests include millimeter wave/THz communications and future mobile communications