Chapter 1
Introduction

Relay has been a hot research topic and triggered numerous papers in academia. Its ultimate performance is still an open problem since the relay system capacity is still unknown. For modern wireless communications systems, relay is regarded as a strong candidate for improving the system performance and the coverage at cell edges. Relay, especially the decode-and-forward relay, is proved to outperform the repeaters.

Macro base stations and the low power nodes such as relay node, remote radio head (RRH) pico node and femto node, constitute a heterogeneous network (HetNet) as illustrated in Fig. 1.1. Compared to the homogeneous network that is solely made up of macro base stations, HetNets have quite different topology and interference scenarios.

From the industry standardization point of view, relay is a rather new topic, with respect to technologies such as multiple antennas. Although its history is relatively short, e.g., less than 4 years, three standards for relay operations have already been specified, two for IEEE WiMAX and one for 3GPP LTE. We in this book focus on the technology and standardization of LTE relay.

1.1 LTE-A Technologies

LTE-Advanced is the enhancement of Release 8/9 LTE. The whole standardization is motivated by meeting the performance requirements set by International Telecommunication Union (ITU) for 4G cellular networks to be deployed globally. Narrowly speaking, LTE-Advanced refers only to Release 10 which is a major release compared to Release 9. The broader meaning of LTE-Advanced would include Release 11. There are five key technologies considered for Release 10 as shown in Fig. 1.2: enhanced MIMO, carrier aggregation, enhanced inter-cell interference coordination (eICIC), relay and coordinated multipoint processing (CoMP). During Release 10 time frame, all of them except CoMP were standardized.

Y. Yuan, *LTE-Advanced Relay Technology and Standardization*,
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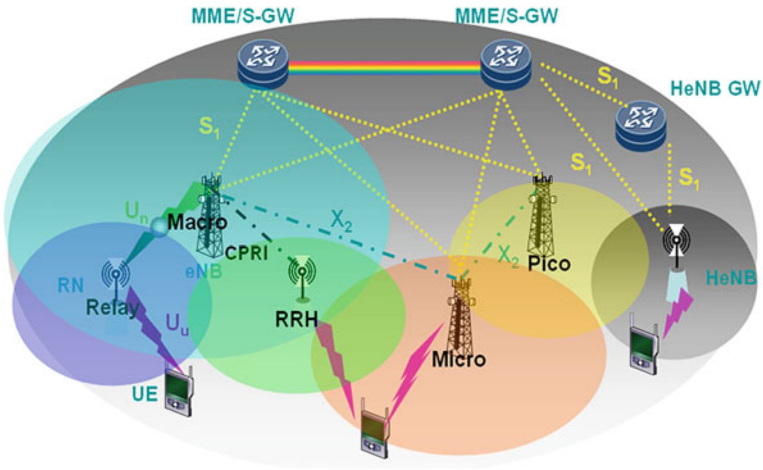

Fig. 1.1 A heterogeneous network with macro, remote radio head (RRH), pico, femto (HeNB) and relay nodes

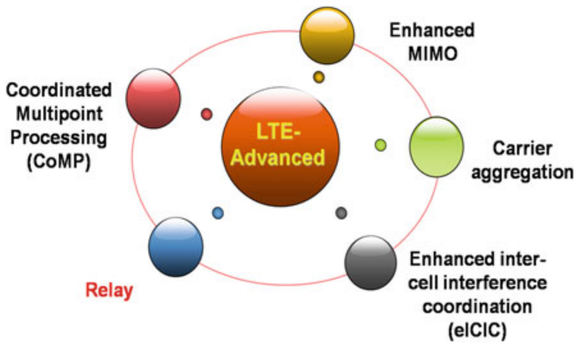

Fig. 1.2 Key technologies of LTE-advanced in release 10

Downlink enhanced MIMO is an extension of Release 9 dual-layer beamforming. Release 9 beamforming primarily works for TDD systems. In Release 10, such beamforming is extended to FDD systems where channel reciprocity generally does not hold. Therefore, channel state information (CSI) feedback is a major specification area. For 8 transmit (Tx) cross-polarization antennas, double codebook structure is specified, which consists of the discrete Fourier Transform (DFT) sub-codebook and the co-phasing sub-codebook, representing the spatial characteristics of the beamforming and the cross-polarization antennas, respectively. The composite codebook is constructed by matrix multiplication of the two sub codebooks, a generalization of Kronecker product of two matrices. The associated downlink signaling, DCI format 2C is defined in Transmission Mode 9, and supports dynamic switching between single-user MIMO (SU-MIMO) and multi-user MIMO (MU-MIMO). A new reference signal channel state information

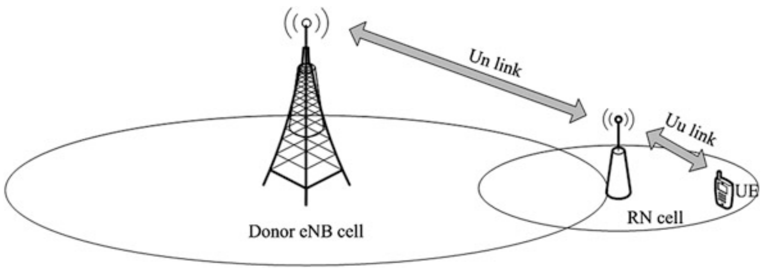

Fig. 1.3 Backhaul (Un) link and access (Uu) link in a two-hop relay

reference signal (CSI-RS), is introduced to facilitate the CSI measurement for SU-MIMO transmission of rank up to 8 and CoMP operations. The configurations for CSI-RS are more flexible than for common reference signal (CRS), both in time and in frequency. In the uplink, the enhanced MIMO supports precoded SU-MIMO of rank up to 4.

From signaling point of view, carrier aggregation allows aggregation up to five component carriers, i.e., 100 MHz, although Release 10 specification optimizes only two-carrier aggregation. In addition to increasing the peak rate, carrier aggregation allows cross-carrier scheduling, which can be used to combat inter-cell interference in heterogeneous networks (HetNets).

In heterogeneous deployment, inter-cell interference can also be mitigated by time domain coordination of transmissions from different nodes, or the so called non-carrier aggregation based ICIC. To achieve that, "almost blank subframe" (ABS) is introduced which contains no downlink traffic channel except some basic signaling channels and reference signals. Almost blank subframes are semi-statically configured by macro base stations and/or low power nodes that have overlapped coverage. The configuration of almost bland subframes should be done in a coordinated manner to minimize the impact of dominant interferers.

Release 10 relay is a decode-forward relay, meaning that the relay node (RN) decodes the data sent from the donor eNB or from UE, re-encodes and forwards to the destination. The relay node has to support LTE Release 8 UEs. The connection between eNB and RN is called backhaul link, or "Un" interface. The connection between RN and UE is called access link, or "Uu" interface, as shown in Fig. 1.3. Backhaul link and access link can be operated in-band or out-band. In-band relay is the focus of the specification. In particular, backhaul link and access link are time division multiplexed in a single frequency band, i.e., only one active at any time.

Relay specified in Release 10 is essentially a stand-alone base station with lower transmit power and wireless backhaul. A Release 10 relay node is typically deployed in fixed locations and shares most of the features of an eNB. It is not designed to exploit the cooperative potential of relaying, a hot topic in academic study. Nevertheless, a lot of experience and lessons were obtained during the Release 10 relay standardization, which will be quite useful for the relay study in

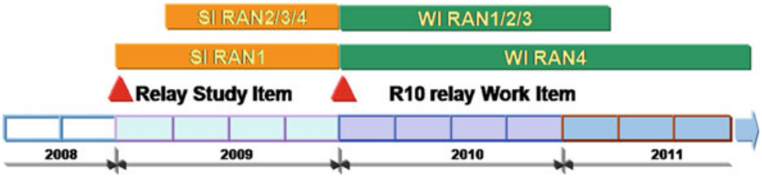

Fig. 1.4 Timeline of release 10 relay standardization

future releases. For example, Type 2 relay, while not specified in Release 10, provides a very good starting point for future relay study, especially for cooperative relays.

Coordinated multi-point processing (CoMP) involves coordinated transmission/reception over multiple points. Those points can be geographically collocated or separated/distributed. When data are available over multiple points, the CoMP transmission is called joint transmission. If data are available only at one point, the CoMP scheme is called coordinated scheduling or coordinated beamforming. The standards development of CoMP was postponed to Release 11 due to some concerns with the backhaul capacity and the spatial channel state information (CSI) feedback for multiple cells.

Major technologies identified and studied during LTE-A Study Item stage were included in 3GPP technical report TR 36.814 [1]. The TR also summarizes the evaluation methodology and simulation results of LTE-A for the submission to ITU-R.

1.2 LTE-A Relay Standardization

In 3GPP, relay study item was officially started in January 2009. The timeline is shown in Fig. 1.4. The study items of other LTE-A technologies also began at that time. By convention, RAN1, responsible for physical layer specification of radio access network (RAN), is the first working group to kick off the study. Slightly later, e.g., in March 2009, RAN2/RAN3, which are responsible for the higher layer and architecture aspects, began their relay study.

In RAN1, the discussions during the relay study item include the application scenarios, categorization of relay, evaluation methodology and high level feature definitions. The relay work progress was slowed down between May and August of 2009 when RAN1 was busy preparing and submitting LTE-A performance evaluations to ITU-R. Since the performance requirements set by ITU-R are for homogeneous networks, relay system performance is not mandatory for the ITU-R submission. Nevertheless, by August 2009, two major relay types, Type 1 relay and Type 2 relay, were identified, and basic parameters for relay evaluation methodology were also agreed. Further refinement of simulation parameters continued till the end of 2009.

Relay work item was kicked off in January 2010, at the same time as the other work items of Release 10. Release 10 relay was primarily for coverage extension scenario, and Type 1 relay was to be specified. At physical layer, the key aspects for relay standardization are backhaul control channels and backhaul subframe configurations. The backhaul control channel specification focused on relay physical downlink control channel (R-PDCCH). The backhaul subframe configurations are coupled with hybrid automatic repeat request (HARQ) timing. The specification consider both FDD and TDD deployments, and in some cases requiring different designs. At higher layers, relay architecture was specified, together with C-plane and U-plane basic procedures. Relay specification work in RAN1, RAN2 and RAN3 was finished in March 2011, slightly later other Release 10 work items. Relay work in RAN4 was not finished in the time frame of Release 10 and the remaining work is continued in Release 11.

1.3 IEEE Relay Standards

IEEE 802.16j includes the most comprehensive relay categories, compared with IEEE 802.16 m and 3GPP LTE-A. In 802.16j, both non-transparent relay and transparent relay are supported. The definitions of “non-transparent” and “transparent” are similar to those for LTE-A relays. A non-transparent relay node has the distinct Cell ID, similar to Type 1 relay in LTE-A. It has the authority of managing the resources and can generate cell control messages. A transparent relay node shares Cell ID and cell control messages with its serving base station, similar to Type 2 relay in LTE-A. 802.16j can support multi-hop relaying, i.e., >2 and mobile relaying.

802.16 m relay focuses only on a subset of relay categories defined in 802.16j. The relay node in 802.16 m is a fixed two-hop non-transparent relay with distributed scheduling, similar to Type 1 relay in LTE.

The radio frame is divided into access and relay zones, used for the transmissions for access link and backhaul links, respectively. The access zone position always precedes the relay zone position. To accommodate the asymmetric DL and UL traffic load, the durations of access zone and relay zone could be different in DL and UL directions. From the aspect of frame structure, there is no particular restriction to support relay zone in 802.16 m. This is a major difference from LTE Release 10 relay where the backhaul subframe allocation is restricted to MBSFN subframes. 802.16 standards support asynchronous HARQ in the uplink. Therefore, 802.16 m relay has more freedom in allocating uplink backhaul subframes, compared to LTE-A relay.

Base station transmits additional MIMO midambles in downlink relay zone for an operational relay node to perform synchronization with the base station. Due to co-existence of mobile terminal and relay node in relay zone, the advanced MAP (A-MAP) control channel and the data channel of access zone are reused in relay zone. The associated channels, e.g. fast feedback control channel, UL hybrid automatic repeat request (HARQ), and sounding channel, should adjust their locations or avoid transmitting on OFDM symbols occupied by switching gaps in relay zone. Overall, the standards impact is smaller than in LTE Release 10 relay.

In 802.16 m relay, HARQ is performed hop-by-hop independently, and so is the header compression. The data plane backhaul control signal interface can terminate either at the base station or the relay node.

802.16 m mobile terminal is aware of relay node including the possible enhanced features, whereas LTE Release 8 UEs are not allowed being enhanced to be "RN-aware". Hence, the backhaul link communication for a LTE-A relay is less flexible than the similar backhaul link of an 802.16 m relay. This disadvantage would be more pronounced in the TDD system due to the further constraints of HARQ timing.

1.4 Book Objectives and Outline

In 3GPP, to minimize the impact on the existing physical layer specifications for eNB-UE connection, a separate specification TS 36.216 [2] was designated for type 1 relay physical layer features. The structure of TS 36.216 is very compact, with the assumption that readers are familiar with Release 8/9 LTE physical layer specifications and can cross reference the corresponding chapters in TS 36.211 (channel structure and format), TS 36.212 (coding and modulation) and TS 36.213 (UE procedures). The very succinct wording in TS 36.216 may require significant amount of effort to fully comprehend the relay operations. Thus, the first objective of this book is to facilitate the understanding of design principles of Release 10 relay and ease the reading of TS 36.216.

The second objective is to provide a comprehensive picture of major relay techniques investigated during the study item stage and the work item stage. These discussions target for readers who have broader interest in relay and related technologies, not limited to the specifications.

As mentioned above, a key specification aspect of Release 10 relay is the backhaul control channel, i.e., relay PDCCH (R-PDCCH). As Release 10 relay node cannot receive PDCCH from donor eNB, certain PDSCH region has to be allocated for R-PDCCH transmission. This prompts the possibility of frequency domain multiplexing (FDM) and use of Release 10 demodulation reference signal (DM-RS) for R-PDCCH. The discussion/standardization of R-PDCCH has a far reaching effect on Release 11 enhanced PDCCH (ePDCCH). From this prospective, the detailed description of R-PDCCH can shed lights on ePDCCH design.

During Release 10 specification, relay timing was one important topic since relay node is half-duplex and needs certain guard period to switch from transmission to reception, or vice versa. To accommodate the guard period and different backhaul propagation delays, several schemes for relay frame timing can be used. Half-duplex operation may become more popular in some emerging technologies such as device-to-device communications. In this sense, relay timing study would provide valuable experience for technologies in future LTE releases.

Type 2 relay, which features cooperation between macro eNB and relay nodes, was studied during the study item. Although not specified in Release 10, type 2 relay showed some promise. The on-going Release 11 CoMP specification, especially Scenario 4, shares some key features with cooperative relay. In this sense, the discussion of type 2 relay in this book is helpful for the understanding of CoMP.

Besides the standards development, implementation is another important step for the relay technology realization in wireless industry. It often requires much more effort and investment for real-world optimizations and developments. One chapter of this book is dedicated to the high level description of relay implementation and deployment.

In academic study, relay is still a topic attracting lots of research interest. Some schemes have strong potentials in improving the system performance and user experience, and thus promising for future wireless systems or standards. The relay study is increasingly connected with other emerging technologies such as device-to-device communications, soft cell network, etc. We use one chapter to provide our thought on the outlook of relay.

The book is organized as follows. Chapter 2 discusses the application scenarios and simulation methodology for relay. Various relay technologies are described in Chap. 3, with performance studies. Chapter 4 contains detailed descriptions of Release 10 relay specifications at physical layer features. High layer aspects and performance requirement are outlined in Chap. 5. Chapter 6 discusses some aspects for Release 10 relay implementation. Outlook of relay and related technologies in future LTE releases are provided in Chap. 7.

References

1. 3GPP TR 36.814: Evolved Universal Terrestrial Radio Access (E-UTRA): Further advancements for E-UTRA physical layer aspects. http://www.3gpp.org/
2. 3GPP TS 36.216: Evolved Universal Terrestrial Radio Access (E-UTRA): Physical layer for relaying operation. http://www.3gpp.org/