Chapter 7
Outlook of Relay in Future LTE Releases

7.1 Some Trends in Mobile Communications

7.1.1 Trends at Terminal Side

Cell phones, as the most common form of terminal for mobile communications, become more powerful in various aspects:

- Carrying more smart applications and vastly increasing the usefulness and functionalities of the terminals, well beyond for voice communications and short messages.
- Ever increasing processing capabilities with the continuing size shrinking of integrated circuits. A smart phone is like a personal computer.
- Mobile social networking and mobile advertising. Proximate services to discover friends in the vicinity and find people that share common interests. Device-to-device (D2D) communications is one example [1, 2]. As Fig. 7.1 shows, the base stations may or may not directly participate in data transfer between users in D2D, such as allocating uplink resources for originating UEs and reception, and allocating downlink resources for target UEs and transmission. Instead, the network would just do some control over D2D communications. Such control can be very loose and at very high level, or it can be very tight, down to L1 level. Nevertheless, since the traffics do not go through the network, security is a major concern for D2D.

7.1.1.1 Trends at Network Side

From the network side, we witness the migration from pure macro-eNB based homogeneous networks to macro and low power node combined heterogeneous networks. The capacity improvement by service operators cannot keep up with the

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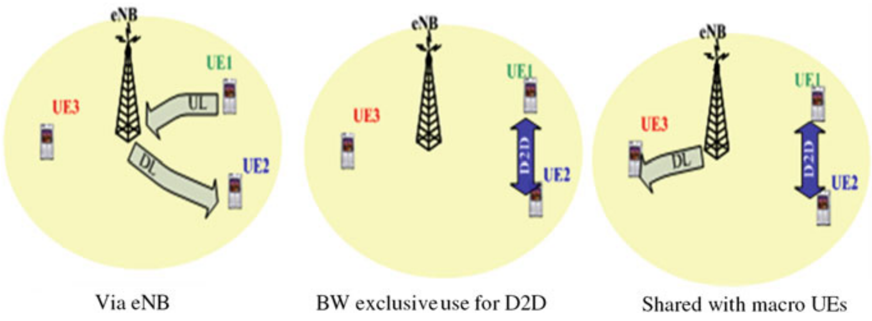

Fig. 7.1 Device-to-device (D2D) communications

explosive growth of the traffic. Therefore, offloading traffic to low power nodes such as pico node, femto node, or even to the terminals becomes more attractive. There are two major approaches on how to use low power node for capacity enhancement:

- Cell splitting

Deploying more pico node, femto node or Release 10 relay node should help to achieve the cell splitting gain. The gain can be further improved by cell range expansion. However, it comes with the price of strong interference, especially from macro transmissions, since these nodes have their own resource scheduler usually independently running. Time domain resource coordination such as configuring almost blank subframe (ABS) can mitigate the interference. Still, basic signals such as common reference signals, paging and synchronization channels, primary broadcast channels are not protected by ABS. Ultimately, cell splitting approach requires strong interference cancellation capabilities at the terminal.

Since mobile processing power is ever growing, more advanced signal processing techniques are becoming feasible, which allows UEs operating in severe interference environment due to the cell splitting.

- Inter-node cooperation

The general inter-node cooperation is CoMP. Here, we specifically refer to CoMP Scenario 4 where the low power node, typically remote radio head (RRH), shares the same cell ID with the macro eNB. Joint transmission and reception can be carried out at multiple nodes, i.e., macro and RRH. Since the resource scheduling is centralized, the number of participating nodes for joint transmission/reception can change dynamically, to better adapt to the traffic variations. Same cell ID RRH appears transparent to UEs, thus the cooperation between macro and RRH constitutes a virtual macro cell of distributed antennas whose coverage shape can constantly change, i.e., "soft cell" [3].

To fully achieve “soft cell”, the traditional common reference signal (CRS) based radio resource management (RRM) needs to be changed. CRS is cell specific and common to all UEs belonging to the same cell. However, the cooperation between macro and RRH is UE specific. In another word, the virtual soft cell is UE specific. In this respect, CSI-RS can be used for RRM, if it is configured as UE specific. This is a fundamental change not only at physical layer specification, but also at higher layers, since RRM affects how UE’s mobility is handled, which involves a lot of higher layer signaling and procedures during the handover.

Removing the reliance on CRS for RRM means that Release 8 PDCCH would no longer be used for L1 control signaling which is based on CRS. The enhanced PDCCH (ePDCCH), currently in the process of standardization [4], may serve the purpose. Frequency domain multiplexing nature with demodulation reference signal (DMRS) allows more flexible resource allocations and increased capacity for L1 control signaling.

- “Cloud” RAN

The base station in traditional wireless network is essentially a piece of standalone equipment with all the necessary baseband capabilities and RF functionalities. The cloud-RAN concept is changing this traditional setting, and advocating centralized baseband processing, an analogy to cloud computing. Its effect is far-reaching, not only on the business model of operators and product plans of telecommunications equipment vendors, but also technology evolutions in future mobile communications.

Cloud RAN is sometimes dubbed as CRAN to emphasize its centralized, clean, cooperative, cloud based nature. CRAN features centralized baseband in a big processing pool. Local baseband processors become unnecessary, therefore saving the expensive air conditioning to maintain the normal operations of the baseband. The air conditioning cost contributes the most percentage in power usage of a base station.

Centralized baseband can serve as a platform supporting multiple radio access technologies. The platform is open for the access since the processing is performed on general purpose servers. Through software (re)configuration and upgrade, different technologies can be easily added in, including the future specifications. This is very beneficial to technology evolutions as equipment vendors and operators do not need to worry about out-date of their hardware investment in previous technologies.

Figure 7.2 shows the network elements in CRAN. The baseband processing is carried out in virtual base station clusters which consist of general-purpose processors to perform PHY/MAC processing. The inter-cluster communication is through X2+ interface. The high speed switching can dynamically balance the traffic load of the network, to maximize the computation efficiency between the clusters, and between the centralized cloud and radio. In the field, a large number cooperative remote radio units (RRUs) can reduce interference and achieve high spectral efficiency.

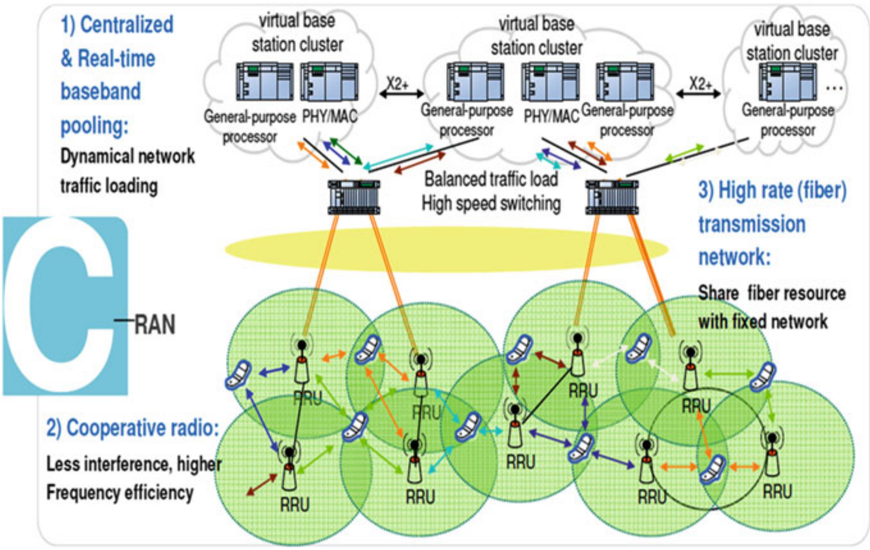

Fig. 7.2 Network elements in CRAN

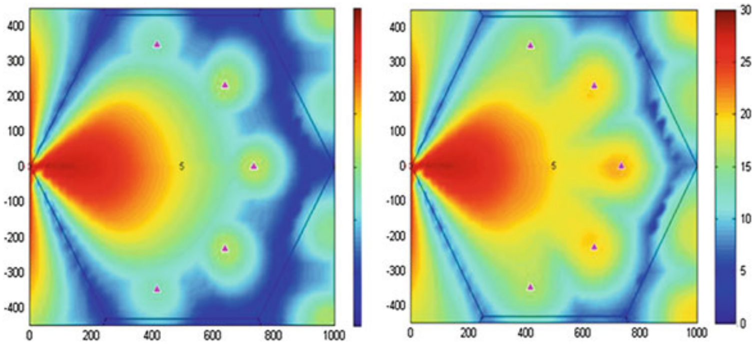

Fig. 7.3 Change of virtual cell shape with cooperation

7.2 Cooperative Relays

Relay node can be cooperative. Type 2 relay studied in Release 10 is one example. Sharing the same cell ID with macro node makes the operation of type 2 relay analogous to the same cell ID remote radio head (RRH), with the only difference in backhaul, fiber optic vs. wireless. While from system capacity prospective, cooperative relay cannot compete with fiber connected RRHs, wireless backhaul allows much more flexibility of the relay deployment, not only with fixed locations, but also with nomadic movement or completely mobile. Cooperative relay

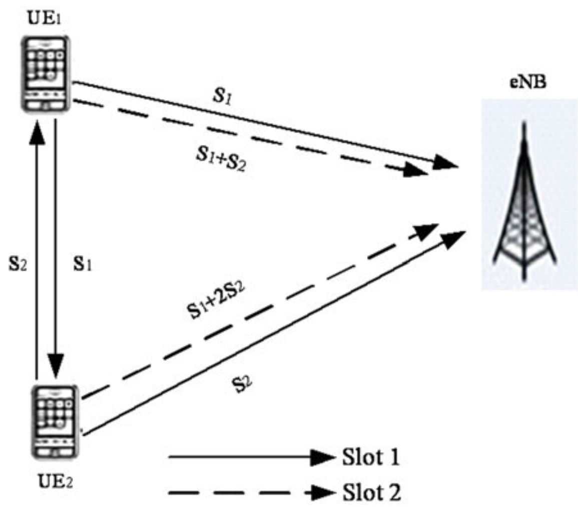

Fig. 7.4 Network coding applied in cooperative transmission

node and macro eNB dynamically form a virtual cell whose shape can change like fluid or amorphous material, as seen Fig. 7.3.

Previous study on type 2 relay was constrained by the backward compatibility for Release 8 UEs, thus closing the door for more advanced features potentially helpful for the performance. For example, type 2 relay does transmit Rel-8 CRS, leading to the pessimistic CQI estimation for combined channel in the case of cooperative transmission, or the totally different CQI estimation for resource reuse. Such mismatch can only be handled by eNB implementation, i.e., outer loop link adaptation. Release 8 HARQ timing in backhaul prevents some more efficient mechanism for cooperative relay in the uplink.

Such backward compatibility is no longer the limiting factor. With the introduction of UE specific CSI-RS and enhanced PDCCH, there are more freedoms for design optimization of cooperative relay. From this respect, some on-going work in LTE Release 11 of enhanced PDCCH, UE specific CSI-RS and power control for uplink CoMP could be reused for cooperative relay to improve its performance.

Cooperative relay is not limited to those already been studied in Release 10. More widely use of network coding is a promising direction. In the context of network coding, the cooperative relaying operation can also involve UEs as Fig. 7.4 shows, as long as they can participate in relaying. In this sense, cooperative relay can also be used in D2D communications. In Fig. 7.4, in addition to transmitting its own data to eNB in the first slot, UE1 and UE2 can try to decode each other's data during the first slot and pass them to eNB in the second slot. Through this cooperation, significant gain is observed in Fig. 7.5.

Network coding not only brings capacity gains, but also improves the multipath diversity and energy efficiency. Certainly, there are quite a few challenges in applying network coding to cooperative relays. For example, strict synchronization is required among sources participate in the cooperation. The performance is

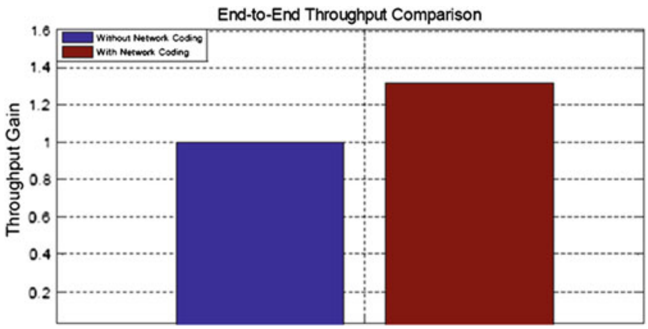

Fig. 7.5 Uplink cell throughput gain with network coding based cooperative transmission

Table 7.1 Achievable spectral efficiency of the cooperative relay compare to the capacity

Bits/Symbol SNR(dB)	Capacity of cooperative relay	Cooperative relay rate achieved via LDPC	Non-cooperative capacity	Rate achieved of non cooperative relay
−20	0.04	–	0.02	–
−12.5	0.14	0.1	0.05	–
−10	0.23	0.18	0.07	–
−9	0.26	0.2	0.09	–
−7	0.3	0.3	0.11	–
−5	0.45	0.4	0.2	–
−4	0.5	0.44	0.22	0.2
−3	0.59	0.5	0.24	0.25
−0.9	0.66	–	0.42	0.38
0	0.68	–	0.5	0.44
2	0.76	–	0.58	0.6
5	0.9	–	0.96	0.95
8	0.97	–	0.96	0.95
10	1	–	1	–

highly relying on source grouping methods which should be optimized, yet also efficient. The control signaling overhead should be carefully considered so that it would not eat out the potential gains in data transmissions.

Network coding based cooperative relay also opens the door for new channel coding. Besides the legacy Turbo codes, LDPC codes prove to be a good candidate as it has more flexibility to adapt to different scenarios of operations. An example is shown in [5] where the rate-compatible LDPC codes have been optimized for the two-hop cooperative relaying. The codes are irregular and designed based on edge growth and parity splitting. For Table 7.1, it is seen that the performance of the LDCP codes is quite close to the capacity of the cooperative relaying.

Any channel coding would be an overhaul from physical layer specification prospective. Hence, extensive study is needed for any newly proposed coding scheme.

7.3 Relay Backhaul for High Speed Mobility

During the study phase of LTE-Advanced, group mobility was identified as one of the key application scenarios for relay deployment. Relay node is more suitable for group mobility due to the following:

- Compared to repeater

Relay node in general is of decode-and-forward type, thus can improve signal to interference and noise ratio (SINR). Compared to a repeater that equally amplifies both signal power and interference power, a relay node allows separate optimization of backhaul link (donor eNB to relay node) and access link (relay node and the UE), and has the potential of improving the link capacity.

Repeater requires much less standards work compared to relay node, especially in RAN1. However, the link capacity issue may significantly limit repeater's use in group mobility scenario where the target is more on capacity enhancement, rather than to overcome the excessive thermal noise.

- Compared to regular UE

Relay node is usually not powered by battery and has less constraint on transmit power compared to regular UE. More advanced and power-consuming baseband processing is affordable in relay node. More antennas can be mounted on a relay node than a regular UE, especially if the UE is a hand-held device. Given the less limitation on its size, directional antenna (both vertical and azimuth) is possible for each antenna element on a relay node, whereas the regular UE antennas are omni-directional in azimuth and very fat in vertical.

All above differences from regular UE give relay node much more potential for spectral efficiency improvement, which is important for group mobility scenario.

Passengers on high-speed train are more likely to be data-hunger professionals and would hook up to the internet & emails when on-board (voice call is considered impolite here). The capacity requirement for relay backhaul is expected to be very high, when the very high user density is considered in a train. The user density would be high even when it is not fully loaded. The high data rate expectation is applicable for both downlink and uplink traffic.

Backhaul channel characteristics, including pathloss, shadow fading and fast fading, would be different from those of eNB to UE connection, due to

- Higher elevation of mobile relay antennas mounted typically on top of train roof ($\sim$5 m)
- Terrain and morphology along the rail track has less scatterers

As discussed above, increasing the backhaul channel capacity should be the main concern of mobile relay for group mobility, especially on fast-moving vehicles.

- Given the less power constraint on relay node, wider bandwidth can be considered in the backhaul with more flexible solutions for carrier aggregation.

- Multi-antenna technologies can be further optimized to fit the mobile relay node capabilities and the propagation environment along the track lines
- Control and signaling channel optimization to improve the reliability and link robustness

The enhancement over backhaul will have no impact on access link to UE. Standard can be kept untouched for UE side as we done in Rel-10 relay. The legacy LTE handset can well access the network without awareness of mobile relay.

7.4 Cooperative Mobile Relay

Device-to-device communication can be considered as a simple mobile relay—a moving terminal disseminating data to nearby terminals. Mobile relay provide more "bridges" to more efficiently transfer the traffic between terminals, and between terminal and eNBs/pico/HeNBs. Mobile relay is often called mesh ad-hoc wireless network that captures a lot of attention from the academia. It is also found use in military applications where centralized networks are generally not available, or too insecure. Even though there is still a long way before the technologies in ad-hoc wireless network would be practical enough to be considered in wireless industry, it reflects the future trend of mobile communications.

Type 2 relay studied during Release 10 is a fixed relay. Unlike type 1 relay which has its own cell id and is more difficult to handover between donor eNBs, type 2 relay has no cell id. This makes it easier to handover between neighboring eNBs. Moving relays have the advantage of achieving more seamless coverage and capacity enhancement. One particular application would be bus-mounted cooperative relay as illustrated in Fig. 7.6. Not only to serve the passengers on the bus, the mobile cooperative relay can also assist data communications for nearby users outside the bus, i.e., pedestrians on the sidewalk. Buses are usually powered by the gas engines or power grid, making transmit power of mobile relay node less an issue. The routes of buses are with high density of populations and type 2 relay can help to boost the network capacity. The traveling velocity of a city bus should be slow to medium, i.e., $<$40 km/h, so the Doppler is not expected high as fast speed trains.

7.5 Local Server

As discussed earlier in this chapter, the difference between relay and UE starts to be blurred in future mobile communications. Powerful UEs will be able to perform relay functionalities, while relay node can be nomadically deployed, or even with mobility. Device-to-device (D2D) communications, while promising for proximity services, has its own drawback, for example:

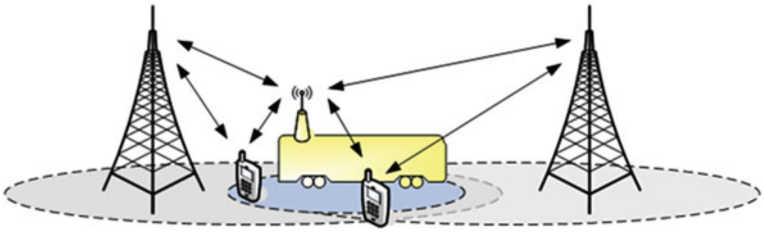

Fig. 7.6 Bus-roof mounted mobile cooperative relay node

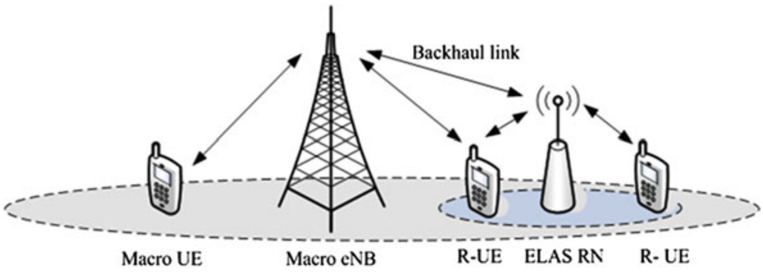

Fig. 7.7 An example of relay based wireless local server

- High requirement for terminals, significant changes at physical layer and upper layers
- Difficult to monitor the information exchanged between D2D users. Big concerns of security
- Size of terminals limits transmission rate, the power consumption and the coverage of users engaged in D2D communications

Alternatively, a wireless local server can be deployed within the coverage of macro cell to enhance local content based services, as shown in Fig. 7.7.

Such server can be based on relay, either type 1 relay or cooperative relay. It can perform data relaying between users, or multicast data to local users of the same group. The local services include advertisement, public information broadcasting in supermarkets, restaurants, hospitals, local media downloading, user data storage/sharing, wireless payment, food ordering, wireless multimedia tour guiding, push-to talk, group mobile gaming, etc.

References

1. Wireless World Initiative New Radio-WINNER+, Innovative concepts in peer-to-peer and network coding
2. Wu, X. et al.,: FlashLinQ—a synchronous distributed scheduler for peer-to-peer ad-hoc networks. 48th Annual Allerton Conference, pp. 514–521. (2010)

3. Soft cell, a HetNet solution for IMT-advanced and beyond. Ericsson Research, Nov 2011
4. 3GPP RP-111776: Enhanced downlink control channel(s) for LTE, RAN #54, Alcatel-Lucent, Alcatel Shanghai Bell, Dec 2011
5. 3GPP R1-083852: TDMA relay code for half-duplex L2-based relay in LTE-Advanced, RAN1 #54bis, Alcatel-Lucent, Sept 2008