

Chapter 2

Opportunities, Challenges, and Terms Related to LTE-A Cellular Network

2.1 Introduction

The well-known generational phase of mobile telecommunications started in the early 1980s, beginning with the introduction of the so-called First Generation (1G) of mobile telecommunications standards. The 1G analog cellular systems supported voice communication with limited roaming and short-range radio waves telephones. Later, Second Generation (2G) was introduced as a digital systems and promised higher capacity and better voice quality. 2G cellular telecom networks were commercially launched on GSM (Global Systems for Mobile Communication) standard in Finland in 1991 (Dahlman, Parkvall, & Skold, 2011a).

The 3GPP (Third Generation Partnership Project) was born out of the International Telecommunication Union's (ITU) of International Mobile Telecommunications "IMT-2000" initiative, covering high speed, broadband, and Internet Protocol (IP) (Khan, 2009).

LTE (Long Term Evaluation) standardization within the 3GPP has reached a mature state since end of 2009. LTE mobile communication systems have been deployed as a natural evolution of GSM and UMTS (Universal Mobile Telecommunications System).

The ITU has coined term IMT-Advanced to identify mobile systems whose capabilities go beyond those of IMT-2000 (Dahlman, Parkvall, & Skold, 2011b; Khan, 2009). Figure 2.1 shows the cellular network generations of standards for mobiles communication and Table 2.1 shows summary of 3GPP-LTE, LTE-Advanced, and IMT-Advanced performance targets.

The rest of this chapter is organized as follows: A survey of basic concepts of using relaying technologies and advantages and disadvantages within cellular network is presented in Sects. 2.3 and 2.4. Section 2.5 introduces the types of relays based on their functionality. A literature survey of relay nodes related with cellular network is presented in Sect. 2.6. A relay enhance cellular network is reviewed in Sect. 2.7. Section 2.8 introduces types of relay transmission mode in the cellular

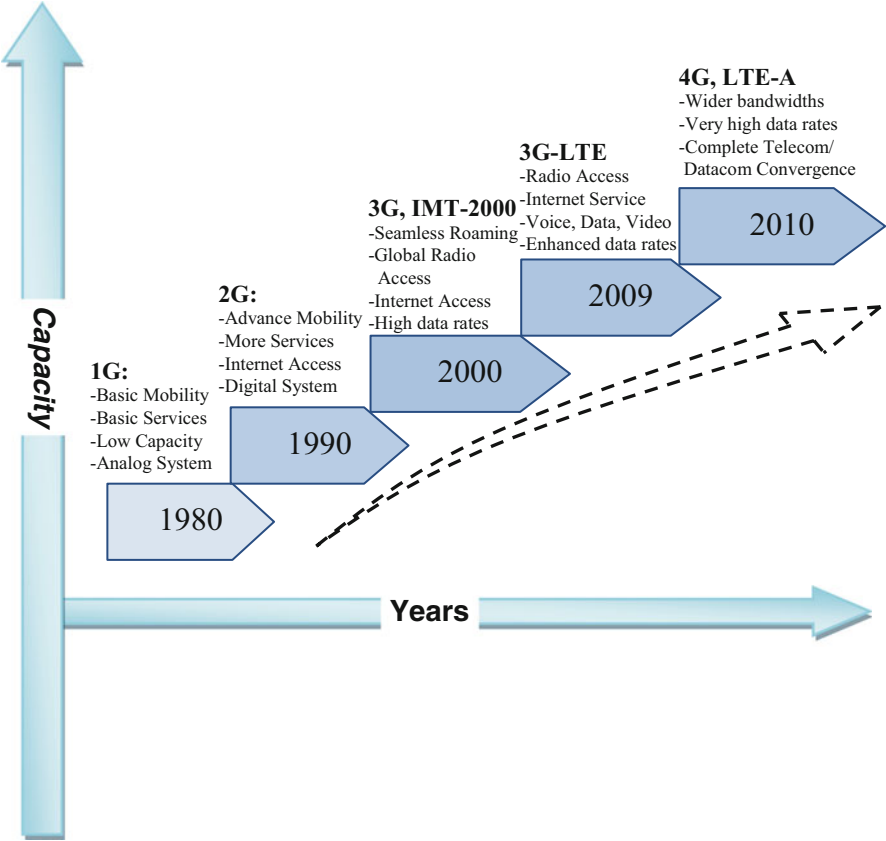


Fig. 2.1 Cellular network generations for standard mobiles communication (Dahlman et al., 2011a)

Table 2.1 3GPP-LTE, LTE-advanced, and IMT-advanced performance targets for downlink (DL) and uplink (UL) (Akyildiz et al., 2010)

Parameters	3GPP-LTE	LTE-Advanced	IMT-Advanced
Peak data rate (DL) (Mbps) (UL)	100	1000	1000
	50	500	1000
Spectral efficiency (DL) (bps/Hz) (UL)	5	30	15
	2.5	15	6.75

network. Section 2.9 is dedicated to relay planning in cellular network and shows the significance of relay location on increasing coverage area and enhancing throughput of the LTE cellular network. A new type of relay known as the moving relay is reviewed in Sect. 2.10. Finally, a summary of this chapter is presented in Sect. 2.11.

2.2 Long Term Evolution Advanced (LTE-A)

Long Term Evolution-Advanced (LTE-A) is an evolution of 3GPP-LTE (Third Generation Partnership Project-Long Term Evolution) which aims to bridge the gap between Third Generation (3G) and Fourth Generation (4G) standards described in IMT-Advanced (International Mobile Telecommunications). LTE-A aims to provide peak data rates of up to 1 Gbps (for low mobility) and 100 Mbit/s (for high mobility) in Downlink (DL) and 500 Mbps in Uplink (UL). LTE-A is required to reduce the latency time as compared to 3GPP-LTE (Dahlman et al., 2011a). LTE-Advanced targets to enhance the cell edge user throughput in order to achieve a homogeneous user experience in the cell and increase the capacity to 30 and 15 bps/Hz in DL and UL, respectively (Sesia, Toufik, & Baker, 2011).

The main new functionalities introduced by LTE-A to enhance 3GPP-LTE are carrier aggregation (CA), enhanced use of multi-input multi-output (MIMO) antenna techniques, coordinated multipoint transmission and reception (CoMP), and support by relay technology (Khan, 2009), as shown in Fig. 2.2.

- *Carrier Aggregation*: In carrier aggregation, multiple carrier components are aggregated, to provide wider bandwidths for transmission purposes both in DL and UL. It allows for transmission bandwidths of up to 100 MHz, by adding five component carriers of 20 MHz bandwidth. CA exploits the fragmented spectrum by aggregating contiguous or noncontiguous component carriers (Dahlman et al., 2011b).
- *Extended MIMO*: LTE-A introduced extending the number of layers in MIMO from 4×4 to 8×8 layer at DL and from 2×2 to 4×4 layers at UL to increase the overall bit rate through transmission of different data streams in multiple antennas (Sesia et al., 2011; Ullah, 2012).
- *Coordinated Multipoint Transmission/Reception (CoMP)*: In CoMP multiple geographically separated base station sites coordinate transmission and reception, in order to achieve good system performance and end-user service quality. CoMP uses coordination techniques; namely, intercell scheduling coordination and joint transmission/reception (Dahlman et al., 2011b; Genc, 2010).

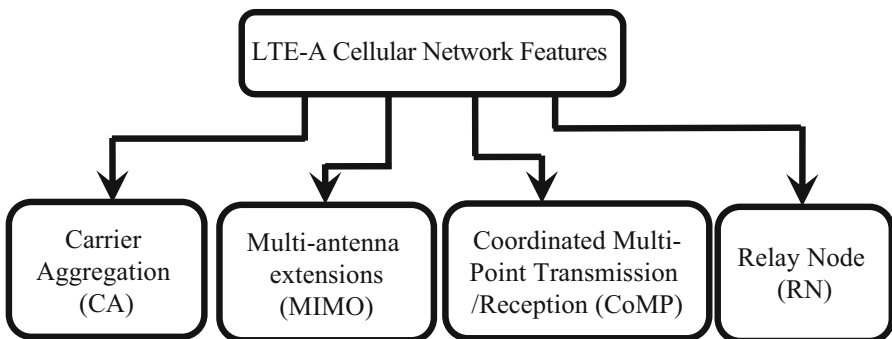


Fig. 2.2 Functionalities introduced by LTE-A to enhance 3GPP-LTE network

- *Relaying Technology*: This technique provides the possibility for heterogeneous network planning through the integration of large cells such as BS, and small cells such as Relay Node (RN). RNs have lower power and a lower cost compared to BSs which provide enhanced coverage and capacity in cellular networks (Dahlman et al., 2011a).

Relaying technologies enable the efficient utilization of communication resources, by permitting the nodes to cooperate in information exchange with each other to enhance the quality of services for current communication networks to suit LTE-A requirements.

This book focuses on exploiting the possibilities of RN to enhance the coverage and capacity for LTE-A cellular networks. This chapter presents surveys of related literature about relaying to enhance 3GPP-LTE cellular networks; Fig. 2.3 shows the chapter scope for the literature survey.

2.3 Cooperative Relaying

Cooperative relaying technologies have been presented as the basic concept of the relaying through proposing three terminals: a source, relay, and destination as shown in Fig. 2.4. The source broadcasts a signal to both the relay and the destination, while the relay rebroadcasts this signal to the destination. Thereafter, the destination combines these received signals from both the source and the relay to improve reliability (Duong & Zepernick, 2009).

Cooperative relaying is a technique for wireless communications, which promises gains in throughput and capacity and allows communication terminals in a network to receive and help the information transmission from each other. Cooperative relaying is based on exploiting the advantage of the broadcasting nature of wireless communications (Sharma, Shi, Hou, Sherali, & Kompella, 2010). Cooperative relaying for wireless communications has become one of the areas of active researches for more than three decades (Nordio, Chiasserini, & ElBatt, 2012).

The classical relay channel model, which consists of a source, a relay, and a destination, was first introduced by Van Der Meulen (1971). He discovered upper and lower bounds on the capacity of the relay channel and provided many observations which led to an improvement of his results. In the following years, Cover and Gamal (1979) significantly improved on Meulen's observations when they established an achievable lower bound to the capacity of the general relay channel. However, the implicit assumptions (Cover & Gamal, 1979; Van Der Meulen, 1971) are unrealistic for the wireless medium because they are not compatible with the current developments in communications systems (Yongchul & Sichitiu, 2011).

In routing scenario, cooperative relaying has two categories, Ad Hoc networks and multihop relay (Sharma & Jain, 2010) which use an independent node known as Relay Node (RN) or sometimes known as Relay Station (RS). In Ad Hoc network

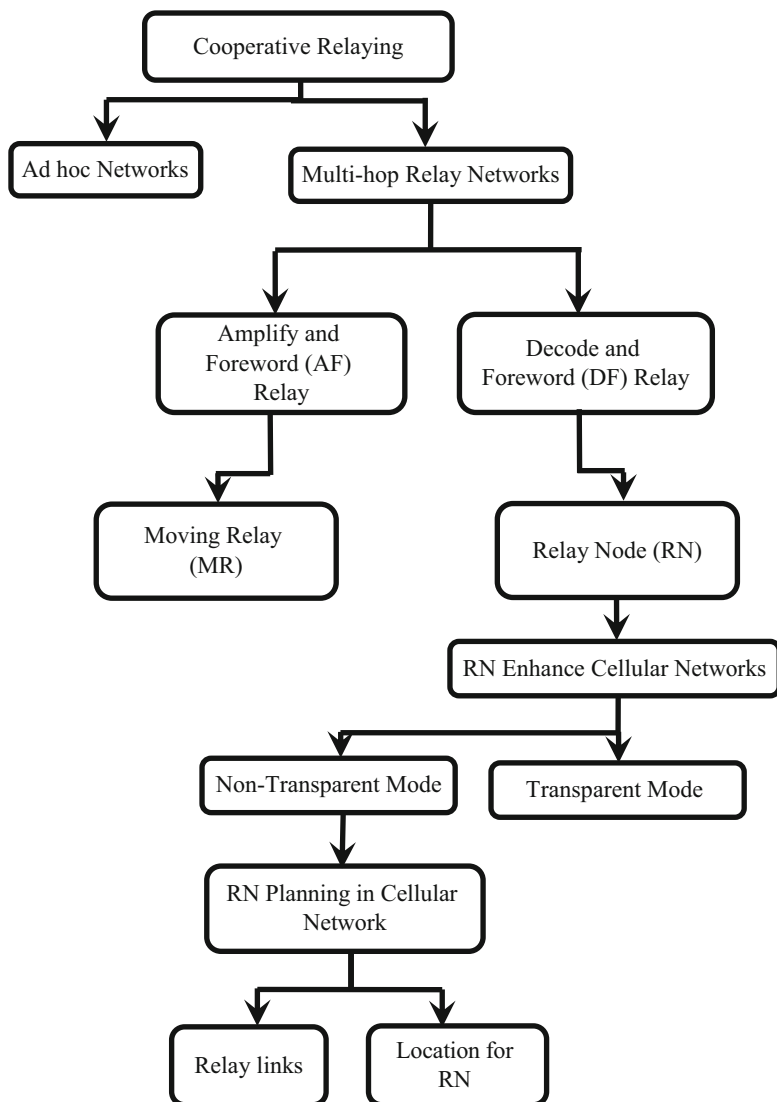


Fig. 2.3 Scope of this chapter

the User Equipment (UE) acts as a base and a receiver to route the information to its destination (Sharma & Jain, 2010). The following subsection explains in brief the Ad Hoc networks and multihop relay.

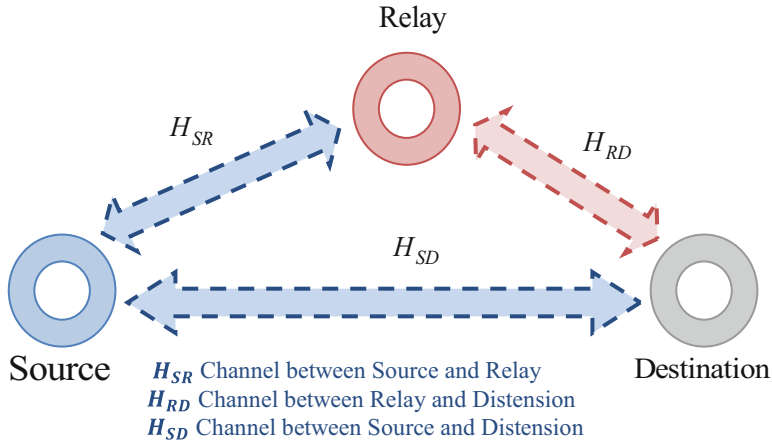


Fig. 2.4 Three terminals of cooperative relaying (Duong & Zepernick, 2009)

2.3.1 Ad hoc Networks

Ad hoc networks, which are also called mesh networks, are defined by the manner in which the network nodes are organized to provide pathways for data to be routed from the user to and from the desired destination. Ad hoc networks are basically those networks that have no Base Station (BS). In other words, every device (or node) in the network can act as a base and a receiver (Frodigh, Johansson, & LaRSSon, 2000).

A multihop ad hoc network consisting merely of mobile users is known as Mobile Ad Hoc Networks (MANETs), where every node can play the role of an intermediary node that relays messages from other nodes toward their destinations and cannot be accessed using a single-hop transmission (Sharma & Jain, 2010). MANETs include a group of mobile nodes that communicate without needing a fixed wireless infrastructure. Therefore, the communication between nodes is implemented by direct connection. Some nodes in the network are expected to help in the routing of packets and all hosts are allowed to move freely through the network. Successful routing protocols introduce methods providing packets to destination nodes given these dynamic topologies (Williams & Camp, 2002).

The Ad hoc network has many advantages. First, it does not require more fixed base transmitter. Second, the Ad hoc network is decentralized from the main network and is self-configured at the nodes and routers. Therefore, it has ability to self-heal by continuous reconfiguration (Williams & Camp, 2002). Finally, Ad hoc network is scalable to absorption of the addition nodes and is flexible to access the internet from different locations (Sharma & Jain, 2010).

The main disadvantage of Ad hoc network is that there should be nodes within the transmission range. If these nodes are not available, the whole network will fail (Frodigh et al., 2000). In addition, there is a lower data rate where the throughput is affected by system loading as well as for large networks, excessive latency (time delay) (Sharma & Jain, 2010).

2.3.2 *Multihop Relay*

Cellular systems conventionally employ single hops between UEs and the BS. The low throughput at the cell edge region has become a major concern to cellular network planners (Pabst et al., 2004). The effective solution to the problem of improving coverage and capacity is the use of small cells between source and destination (Li, Seet, & Chong, 2008).

Analog repeaters are used in cellular networks to help extend coverage to areas that the BS cannot cover. Drucker (1988) was one of the first to use the term cellular repeater and address the idea of using relays as repeaters to extend the coverage of an underlying cellular network.

In recent years, Multihop Relay-based networks have become an area of significant research interest in both industry and academia. Relaying information through multihops reduces the overall transmission power of the network without loss of reliability, thereby resulting in extended battery life (Seo, Mok, & Lee, 2007).

In order to meet with the rapid growth of wireless communications, which requires higher data rates and a more reliable transmission link while keeping a satisfactory Quality Of Service (QoS), researchers have focused on Multihop Relay scenarios (Duong & Zepernick, 2009). Multihop Relay is a low-cost solution, which provides a wide range of services in next-generation wireless networks. It can reduce the transmission distance and increase the number of users under channel conditions, for better link quality and higher throughput (Zheng, Lei, Wang, Lin, & Wang, 2011).

Yu et al. (2008) incorporated the multiple-hop scheme based on mathematical formulas to minimize the network cost and reduce the path losses between users and BS/RS. However, their proposed technique could not guarantee access quality for multiple-hop networks because authors relied on a random deployment of RSS within the cell. In addition, the location for RSS was chosen based on minimizing the network installation cost, regardless of the interference between stations and achieving the best enhancement in capacity (Prommak & Wechtaison, 2012).

Multihop Relay is one of enhancement keys which are introduced in LTE-A to improve the performance of 3GPP-LTE, in terms of capacity enhancement and coverage extension (Joshi & Karandikar, 2011).

2.3.3 *Advantages of Multihop Relay*

The concept of using Multihop Relay for wireless communication has been an active research topic for more than three decades. The main advantages of using Multihop Relay in cellular networks can be identified as follows:

1. *A reduction in total transmission power:* The total power consumption through the multihop relay is lower than direct transmission (Seo et al., 2007).

2. *An increase in network capacity*: Reducing transmission power leads to a reduction in the coverage radius of BS in Multihop Relay network compared with single hop. Therefore, the spectra can be reused more frequently as a result of the shorter reuse distances and the network capacity can be increased. This is similar to small cellular networks, where the coverage area is inversely related to spectral efficiency (Sharma & Jain, 2010).
3. *Higher throughput services*: Typically in cellular network, UEs near the BS are able to enjoy high throughput services, while those far away from the BS will have low throughput services due to power limitations. However, with Multihop Relay, the users far away from the BS can still access high throughput services whose data can be relayed via multihop networks (Boccardi, Yu, & Alexiou, 2009; De Moraes, Nisar, Gonzalez, & Seidel, 2012).
4. *Balancing traffic load*: Unbalanced traffic distributions complicate the management issue which allocates capacities in the network. This means that, some cells have enough available channels while other cells are heavily crowded, even though the traffic load has not reached the planned maximum capacity for the cellular network. Therefore, some users may be blocked due to the saturation in crowded cells in the network (Chiang, 2005). The Multihop Relay considered as a possible solution because it allows the traffic from congested cells to be transferred to other noncongested cells. Because of this, the probability of call blocking at the network point can be decreased due to load balancing between the cells (Chiang, 2005; Hyytiä & Virtamo, 2007).
5. *Mitigating capacity bottleneck*: The peer-to-peer communication process in multihop systems without involving the BS mitigates the potential capacity bottleneck that can rise due to the limited channels available to the BS in the single hop system (Lee, Han, Song, & Cho, 2006; Li et al., 2008).
6. *An increase in network coverage*: An improvement in capacity and an increase in coverage area in cellular networks are the major benefits of Multihop Relay networks due to a reduction in the path loss effect and an improvement in the Received Signal Strength (RSS) at UEs that are located in dead-spot areas of the cellular networks (Pabst et al., 2004). Dead spots may include the regions near the cell border, areas with deep fading (e.g., behind a building or in a tunnel), or areas where high interference prevents a clear reception of cellular signals (Sharma & Jain, 2010).
7. *An improvement in routing reliability*: In pure Ad hoc networks, the routing path is often vulnerable to node mobility and node failure, while in Multihop Relay the routing decisions can be controlled by intelligent BSs (Sharma et al., 2010).

2.3.4 Drawbacks of Multihop Relay

The advantages of Multihop Relay are also accompanied by several disadvantages that limit the use of the Multihop Relay technique. The main disadvantages are as follows:

1. *Increased network complexity*: Multihop Relay networks are small stations combined with main stations in the network. Therefore, network complexity is increased in terms of handover, routing, and resource allocation for peer-to-peer communications compared to single hop or the MANETs. In addition, the main BS may require a careful routing mechanism for a large number of UEs, with much larger than normal MANETs to exploit the benefits of relaying (Liu, Wan, & Jia, 2006).
2. *Increased interference*: The use of Multihop Relay will certainly generate extra intra- and intercell interference, which may potentially cause system performance to deteriorate.
3. *Delay*: At the multihop transmissions, packets are buffered at the relays before being forwarded to their destination. As a result, end-to-end delays are higher compared to single-hop transmissions, especially when congestion occurs due to high traffic loads (Wei & Gitlin, 2004).

2.4 Concept of Relay Node

Signal propagation through a wireless channel faces more constraints than a guided wire including greater additive noise, multipath, fading, cochannel interference, and adjacent channel interference (Rappaport, 1996). However, wireless transmission has become the appropriate platform to transfer information nowadays, due to the associated support, the freedom of the user from being physically connected and providing, portability and flexibility (Wyglinski, Nekovee, & Hou, 2010). The design of a reliable wireless system is difficult due to the random nature of the wireless channel and the diversity of environments in which they are likely to be deployed. Then next generation of wireless systems requires a higher voice quality as compared to current cellular mobile radio standards and has to provide higher bit rate data services with extension in coverage Dahlman et al. (2011a).

Recently, LTE-A technology has advanced and provides high capacity, low latency, and flexible bandwidth. Relaying is considered to be one of the main aspects of LTE-A which allows the system to meet the IMT-Advanced to improve 3GPP-LTE performance, in terms of coverage and throughput (Akyildiz, Gutierrez-Estevez, & Reyes, 2010; Khan, 2009).

Most wireless services in LTE provide enhancement in data service by adopting recently developed technologies such as multiple-input multiple-output (MIMO) antenna and by employing Orthogonal Frequency Division Multiplexing (OFDM) (Can, Yomo, & De Carvalho, 2007). However, in practice there are still issues such as coverage holes due to shadowing, and poor Signal to Interference plus Noise Ratio (SINR) for users that are far away from the BS (Yongchul & Sichitiu, 2011).

A solution for these problems is to add more base stations (BSs) with a small size coverage area; however, it is a very costly solution, especially when there are few users to be served (e.g., in rural areas). In addition, this solution increases interference (Abdallah Bou Saleh, Hämäläinen, Redana, & Raaf, 2012). An alternative to

adding more BSs is deploying low-cost relay nodes (Rahman & Ernstrom, 2004) which provide a cost-effective way to overcome the problem (RNs are a simplified version of a full BS requiring lower cost than BS). Moreover, RNs do not require backhaul connections, thus reducing operating costs (Huang, Wang, Chang, & Su, 2010). Relay technology specification is considered by the LTE-A to meet the next generation of wireless communication technology, where it enables efficient use of communication resources, by allowing nodes to exchange information with each other to enhance the quality of services for current communication networks (Frederiksen, 2008).

An RN is connected wirelessly to the radio access network via a BS cell and receives, amplifies, and then retransmits the downlink and uplink signals to overcome areas of poor coverage within the cell. The RN is located either at the cell edge or in some other area where the coverage is poor. For multihop relay a downlink signal is sent from the BS to the RN and then to the UEs, while an uplink signal comes back from the UEs and is transmitted via the RN and back to the BS. The relay link between the BS and the RN caters for a growing number of users (Bulakci, 2012b).

The RN helps to resist the propagation loss through a division of the path loss between source and destination into two parts, thus the path loss in the sum of two parts is less than the path loss in the whole path. This feature of the relay technique reduces the impact of path loss and can be referred to as path loss gain. Theoretically, SINR is inversely proportional to the signal propagation distance $\text{SINR} \propto 1/d^\alpha$ where d is the distance between the BS and UE and α is the path loss exponent, which typically ranges between 2 and 6 based on the type of the propagation environment (Sesia et al., 2011). When the RN is midway between the BS and UE and the transmitted power (p_t) is divided equally between the BS and the RN, the gain of received power (p_r) compared to the traditional point-to-point system, as shown in Fig. 2.5, is determined by the following equations (Chen, 2012).

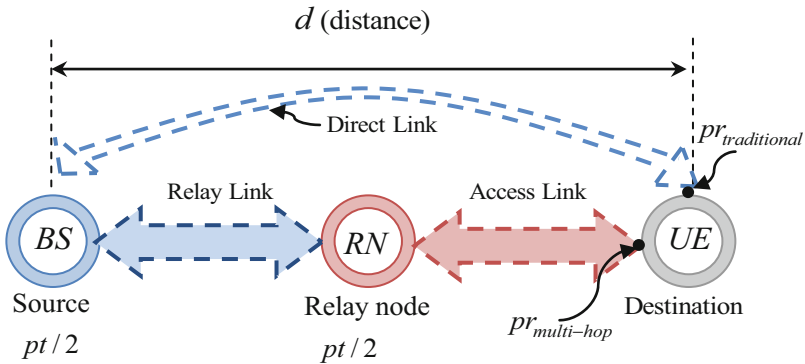


Fig. 2.5 Typical scenario of multihop relay

$$p_r = p_t \cdot d^{-\alpha} \quad (2.1)$$

$$\frac{p_{r \text{ multi-hop}}}{p_{r \text{ traditional}}} = G_p = \frac{\frac{1/2(p_t)}{(d/2)^\alpha} + \frac{1/2(p_t)}{(d/2)^\alpha}}{1(p_t)/d^\alpha} = 2^\alpha \quad (2.2)$$

$$p_{r \text{ multi-hop}} = 2^\alpha p_{r \text{ traditional}} \quad (2.3)$$

Relay offers several advantages and disadvantages for mobile communications (Sharma & Jain, 2010; Wyglinski et al., 2010), which are listed as follows:

2.4.1 Advantages

There are many advantages associated with relay node deployment within LTE cellular network and stimulated researchers to use relaying technique. The main advantages are as follows:

1. *Coverage Extension*: Coverage of the cell is affected by signal transmission loss, especially a user at the cell edge (Guo, Wang, & Chu, 2013). However, a relay node can effectively expand the network coverage by signal amplification.
2. *Quality of Service (QoS)*: The Relay system is effective in resolving the effects of channel fading by cooperative diversity and effectively enhancing transmission robustness by guaranteeing the transmission between the BS and users (Huang et al., 2010).
3. *Capacity Enhancements*: For cellular networks which have a wide coverage area, high performance gains can be achieved using relay by dividing the path loss into two or more hops. These gains provide a higher capacity and transmission rate (Chen, 2012; Wyglinski et al., 2010).

2.4.2 Disadvantages

The advantages of relay in cellular networks are that they rely on location for the RN in the cell (Khakurel, Mehta, & Karandikar, 2012; Meko, 2012).

1. *Increased Interference*: Using relays introduces extra intra- and intercell interference, which potentially causes the system performance to deteriorate (Zhao, Fang, Huang, & Fang, 2014).
2. *Network Complexity*: Relays increase network complexity in terms of handover, overlapping, and resource allocation for peer-to-peer communications, as compared to single hop.

A new type of relay called Moving Relay may be installed in vehicle (Sui, Papadogiannis, & Svensson, 2012a). MR improves throughput for passengers in

urban areas where there is a high shadowing effect due to buildings, as well as in rural areas, where there is a weak signal from BSs, especially at the cell boundaries (Bulakci, 2012a; Sui et al., 2012a). The disadvantage of MR is that transmission continues irrespective of the high received signal strength from BS at users (Bulakci, 2012a). This work proposes a method to minimize transmission power from the MR.

2.5 Relays Classification

Relays can be classified according to the signal processing techniques employed and the functionality of relay in the Amplify-and-Forward (AF) relay and the Decode-and-Forward (DF) relay.

2.5.1 Amplify-and-Forward (AF)

The basic function of the AF relay is the amplification of the received signal from the source and a retransmission of the same signal to the destination without processing. The AF relay not only amplifies the desired signal but also amplifies interference and noise which deteriorates the overall SINR level as well as limits the system throughput.

The AF relay introduces low delay due to filtering, processing, and feeder links used in its application which deteriorate the signal coming to the user terminal. However, there are weak points with this type such as an increase in the noise and interference level in the system, and an accumulation of erroneous data over multiple links (Bletsas, Shin, & Win, 2007; Yang, Hu, Xu, & Mao, 2009) as shown in Fig. 2.6.

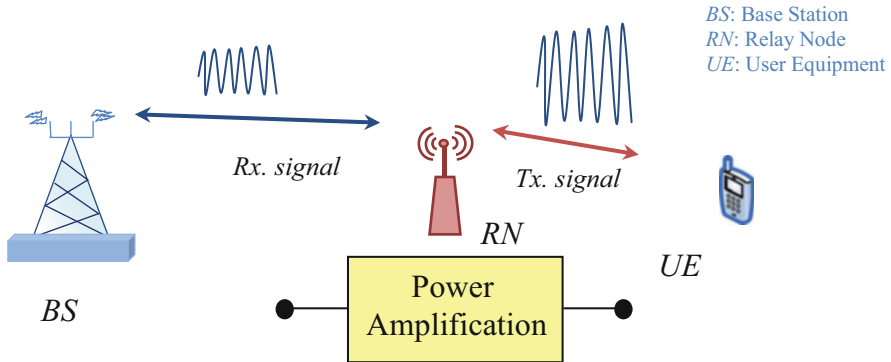


Fig. 2.6 Amplify and foreword relay

Researchers have discussed increasing the coverage in cellular networks through the use of AF relay. Jeon et al. (2002) and Rahman and Ernstrom (2004) studied the effects of installing AF relay in hotspots in Code Division Multiple Access-2000 (CDMA2000) for 3G cellular networks. The authors based the relation of the QoS system with both capacity and coverage analysis by using AF relay as repeater between the BS and users. The simulation results proved that there was improvement in downlink coverage, especially for hotspots which were located halfway between the BS and the cell border. However, the authors did not discuss increasing of the coverage for the whole cell as well as the interference and power allocation for stations has been neglected in the study.

The protocol of AF relay is lower complexity than all cooperative strategies; more studies are proposed to maximize the achievable rate for AF relay (Fei, Qinghua, Tao, & Guangxin, 2007). Laneman Tse, and Wornell (2004) proposed AF relay of low complexity protocols for cooperative diversity. In their proposed scheme, a simple AF relay for the half-duplex mode was analyzed where the sender and relay had equal power constraints. The authors improved the performance descriptions for AF relay in terms of outage statuses and associated outage probabilities. The study was based on measured robustness of the transmissions against the fading channel with a high considered SNR for the system. The performance characterizations for the scheme showed that large power savings result from the use of these protocols.

Rizinski and Kafedziski (2011) introduced a scheme to achieve maximum rates of the AF relay strategy for the Gaussian relay channel. Both full-duplex (FD) and half-duplex (HD) modes are proposed with the proposed channel. The numerical results showed that the AF strategy achieves highest rates when the relay is located midway between the transmitter and the receiver. However, these studies are based on assumption of perfect transmission at the transmitter and relay so that the channel conditions of direct and relay links are assumed equal. As a result, the results were ideal. In addition, interference and power allocation were not considered in the studies.

Fei et al. (2007) and Gurralla and Das (2012) studied the impact of relay location in terms of Sample Error Rate (SER) performance. The effect of relay placement was studied according to the SER performance analysis through a simple line topology. Transmission powers allocated for source and relay are assumed equal. Simulation results indicated that the maximum rate is achieved when AF relay is located halfway between source and destination. However, the mathematical analysis of the study was based on a single relay in the cell as well as interference between the stations is ignored, thus giving unreliable results.

Wirth, Thiele, Hausteine, Braz, and Stefanik (2010) introduced an approach to improve capacity and RSS within an indoor office scenario with different locations to install the optical Distributed Antenna System (DAS) for AF relay. Simulation results showed there was an improvement in RSS and throughput inside the building after using relay and when the antennas were installed in the four corners of the room. The drawback in the study is that increasing the self-interference among the antennas in addition to using DAS for AF relay leads to increased cost and complexity of the network by combining the fiber systems with RF devices.

2.5.2 Decode-and-Forward (DF)

DF relay fully decodes and reencodes the received signal before the retransmitting to the destination (Duong & Zepernick, 2009). This scheme provides advantages for radio resource management and is employed in interference-limited environments. However, these proceedings of the signal require some time at the RN which leads to delay and an increase in system complexity, as shown in Fig. 2.7.

Host-Madsen and Zhang (2005) introduced the approach of three-node wireless DF relay channels in a Rayleigh fading environment for the upper bounds and lower bounds on the outage capacity. The scheme showed the comparison between the direct transmission and traditional multihop protocols for a variety of wireless relay channel models. The results showed that optimal relay channel signaling can significantly outperform multihop protocols, and power allocation can yield a significant gain in wireless relay channels. Although the study addressed important issues for the optimum DF relay channel, the work is a theoretical study for DF relay channel performance apart from the interference and resources allocation if used with cellular networks. As a result, it may not provide high-precision results (Ng & Yu, 2007).

DF relays are currently being specified in 3GPP-LTE work to provide the LTE-A network requirement in order to meet the growing demand for coverage extension and capacity enhancement (Iwamura, Takahashi, & Nagata, 2010).

Abdallah Bou Saleh et al. (2012) investigated the performance of DF relay for in-band and out-band within the LTE-Advanced for different propagation scenarios in terms of both coverage extension and capacity enhancement. In order to study the effect of the relaying overhead on system performance, the study compared the in-band and out-band operation mode for DF relay. Simulation results showed that in-band relay deployment offered low to very high gains compared to out-band based on the differences of the environment. However, the spectrum sharing and power allocations have not been taken into account in the study. On the other hand, should allocate the frequency band between relays and BS when using in-band operation mode to reduce the interference between the nodes.

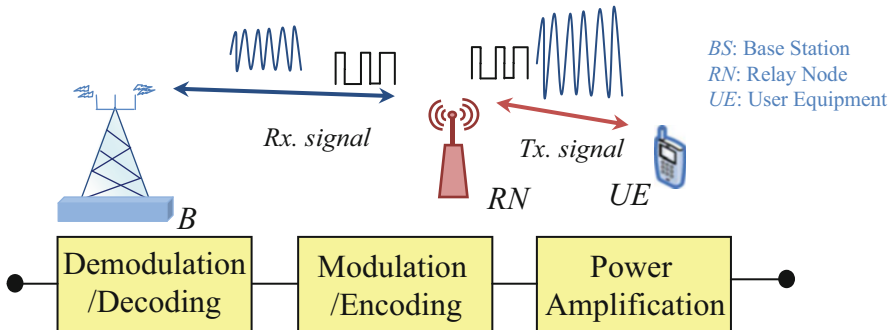


Fig. 2.7 Decode-and-forward relay

Zhao et al. (2007) analyzed the coverage extension of LTE-A cellular networks using DF relays. They showed the relationship between the number of relays and the coverage range extension based on the coverage angle and coverage range for relay with BS. The coverage is determined by moving one UE around the size of BS and then receiving the data from the nearest relay. The authors assumed the transmitted power allocation for different numbers of antenna configured in BS and RNs was equal. The simulation results indicated the coverage range extension for MIMO relaying systems provided a huge improvement as compared to direct transmission. The main drawback in their work is that the orderly distribution of relays, regardless of the optimal placement of the relay that provides the best coverage and ignores the fact that allocating the transmission power for each relay could exacerbate interference among the stations.

Rizinski and Kafedziski (2011) analyzed achievable rates and capacity bounds for the Gaussian relay channel by using DF relay within decoding and without decoding to channel. The authors investigated the effect of various channel states of the relay links (sender to relay, relay-receiver) and direct link (transmitter–receiver) on the achievable rates. The numerical results indicated the DF strategy with decoding was preferable when the relay was close to the transmitter, while the DF strategy without decoding was preferable when the relay was close to the receiver. In addition, using multihop strategies in wireless provides high bit rates compared with direct transmission. Although the study presented the analysis of DF relay channels with different strategies, the supposed transmission power for both relay and BS being equal could give unrealistic results.

The following section explains other relay categories which are considered by LTE-A networks to enhance 3GPP-LTE networks. The first is known as Relay Node (RN), while the second is called Moving Relay (MR).

2.6 Relay Node (RN)

The Relay Node (RN) and sometimes called Relay Station (RS) is a fixed small cell usually deployed in dead and crowded regions (Yongchul & Sichitiu, 2011). This means that the RNs are deployed to the poor coverage area of the cell to enhance the capacity of users in these areas (Salem et al., 2010). These areas might not necessarily be on the cell edge but in highly shadow-faded areas like behind large obstacles or inside or behind buildings. RN can also be deployed to enhance the existing capacity of certain areas, such as a busy street in a city center or an indoor office. These areas are called hot spots as shown in Fig. 2.8.

RNs are connected to the power supply unit, thus allowing them to have high access to processing capabilities and possibly higher transmission powers than regular UE, which can ease the process in finding the capacity enhancement in relaying (Meko, 2012). The location of the best spots for the RN can be found either via measurements, simulations, or demand (Khakurel et al., 2012). The RN can have fixed antenna higher from the ground level toward the BS to enhance the radio

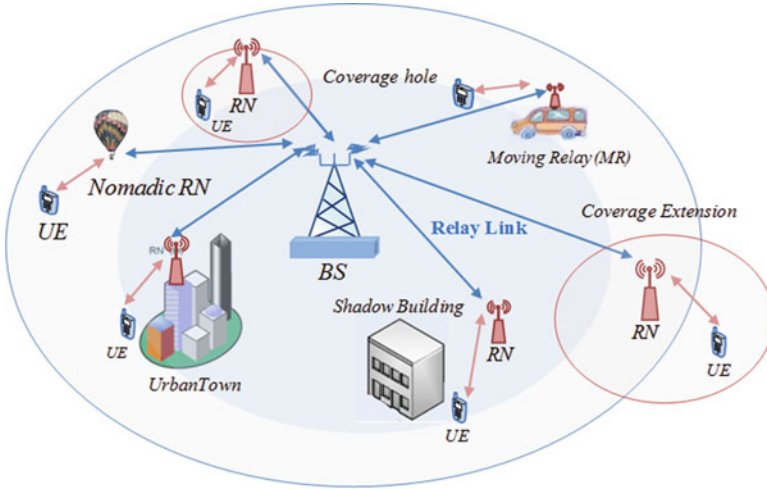


Fig. 2.8 Scenarios of relay nodes

links and increase throughput. MIMO capabilities may be also easier to implement in RNs when the antennas and radio are fixed in one place (Ding, Krikidis, Thompson, & Leung, 2011; Xu, Dong, & Lu, 2011).

In recent years, the interest in RN has increased with the rapid growth of technologies which require high data rate irrespective of the user's location such as LTE-A cellular networks in order to meet with 4G requirements.

Vidal, Marina, and Host-Madsen (2008) analyzed the DL spectral efficiency of multicellular networks so that each cell consists of BS and a certain number of deployed RS. HD mode is proposed in the study where the BS transmits the signals either direct or via RS in two hops. Based on the classical Shannon capacity expressions, the authors discussed the impact of the position of the RS which enhances DL spectral efficiency. Simulation results showed for a fixed cell radius the spectral efficiency doubled compared to direct transmissions using a single antenna at the BS, RS, and UE. The study demonstrated the enhancement in the capacity for the cell by deploying RS based on Line Of Sight (LOS) transmission. However, the authors assumed a uniform distribution of RS in the cell and did not discuss the interference and resource allocation issue, which are the main challenges facing relay deployment for cellular networks

Martins, Rodrigues, and Vieira (2012) showed a way to determine the location for RS in the coverage size of BS and also quantified the associated performance gain using different cluster size configuration. In the work, the relays were deployed within selected area. The system performance was tested with a different number of relays according to path loss variations. The simulation results indicated that there was an enhancement in coverage when the number of RS increased. Although, the increasing number of RSS in cell increases the coverage and capacity, it also exacerbates the interference between stations and adds extra cost to the network.

Moreover, determining the position for relays in the work relied on the selection of the best position for RS among predefined positions. As a result, the work did not provide the selection of optimal RN locations within overall cell dimensions. Survey for relay node in details is reviewed in Sects. 2.7 and 2.8. The following section shows relay node enhancement in cellular networks.

2.7 RN Enhance Cellular Network

Cellular systems have evolved dramatically in recent decades with the advent of new and efficient radio access technologies, and the implementation of advanced techniques to support the increments in capacity and coverage in cellular networks (Akyildiz et al., 2010). Although great efforts have been made in the research community, the traditional single hop cellular architecture fails to provide high and fair QoS across the cell area. Because the effect of propagation loss does not guarantee a fair distribution of the signal strength across the cell, it means that there are large areas which have a low signal level, especially at cell boundaries (Joshi & Karandikar, 2011).

One of the solutions to this problem is increase the number of base stations, so that station is able to cover every small area. However, increasing the number of BSs requires a high deployment cost and causes higher intercell interference. Hence, a cost-effective solution is needed to cover the required area while providing the desired high SINR to users meeting with the demand of future cellular networks (Meko, 2012).

Using multiple hops from source to destination reduces the communications distance and signal loss in each hop, and thereby gives the ability to increase the overall multihop transmission capacity compared to long-distance and single-hop communication links (Pabst et al., 2004). In addition, the use of relay nodes improves signal quality by replacing NLOS links by multiple hops with LOS propagation conditions (Muñoz, Coll-Perales, & Gozalvez, 2010). Recently, there has been increasing interest in integrating Multihop Relay functionalities into cellular wireless networks (Lin & Ho, 2007).

Dinnis and Thompson (2007) investigated the enhancement in the DL data rate and coverage in randomly positioned UEs of a cellular network using RNs. The SNR was evaluated and a channel in the model was based on both path loss and lognormal shadowing for relays deployed in the cell. The numerical results showed improvements in coverage and capacity with relay deployment so that the amount of this improvement depended on the relay transmit power and relay density in cellular networks. However, the results were based on the assumption that there was no interference between the different nodes.

Viswanathan and Mukherjee (2005) proposed a centralized DL scheduling scheme in a cellular network with a small number of relays. The scheme guaranteed the stability of the user queues for the largest set of arrival rates based on the potential gains which were achievable in a relatively idealized setting (including a

simple model for the signaling overhead). Simulation results indicated larger gains achieved in terms of throughput where the relays were placed in hot spot locations. The drawback of the scheme is the consideration that in the ideal environment there is no interference between the nodes based on complex algorithms. Besides, deploying a small number of relays irrespective of the optimal location could provide unrealistic results.

Madan et al. (2010) describe schemes for designing the heterogeneous cellular networks such as pico/femto BSs and relays in a macrocellular network in terms of cell splitting, range expansion, and resource allocations. The authors discussed the fair distribution of resources based on the concept of a concave utility function of average rate. In addition, they designed simple fast distributed mechanisms and algorithms for dynamic interference management for every subframe. Numerical results showed that there were large gains over currently used methods for cellular networks. Although this study introduced important concepts for heterogeneous cell deployment within cellular networks, the optimal locations of each small cell and appropriate number required in the cell to ensure best performance for the network was not addressed in the study.

Krishnan et al. (2012) investigated bandwidth allocation in LTE-A cellular networks employing AF relays, where they studied the jointly optimized bandwidth and power usage under constraints such as the required rate, bandwidth, and transmission power. They also showed specific results with many users in order to allocate bandwidth and power. Numerical results indicated that transmission power savings were at least 3 dB, which could be achieved by optimizing both bandwidth and power. However, this scheme did not address multiple cell and intercell interference, which is considered to be an important issue in relay deployment scenarios to achieve realistic results.

In general, it can be stated that most of the earlier studies discussed improving at cellular network performance by deploying RNs. Nevertheless, these approaches proposed the random distribution of relays over cells with channel selection according to path loss and SNR and did not discuss the effective cost and power allocations for the relays. The following section explains relay mode operation which is considered as a standard of LTE-A specifications.

2.8 RN Mode Operation in LTE-A

Two of the operational modes considered in LTE-A standard are the transparent and nontransparent mode (De Moraes et al., 2012). These modes are employed based on the purpose of usage, whether for throughput enhancement at the cell edge for users or for coverage extension. Therefore, the modes of operation at Multihop Relay for LTE-A cellular network may be classified into transparent and nontransparent.

2.8.1 Transparent Mode

In this operational mode, a UE connected to a RN is located within the coverage of the BS and the control signaling from the BS can be accessed directly to the UEs, while the data traffic is relayed via the relay node. Therefore, the control signaling and the data traffic are separated (Genc, Murphy, & Murphy, 2008; Kwon, Chang, & Copeland, 2008) as illustrated in Fig. 2.9.

BS coordinates and allocates the radio resources to UEs and RNs within the cell coverage, by guiding and distributing the control information and access requests. Transparent mode is dedicated to throughput enhancement inside buildings and congested areas where the UEs are located within the coverage of BS (Zeng & Zhu, 2008).

Recently, the rapid growth of wireless services has required high throughput to users: Thus, the multihop with transparent relay type provides a high data rate inside crowded buildings. In this regard, Genc et al. (2008) investigated system throughput enhancement which can be provided by the deployment of transparent relays in a Worldwide Interoperability for Microwave Access (WiMAX) network. Later Genc, Murphy, and Murphy (2009) studied the network capacity of IEEE 802.16j systems operating in transparent mode with varying numbers of relays and incorporated transmission power. Satish Kumar and Nagarajan (2012) proposed a new adaptive model to improve throughput and to select appropriate relay node according to the optimal relay selection procedure. The results indicated improvement in throughput by placing a transparent mode relay. However, resource allocation such as power and frequency as well as the issue of interference was not considered, meaning that the results were unreliable.

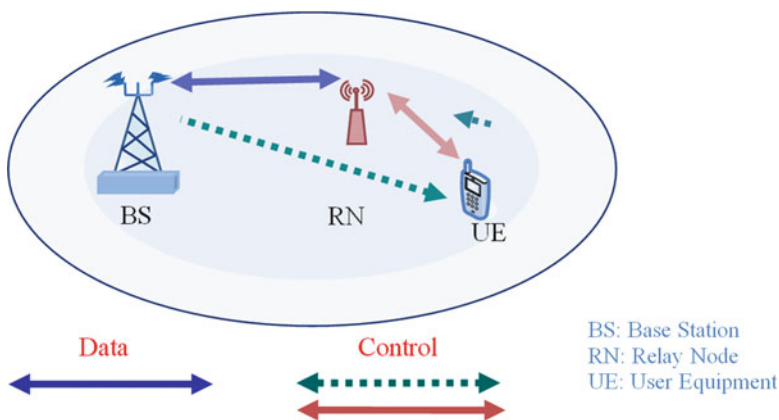


Fig. 2.9 Transparent mode

2.8.2 Nontransparent Mode

In nontransparent mode all data and control signaling transmissions between the BS and UE are relayed via RN. Therefore, the RN operates in both centralized and distributed scheduling and has ability to extend the coverage as illustrated in Fig. 2.10. Table 2.2 presents the comparison between transparent and nontransparent mode.

The comparison of network coverage and throughput (cell throughput) for multihop relay networks with single-hop system (as a baseline), transparent and nontransparent, were studied by (Zeng & Zhu, 2008). The authors paid special attention to simulate the multipath fading channel and interference among BSs or RNs in DL transmission. However, the study made an important comparison between transparent and nontransparent relay modes in terms of both scheduling distribution and the adaptive modulation scheme based on the channel variations.

Kyungmi et al. (2009) investigated bandwidth efficiency and the associated service outage performance for different nontransparent relay mode scenarios using system level simulation for a cellular Orthogonal Frequency Division

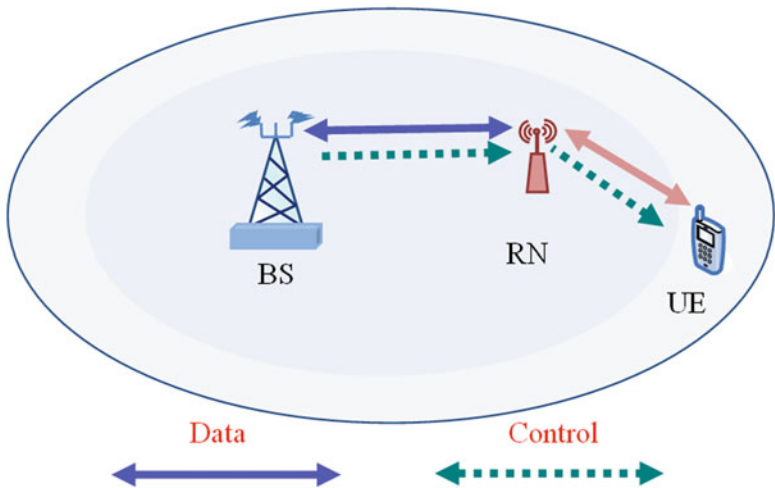


Fig. 2.10 Nontransparent mode

Table 2.2 Comparison of transparent and nontransparent mode (Akyildiz et al., 2010)

	Transparent	Nontransparent
Coverage extension	No	Yes
No. of hops	2	2 or more
RN cost	Low	High
Scheduling	Centralized scheduling only	Centralized/distributed scheduling

Multiple Access-Time Division Duplexing (OFDMA-TDD) system. The authors showed that multihop relays increase the coverage and system capacity by using a simple AF relay. In addition, the simulation results demonstrated improvements of data rate per user at the cell edges. Although the results provided enhancement in coverage, the number of relays and their placements was not discussed, whereby system performance remains unfair in terms of coverage distribution within the overall cell.

2.9 RN Planning in Cellular Network

Conventional cell planning includes positioning the BSs, determining the power level of each BS, and aggregating radio frequency among BSs antennas. The optimization objective is to minimize the total deployment cost or maximize the number of demand nodes with a given deployment budget (Amaldi, Capone, & Malucelli, 2003).

Relaying technology introduced in LTE-A provides high link quality and achieves high data rates for the users in 3GPP-LTE cellular networks. In addition, RN deployment cost is lower than BS where RNs are smaller in size, there have lower power outputs, and also there is the possibility to install it on preexisting lamp posts (De Moraes et al., 2012; Doppler et al., 2007; Joshi & Karandikar, 2011; Khakurel et al., 2012).

Guo et al. (2010) investigated relay deployment to assist disaster area networks for first responders as user nodes. They studied the relay management problem of finding a minimum number of RNs and their dynamic locations to cover all the user nodes within the disaster area. The authors proposed an algorithm to control the amount of relay deployment with a transmission range of user nodes in a disaster area. The simulation results indicated that the number of relay increases as the transmission range of user nodes decreases. However, the approach provides for RN deployment within specific areas known as disaster areas and did not address the frequency reuse issue and power allocation for each RNs. Moreover, the optimal location of the relay within the BS was not discussed. Therefore, the study is appropriated for special cases when increased traffic is suddenly required in special area.

Abdallah Bou Abdallah Bou Saleh et al. (2012) and Bulakci, Redana, Raaf, and Hamalainen (2011) studied relay site planning by improving the quality of the relay link. The impact of site planning in terms of two proposed techniques such as cell selection and location selection on the system and end-to-end rate has been investigated in order to enhance overall system performance. The study was based on the channel quality of relay links to deploy RNs within the cell size. Results demonstrated significant improvements in bit rate which justify the need for relay site planning in relay enhanced networks. The study highlighted limitations of the relay link and showed the potential for significant extra gain if these limitations are relaxed. However, the results are incomplete for RN planning with cellular networks

because the optimal location for the RN and the number of RNs was not discussed in order to avoid interference and provide more realistic and authentic results.

The relay deployment concept and overview of many parameters such as propagation and physical layer challenges, interference effects on the relay planning within cellular network were investigated in detail by Damjanovic et al. (2012) and Pabst et al. (2004)

In order to ensure the optimization for relay deployment in the cell, it is necessary to specify the number of relays and optimal locations for relays which provide higher and fair QoS that mitigate interference problems (Genc, 2010). The following subsections present some of these aspects.

2.9.1 RN Location

With the increasing number of cellular subscribers, cellular systems are facing difficulties in providing satisfactory SINR level to users especially at the cell boundaries. One of many solutions to support the ever increasing number of subscribers per cell is to decrease the cell radius. However, this requires more base stations per area, thus increasing cost and causing higher intercell interference between stations (Joshi & Karandikar, 2011).

An encouraging solution is employed in LTE-A cellular systems by deploying low-cost RNs in each cell. The deployment of RNs has many advantages: capacity enhancement, coverage extension, and cost reduction (Khakurel et al., 2012; Meko, 2012). However, these benefits are based on the location of RNs in the cell. Therefore, it is very important to study the impact of optimal location for the RN in terms of link reliability and system capacity (Huang et al., 2010). When RN is deployed far away from the BS, the users at the cell boundary can receive a stronger signal to improve communication reliability, but the longer hop distance between the BS and RN leads to degradation in relay link capacity and increases the interference level among cells. On the other hand, placing the RN close to the BS causes more outage for users at the cell boundary and does not achieve the required objectives. Determining the appropriate location of relay provides the trade-off between communication reliability and system capacity (Khakurel et al., 2012; Yongchul & Sichitiu, 2011).

To date, only a few researchers have addressed the issue of optimal RN location in cellular network (Joshi & Karandikar, 2011; Lin & Ho, 2007). The cooperative relaying system with distributed Alamouti code is investigated by Lin et al. (2009), AF relay, DF relay, or hybrid AF/DF relay protocols were used in this scheme, and the performance of the system was based on optimal relay locations for different protocols and modulation schemes. Herein the relay location varied with selected modulation schemes and the effect of channel environment. Simulation results showed that the best performance for AF protocol was achieved when the relay location was 0.55 % of the distance between the source and destination with a Binary Phase-Shift Keying (BPSK), Quadrature-Phase-Shift Keying (QPSK), and

16-Quadrature-Amplitude Modulation (16-QAM) modulation scheme. However, the relay location varied from 0.53 to 0.6 % of the distance between the source and the destination with a selected modulation scheme by DF and AF/DF relay protocols. Although this work addressed the relay location for different modulation schemes and showed that the relay location depends on selected modulation schemes, the work did not study power distribution, interference, or the number of relays that provided integrated and realistic results.

B. Lin and Ho (2007) introduced network dimensioning and location planning (DLP) in a multihop wireless network model, by identifying a model of dimensioning and location planning of RSS and integrating the multilevel of cooperative relaying in the network design. In the model, the authors considered RS placement, relay allocation, and relay sequence design together in a unified framework. Two algorithms, the single and multihop system, were proposed in the model. Simulation results demonstrated significant cost reduction and achievable rate improvement due to the multilevel cooperative relaying rather than the single hop network. In the study, the authors discussed the cost effectiveness of multihop networks which employed relays and compared them with traditional planning. It is worth mentioning here that the works were based on complex algorithms to select the relay location as well as the optimal number of relays per cell related with interference mitigation which was not addressed in the study.

Esseling, Walke, and Pabst (2004)) and Pabst et al. (2005) showed that the analysis related to the traffic performance for a wireless broadband system was based on a fixed relay acting as wireless bridges. The authors discussed three typical resource allocation schemes for relaying networks including relaying in time domain, frequency domain, and hybrid time/frequency domain schemes. The analysis focused on the end-to-end performance in terms of throughput and delay. In addition, the scheme discussed both densely populated urban areas and wide-area environments to provide a coverage area within the 3GPP cellular network. Simulation results showed that an enhancement in capacity and broadband radio coverage in cellular wireless broadband systems through relay. The authors established that a suitable concept of fixed relay contributed substantially to providing high capacity and coverage through a relay which was deployed in next-generation cellular wireless broadband systems. However, the relay placement problem that provides maximum gains at the cell edges was not debated. In addition, the number of relays per cell which is related to the total cost and interference was not studied in these works.

Laneman et al. (2004) developed and analyzed low-complexity cooperative diversity protocols to combat fading and multipath propagation in wireless networks. They employed strategies of cooperating radios including relay such as AF relay and DF relay schemes and selected relaying schemes based on SNR. The relay selection scheme adapts based on channel measurements and outage probabilities which measure the robustness of the transmissions to fading. It should be noted that the study discussed important issues related to relay strategies in terms of downlink signal analysis and spectral efficiency based on complex algorithms.

Sadek, Han, and Liu (2010) developed the hybrid version of the incremental and selection relaying protocols proposed by Laneman et al. (2004). They addressed the relay-assignment problem for coverage extension based on the knowledge of the channel statistics governed by the user distribution in the cell. The authors analyzed the performance of two schemes: a distributed nearest neighbor relay assignment in which users can act as relays and an infrastructure-based relay-assignment protocol in which relays are deployed in the network to help the users to forward their data. The outage probabilities of the two schemes were derived. The optimal relay position was characterized to minimize the outage probability for the user. Simulation results showed significant gains when applying the proposed algorithm over direct transmission in terms of coverage area and spectral efficiency. The weakness in the work is that the number of relays determined previously with six RNs deployed in the cell and the assumption that the transmission power is equal for both BS and relay, which leads to overlapping among stations; especially interference has been neglected.

Dong, Zhang, Song, Teng, and Man (2009) and Wang et al. (2008) investigated the impact of relay location on the system capacity. Received data from the relay is determined according to both Received Signal Strength (RSS) and achieved throughput. The results showed the achievable throughput at UE via RS can be higher than that in the direct transmission at some UE locations. Based on the assumptions of Wang et al. (2010) proposed the optimal location of relay aims to maximize system capacity. Two relay selection rules: signal strength-oriented and throughput-oriented selections were adopted to determine whether multihop transmission would be used. Simulation results showed there was an improvement in throughput when increasing the number of relays based on the assumption that relay placement is fixed. However, the authors proposed K^{th} . RS regularly deployed around the BS and did not discuss the relation between number of relays per cell and the power allocated for relay which exacerbates interference and performance deterioration.

Finally, Meko (2012) studied the optimal relay placement for DF relay in cellular networks. The study based on evaluation of BS-UE, BS-RN, and RN-UE links through both signal strength and SNR as shown in Fig. 2.11.

The author considered a cellular system with six RNs that were placed symmetrically around the BS and evaluated the optimal relay placement based on the reference level of outage probability given by Joshi and Karandikar (2011) and Khakurel et al. (2012). Simulation results showed optimal relay placement schemes significantly reduced the outage of the cellular system and provided better QoS for users at cell boundaries. Although the technique showed substantial gains in terms of capacity, it should be remembered that the number of relays is specific and the relays are distributed regularly around BS irrespective of power allocated for each relay which does not provide the desired objectives of achieving the fair distribution of capacity at the cell edge. The work did not discuss intracell interference among the stations, which is an important issue in the relay deployment.

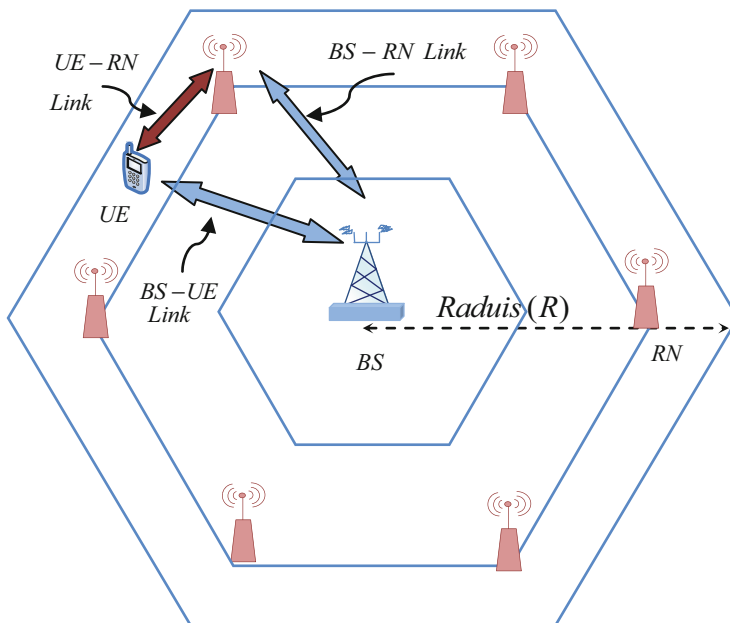


Fig. 2.11 Layout of RN enhanced cellular system and illustrating the coverage of UE-BS, RN-BS, and UE-RN links (Meko, 2012)

2.9.2 Relay Links

Relaying improves the coverage of cellular networks in LTE-A by providing high data rate coverage in the cell edge region, reducing the deployment costs of cellular networks, and improving the effectiveness of cell throughput and capacity. In order to minimize the cost of installation, the fixed microwave link (i.e., LOS microwave systems), the relay node was designed as wireless and connected with both BS via relay link and UEs via access link. Relay link provides flexible, cost efficient, and less time to deploy RNs in the cell (Han & Wang, 2010; Sadek et al., 2010). In LTE-A, the relay link is designed to operate with an in-band or out-band transmission mode. In the in-band mode the relay link operates in the same frequency band as the access and direct links (De Moraes et al., 2012) as shown in Fig. 2.12.

However, the in-band mode causes interference between the access and relay links when the relay link shares the same spectrum of access link. In order to avoid the interference of two links, additional mechanisms are required such as separation in the time domain between the relay and access links, so that the two links cannot operate simultaneously (Dahlman et al., 2011a). In out-band relaying mode, the relay link operates on a different frequency band than the rest of the cellular UEs. As a result, the interference between the relay and access links can be avoided and the necessary isolation be obtained in the frequency domain (Dahlman et al.,

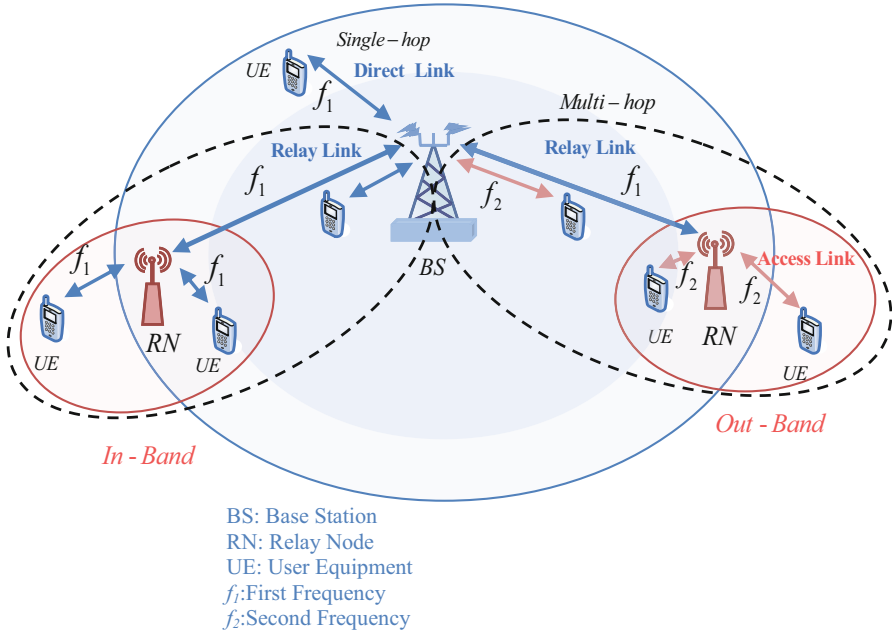


Fig. 2.12 In-band and out-band relay mode for LTE-A multihop network

2011b). However, this type requires separate RF filter and antennas which are expensive compared to in-band mode as shown in Fig. 2.12.

The long distance between the relay location and BS improves the coverage at cell boundaries but degrades the relay link capacity, thereby increasing the probability of outage. On the other hand, the approximating of the relay location does not achieve the desired goals for RN deployment. Therefore, any improvements in link quality ensure the capacity and required throughput for the growing number of users at the cell boundaries. So far there has been little research focusing on improving relay link throughput or introducing effective solutions to solve the problem (Kitayama, Hasegawa, Taniguchi, & Nakano, 2013).

Coletti, Mogensen, & Imer, 2011a, 2011b introduced a study, which evaluated and compared the potential of LTE relay and micro deployment in a realistic metropolitan scenario. The authors proposed an algorithm of both modes (In-Band/Out-band) in relaying which combines both network coverage and a realistic spatial of user density information. The results indicated that for the downlink, the network improved in terms of coverage and reduced the user outage service values for users at in-band operation mode, whereas at out-band the capacity improved with a lower frequency carrier at the BS. However, these results were based on postulating a high quality at the relay link and the authors did not

mention how to improve relay link quality which enables blocked users to access the network, especially at the cell edge.

A comparison of two operations, in-band and out-band modes in LTE-A networks was introduced by Gora and Redana (2011). Resource allocation schemes are proposed in the study to evaluate the system with dual-carrier networks taking advantage of both in-band and out-band relay operation modes. Simulation results showed few improvements at out-band compared to in-band, while in the case of combination of in-band and out-band operation modes the system gave the highest performance and flexibility. The weakness in the study is that the proposed multimode operation required radio spectrum allocation to each mode, thereby reducing bandwidth transmission for the network.

Most modern studies have focused on in-band mode as the main solution in LTE-A specification because this solution requires only one carrier frequency at the RN. Moreover, this is cheaper than out-band mode (Gora & Redana, 2011). RN performance is restricted by the capacity of the relay link, which carries information generated by users attached to the RN and forwards it to the BS via relay link. Although the relay link seems to be a bottleneck especially in terms of throughput, enhancing the relay link capacity yields significant gains (Bulakci, 2012b; Van Den Berg, Mandjes, & Roijers, 2006; Zhang, Hong, & Xue, 2012).

Han and Wang (2010) studied the in-band mode AF relay type of transparent relay in LTE-A networks. They analyzed the performance of the uplink transmission with realistic modeling of relay link and then scheduled the limitation of the access link. The relay link and access link are time multiplexed, which means the transmission of the relay on relay link, while the reception on the access link. By using a system-level simulator, the results indicated an improvement in relay link efficiency after load balancing between the access and relay link. The authors based the study on the scheduler algorithm of subframes transmission for both relay and access links, which was constrained by relay buffer size and transmission. The work discussed improving the relay link through scheduling the frames for the relay and access link to exploit the maximum capacity for relay link. However, the algorithm could increase the time delay through the buffering in relay and did not provide a radical and effective solution to limited capacity for the relay link.

Finally, Bulakci (2012b) gave an overview of multihop relaying concepts and discussed the relay deployment within the LTE-A. He studied the impact of relay links on multihop systems, while Mumey et al. (2011) focused on topology control for efficient communications in wireless relay networks through the use of smart antennas to enhance relay performance. They presented a new algorithm to solve the beam selection problem through a simple and fast greedy algorithm. Simulation results show that the proposed algorithms provide close-to-optimal performance. The authors focused on improving the access link through beam selection algorithm. However, they did not discuss the relay link responsible for passing the users' information to the BS via the relay node.

2.10 Moving Relay (MR)

MR has similar functionality with RN but with the difference that it provides communication to users inside the vehicle (train or bus) during their journey. MR is a new innovation to improve the throughput for vehicular users in LTE-A networks (Bulakci, 2012a). MR can be deployed flexibly to increase the throughput in wireless services for passengers on public transportations within rural areas' where RNs are not available or not economically justifiable or have a weak received signal from BSs (Bulakci, 2012a).

MR can be installed on vehicles and connected wirelessly with the BS via relay link and with passengers via access links. As a result, MR and passengers are called group mobility (Pabst et al., 2004; Peters & Heath, 2009) as shown in Fig. 2.13. In fact, group mobility can be provided anywhere a large number of users are moving together while using cellular network services. MR provides reliable services, with the assumption that the relay link has a much better channel than regular UEs (Ding et al., 2011) because the MR antennas are high and therefore have fewer obstacles in the path of radio waves in comparison to regular UE antennas (Jing & Hassibi, 2005). Moving relays are connected to an external power source via a battery charger or have their own power supply unit, which allows them to have a relatively high access to processing capabilities and to higher transmission powers. Using MRs in cellular systems is still under discussion in the 3GPP-LTE (Sui et al., 2012b). Studies have shown that through deployment of symmetrical and cooperative relays on top of trains, the QoS of a UE inside a vehicle can be significantly improved (Farber, 2011; Van Phan, Horneman, Yu, & Vihriala, 2010).

The most promising MR such as relay on trains has a high passenger capacity. Many of these passengers use mobile services and some even use mobile broadband. Each car in the train can be installed with its individual MR, which can be

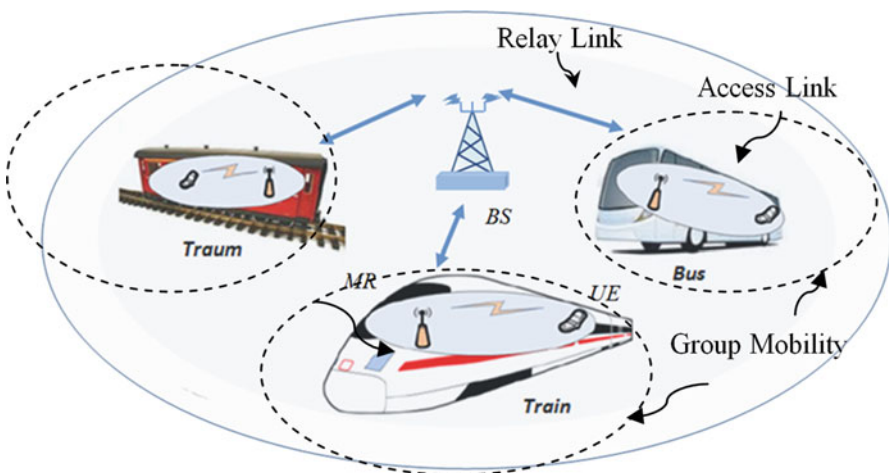


Fig. 2.13 Scenarios of moving relay (MR) installed on public transportations

interconnected. The number of MRs is based on the relay capability infrastructure (Bulakci, 2012a).

Previous studies have shown that vehicle penetration loss (VPL) can be high for UE inside a minibus at a frequency of 2.4 GHz (Tanghe, Joseph, Verloock, & Martens, 2008). The VPLs worsen with higher frequency, e.g., in LTE-A networks frequency band, for some well isolated vehicles. Therefore, the deployment of MRs on top of vehicles is very beneficial as it can eliminate VPL (Sui et al., 2012a). Most studies have been focused on fixed relay problems and handover strategies for moving relay. However, few studies have been concerned with the enhancement of throughput in public transportation users using moving relay (Van Phan et al., 2010).

Sui et al. (2012a) and Sui, Papadogiannis, Yang, and Svensson (2012b) showed the potential of moving relays, mounted on top of vehicles, to improve throughput and coverage for users in future wireless networks. They compared the performance of dual hop for moving relay assisted transmission and dual hop transmission assisted by a RN deployed on the street based on the SNR at moving relay. According to studies, the downlink of an RN system is supported with two cells: one primary cell where the outage probability performance at the vehicular UE is investigated and one interfering cell is shown in Fig. 2.14. BSs in both cells have fixed cell radius coverage, while vehicles move along a highway. When VPL is moderate to high, moving relay assisted transmission is shown to greatly outperform transmission assisted by an RN as well as direct transmission. The BS-RN and RN-UE links are denoted as relay and access links, respectively. Numerical results in the studies showed that employing moving relay on top of a public transportation vehicle can significantly enhance the QoS of the vehicular UEs. On the other hand, moving relay transmission greatly outperforms assisted RN especially, when UE moves close to cell boundaries. It is worth mentioning that these studies have introduced the important concepts of performance analysis in terms of linking the MR system with cellular networks via the RN system.

Grieger and Fettweis (2012) introduced a new solution to improve the uplink transmission for users inside vehicles by using a multiantenna in the relay: The first is outside vehicle to connect with BS, while the second is inside the vehicle to link with the users. Simulation results showed an improvement in uplink transmission for the proposed model. Often when increasing antenna diversity, there is coverage improvement. However, this requires increasing the power feeder to the antennas and ensuring the robust isolation in order to avoid self-interference between the antennas.

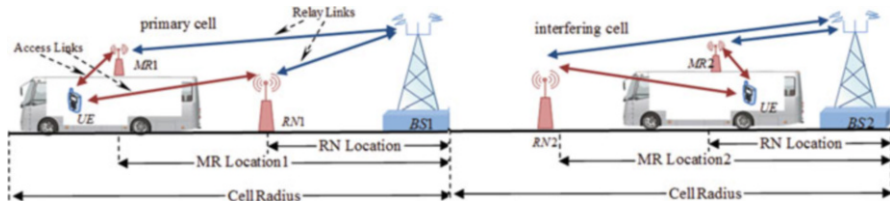


Fig. 2.14 System model of (Sui, Papadogiannis, & Svensson, 2012b)

Scott et al. (2013) discussed coverage enhancement in public transportation through deploying eight MR on board high speed train. The passengers are connected with MR via access links and MR is connected with advanced cellular networks through relay links. Simulation results showed improvements to achievable throughput of users compared to direct transmission. Although the study has improved system performance, the balance of transmission power for moving relay with received signal from the BS has not been addressed in order to minimize transmission power consumption for moving relay.

It can be seen that most studies have focused on MR analysis performances to increase users throughput inside vehicles based on channel environment and path loss. However, no author has discussed the power distribution between the relays (MR, RN) and the saving of nonrequired power for MR, especially when the vehicle passes near high resource links such as BS or RN.

Finally, there is another type of relay known as the nomadic relay node. It is a special RN case, as shown in Fig. 2.8, which is semistatic in nature. It can be deployed anywhere on the cell area such as moving relay but with the exception that while it is operational, it does not move (Frederiksen, 2008). Possible cases for using a nomadic RN could be in accident or natural disaster areas, where a sudden increase in capacity is needed. Nomadic relay nodes could also be deployed in more predictable scenarios. They might be useful during large events like sporting events, exhibitions, conferences, or demonstrations. The interval between these events might be so large that the deployment of regular BS or even RN might not be feasible (Ullah, 2012).

MR and RN are new keys introduced by LTE-A to enhance existing cellular networks and to improve the RSS within cell edge regions, crowded areas, and rural areas when BSs are inaccessible or unable to provide adequate solutions in terms of cost. In general, MR and RN represent attractive solution to meet rapid growth in future communication services (Meko, 2012; Qian Li, Qian, & Geng, 2013).

2.11 Summary

The work presented in this book has been reviewed in this chapter through the examination of the fundamentals of cooperative relaying, which consists of two basic categories; namely, Ad hoc network and multihop relay networks. The use of these networks has been elaborated with greater emphasis placed on multihop cellular networks, which can be introduced by LTE-A to enhance 3GPP-LTE cellular networks. The types of AF, DF, MR, and RN relay are studied in detail. In addition, the performance advantages of each have been highlighted and the principle of the multihop relay technique with its advantages and disadvantages has been highlighted. Earlier attempts to expand wireless network coverage with the use of multihop relay networks have also been discussed. The improvement in coverage and throughput are the main benefits of RN at LTE-A cellular networks. However, these benefits are based on location of the relay from the BS. In addition,

a literature survey of this issue has been introduced. Most current publications that have various models to harness the available opportunities for multihop relay networks motivated by improving the capacity at the cell edge have also been reviewed. By examining previous studies, it was observed that almost all of the current studies rely heavily on SNR based on classical Shannon formula irrespective of interferences among cells and resource allocation such as frequencies and powers for RNs. The opportunities, challenges, and terms related to the migration from conventional cellular networks to cellular networks that use multihop relaying have been reviewed in this chapter.

References

- Abdallah Bou Saleh, Ö. B., Hämmäläinen, J., Redana, S., & Raaf, B. (2012). Analysis of the impact of site planning on the performance of relay deployments. *IEEE Transactions on Vehicular Technology*, 61(7), 3139–3150.
- Akyildiz, I. F., Gutierrez-Estevez, D. M., & Reyes, E. C. (2010). The evolution to 4G cellular systems: LTE-advanced. *Physical Communication*, 3(4), 217–244.
- Amaldi, E., Capone, A., & Malucelli, F. (2003). Planning UMTS base station location: Optimization models with power control and algorithms. *IEEE Transactions on Wireless Communications*, 2(5), 939–952.
- Bletsas, A., Shin, H., & Win, M. Z. (2007). Outage optimality of opportunistic amplify-and-forward relaying. *IEEE Communications Letters*, 11(3), 261–263.
- Boccardi, F., Yu, K., & Alexiou, A. (2009). Relay-aided multiple antenna transmissions for wireless backhaul applications. *Bell Labs Technical Journal*, 13(4), 161–173.
- Bulakci, O. (2012a). *Multi-hop moving relays for IMT-advanced and beyond*. arXiv preprint arXiv, Department of Communications and Networking, Aalto University :1202.0207, Helsinki.
- Bulakci, O. (2012b). *On backhauling of relay enhanced networks in LTE-advanced*. arXiv preprint arXiv, Department of Communications and Networking, Aalto University: 1202.0212, Helsinki.
- Bulakci, O., Redana, S., Raaf, B., & Hamalainen, J. (2011). Impact of power control optimization on the system performance of relay based LTE-advanced heterogeneous networks. *Journal of Communications and Networks*, 13(4), 345–359.
- Can, B., Yomo, H., & De Carvalho, E. (2007). Link adaptation and selection method for OFDM based wireless relay networks. *Journal of Communications and Networks*, 9(2), 118–127.
- Chen, G. (2012). *Rate enhancement and multi-relay selection schemes for application in wireless cooperative networks*. Loughborough, England: Loughborough University.
- Chiang, M. (2005). Balancing transport and physical layers in wireless multihop networks: Jointly optimal congestion control and power control. *IEEE Journal on Selected Areas in Communications*, 23(1), 104–116.
- Coletti, C., Mogensen, P., & Irmer, R. (2011a, September). *Deployment of LTE in-band relay and micro base stations in a realistic metropolitan scenario*. Paper presented at the IEEE Vehicular Technology Conference (VTC Fall), San Francisco, CA.
- Coletti, C., Mogensen, P., & Irmer, R. (2011b, May). *Performance analysis of relays in LTE for a realistic suburban deployment scenario*. Paper presented at the IEEE 73rd Vehicular Technology Conference (VTC Spring), Budapest.
- Cover, T., & Gamal, A. E. (1979). Capacity theorems for the relay channel. *IEEE Transactions on Information Theory*, 25(5), 572–584.

- Dahlman, E., Parkvall, S., & Skold, J. (2011). *4G: LTE/LTE-advanced for mobile broadband: LTE/LTE-advanced for mobile broadband*. Chichester, England: Academic Press.
- Damjanovic, A., Montojo, J., Cho, J., Ji, H., Yang, J., & Zong, P. (2012). UE's role in LTE advanced heterogeneous networks. *IEEE Communications Magazine*, 50(2), 164–176.
- De Moraes, T. M., Nisar, M. D., Gonzalez, A. A., & Seidel, E. (2012). Resource allocation in relay enhanced LTE-advanced networks. *EURASIP Journal on Wireless Communications and Networking*, 2012(1), 364.
- Ding, Z., Krikidis, I., Thompson, J., & Leung, K. K. (2011). Physical layer network coding and precoding for the two-way relay channel in cellular systems. *IEEE Transactions on Signal Processing*, 59(2), 696–712.
- Dinnis, A., & Thompson, J. (2007, April). *The effects of including wraparound when simulating cellular wireless systems with relaying*. Paper presented at the Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65th, Dublin.
- Dong, Y., Zhang, Y., Song, M., Teng, Y., & Man, Y. (2009, September). *Optimal relay location in OFDMA based cooperative networks*. Paper presented at the WiCom'09. Proceedings of the 5th International Conference on Wireless Communications, Networking and Mobile Computing, Piscataway, NJ.
- Doppler, K., Redana, S., Schultz, K., Johansson, N., Wodczak, M., Rost, P., et al. (2007). *Assessment of relay based deployment concepts and detailed description of multi-hop capable RAN protocols as input for the concept group work [R]: IST-4-027756 WINNER II*.
- Drucker, E. H. (1988, June). *Development and application of a cellular repeater*. Paper presented at the IEEE 38th Vehicular Technology Conference, Philadelphia, PA.
- Duong, T. Q., & Zepernick, H. J. (2009). On the performance gain of hybrid decode-amplify-forward cooperative communications. *EURASIP Journal on Wireless Communications and Networking*, 2009, 12.
- Esseling, N., Walke, B. H., & Pabst, R. (2004, September). *Performance evaluation of a fixed relay concept for next generation wireless systems*. Paper presented at the 15th IEEE International Symposium on Personal Indoor and Mobile Radio Communications, PIMRC 2004, Barcelona.
- Farber, M. (2011, November). *Densification in mobile networks and the potential evolution paths of the base station*. Paper presented at the 2011 8th International Symposium on Wireless Communication Systems (ISWCS), Aachen, Germany.
- Fei, L., Qinghua, L., Tao, L., & Guangxin, Y. (2007). *Impact of relay location according to SER for amplify-and-forward cooperative communications*. Paper presented at the 2007 I.E. International Workshop on Anti-counterfeiting, Security & Identification.
- Frederiksen, F. B. (2008). Improving spectral capacity and wireless network coverage by cognitive radio technology and relay nodes in cellular systems. *Wireless Personal Communications*, 45(3), 355–368.
- Frodigh, M., Johansson, P., & LaRSSon, P. (2000). Wireless ad hoc networking-the art of networking without a network. *Ericsson Review*, 4(4), 249.
- Genc, V. (2010). *Performance analysis of transparent mode IEEE 802.16 j relay-based WiMAX systems*. University College Dublin, Dublin.
- Genc, V., Murphy, S., & Murphy, J. (2008, April). *Performance analysis of transparent relays in 802.16 j MMR networks*. Paper presented at the 2008 6th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, Wireless Networks and Workshops, Berlin.
- Genc, V., Murphy, S., & Murphy, J. (2009, April). *Analysis of transparent mode IEEE 802.16 j system performance with varying numbers of relays and associated transmit power*. Paper presented at the Wireless Communications and Networking Conference, 2009 (WCNC 2009). IEEE, Budapest.
- Gora, J., & Redana, S. (2011, September). *In-band and out-band relaying configurations for dual-carrier LTE-advanced system*. Paper presented at the 2011 I.E. 22nd International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC), Toronto, ON.

- Grieger, M., & Fettweis, G. (2012). Field trial results on uplink joint detection for moving relays. In *Paper presented at the IEEE 8th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)* (p. 2012).
- Guo, W., Huang, X., & Liu, Y. (2010). Dynamic relay deployment for disaster area wireless networks. *Wireless Communications and Mobile Computing*, 10(9), 1238–1252.
- Guo, W., Wang, S., & Chu, X. (2013). *Capacity Expression and Power Allocation for Arbitrary Modulation and Coding Rates*. Paper presented at the IEEE Wireless Communications and Networking.
- Gurralla, K. K., & Das, S. (2012). Impact of relay location on the performance of multi-relay cooperative communication. *International Journal of Computer Networks and Wireless Communications*, 2(2), 226–231.
- Han, J., & Wang, H. (2010, September). *Uplink performance evaluation of wireless self-backhauling relay in LTE-advanced*. Paper presented at the 2010 6th International Conference on Wireless Communications Networking and Mobile Computing (WiCOM), Chengdu, China.
- Host-Madsen, A., & Zhang, J. (2005). Capacity bounds and power allocation for wireless relay channels. *IEEE Transactions on Information Theory*, 51(6), 2020–2040.
- Huang, J. H., Wang, L. C., Chang, C. J., & Su, W. S. (2010). Design of optimal relay location in two-hop cellular systems. *Wireless Networks*, 16(8), 2179–2189.
- Hyttiä, E., & Virtamo, J. (2007). On traffic load distribution and load balancing in dense wireless multihop networks. *EURASIP Journal on Wireless Communications and Networking*, 2007(1), 21–21.
- Iwamura, M., Takahashi, H., & Nagata, S. (2010). Relay technology in LTE-advanced. *NTT DOCOMO Technical Journal*, 12(2), 29–36.
- Jeon, H. c., Jung, Y. s., Kwon, B., & Ihm, J. t. (2002). *Analysis on coverage and capacity in adoption of repeater systems in CDMA 2000*. 2002 I.E. International Conference Paper presented at the 2002 International Zurich Seminar on Broadband Communications, Access, Transmission & Networking, Zurich, Switzerland
- Jing, Y., & Hassibi, B. (2005, September). *Cooperative diversity in wireless relay networks with multiple-antenna nodes*. Paper presented at the International Symposium on Information Theory, 2005. ISIT 2005, Adelaide, SA.
- Joshi, G., & Karandikar, A. (2011, January). *Optimal relay placement for cellular coverage extension*. Paper presented at the 2011 National Conference on Communications (NCC), Bangalore, India.
- Khakurel, S., Mehta, M., & Karandikar, A. (2012, February). *Optimal relay placement for coverage extension in LTE-A cellular systems*. Paper presented at the 2012 National Conference on Communications (NCC), Kharagpur.
- Khan, F. (2009). *LTE for 4G Mobile Broadband Air Interface Technologies and Performance* (1st ed.). New York: Cambridge University Press.
- Kitayama, T., Hasegawa, G., Taniguchi, Y., & Nakano, H. (2013, January). *Time slot-adding algorithm for improving bottleneck link throughput in IEEE 802.16 j relay networks*. Paper presented at the 2013 International Conference on Information Networking (ICOIN), Bangkok.
- Krishnan, N., Yates, R. D., Mandayam, N. B., & Panchal, J. S. (2012). Bandwidth sharing for relaying in cellular systems. *IEEE Transactions on Wireless Communications*, 11(1), 117–129.
- Kwon, B., Chang, Y., & Copeland, J. A. (2008, November). *A network entry protocol and an OFDMA symbol allocation scheme for non-transparent relay stations in IEEE 802.16 j MMR networks*. Paper presented at the Military Communications Conference, San Diego, CA.
- Kyungmi, P., Hyun S, R., Chung G, K., Daeyoung, C., Seungho, S., Jongguk, A., et al. (2009). The performance of relay-enhanced cellular OFDMA-TDD network for mobile broadband wireless services. *EURASIP Journal on Wireless Communications and Networking*, 2009. Article No. 5.
- Laneman, J. N., Tse, D. N., & Wornell, G. W. (2004). Cooperative diversity in wireless networks: Efficient protocols and outage behavior. *IEEE Transactions on Information Theory*, 50(12), 3062–3080.

- Lee, K. H., Han, K. Y., Song, J. Y., & Cho, D. H. (2006). Capacity enhancement of uplink channel through spatial reuse in multihop cellular networks. *IEEE Communications Letters*, 10(2), 76–78.
- Li, X. J., Seet, B. C., & Chong, P. H. J. (2008). Multihop cellular networks: Technology and economics. *Computer Networks*, 52(9), 1825–1837.
- Lin, B., & Ho, P.-H. (2007). Dimensioning and location planning of broadband wireless networks under multi-level cooperative relaying. *IEEE Transactions on Wireless Communications*, 8(11), 5682–5691.
- Lin, W., Wu, G., Zhang, L., & Li, S. (2009, March). *SER performance analysis and optimal relay location of cooperative communications with distributed Alamouti code*. Paper presented at the 43rd Annual Conference on Information Sciences and Systems, 2009 (CISS 2009), Baltimore, MD.
- Liu, H., Wan, P., & Jia, X. (2006). On optimal placement of relay nodes for reliable connectivity in wireless sensor networks. *Journal of Combinatorial Optimization*, 11(2), 249–260.
- Madan, R., Borran, J., Sampath, A., Bhushan, N., Khandekar, A., & Ji, T. (2010). Cell association and interference coordination in heterogeneous LTE-A cellular networks. *IEEE Journal on Selected Areas in Communications*, 28(9), 1479–1489.
- Martins, A., Rodrigues, A., & Vieira, P. (2012, September). *Finding optimized positioning for fixed relay stations in a cooperative LTE network*. Paper presented at the 2012 15th International Symposium on Wireless Personal Multimedia Communications (WPMC), Taipei, Taiwan.
- Meko, S. F. (2012). Optimal relay placement schemes in OFDMA cellular networks. *International Journal of Engineering Research and Applications*, 2(4), 1501–1509.
- Mumey, B., Tang, J., Xing, Y., & Wolff, R. (2011, December). *Relay beam selection with directional antennas*. Paper presented at the 2011 I.E. Global Telecommunications Conference (GLOBECOM 2011), Houston, TX.
- Muñoz, J., Coll-Perales, B., & Gozalvez, J. (2010, October). *Research testbed for field testing of multi-hop cellular networks using mobile relays*. Paper presented at the 2010 I.E. 35th Conference on Local Computer Networks (LCN), Denver, CO.
- Ng, T. C. Y., & Yu, W. (2007). Joint optimization of relay strategies and resource allocations in cooperative cellular networks. *IEEE Journal on Selected Areas in Communications*, 25(2), 328–339.
- Nordio, A., Chiasserini, C., & ElBatt, T. (2012). Fair traffic relaying for two-source-one-destination wireless networks. *IEEE Wireless Communications Letters*, 1(1), 1–4.
- Pabst, R., Esseling, N., & Walke, B. H. (2005). Fixed relays for next generation wireless systems—System concept and performance evaluation. *Journal of Communications and Networks*, 7(2), 104–114.
- Pabst, R., Walke, B. H., Schultz, D. C., Herhold, P., Yanikomeroglu, H., Mukherjee, S., et al. (2004). Relay-based deployment concepts for wireless and mobile broadband radio. *IEEE Communications Magazine*, 42(9), 80–89.
- Peters, S. W., & Heath, R. W. (2009). The future of WiMAX: multihop relaying with IEEE 802.16 j. *IEEE Communications Magazine*, 47(1), 104–111.
- Prommak, C., & Wechtaison, C. (2012). Network planning and optimization for multi-hop relay placement in WiMAX networks. *Journal of Computer Science*, 8(9), 1414.
- Qian Li, R. Q. H., Qian, Y., & Geng, W. (2013). Intracell cooperation and resource allocation in a heterogeneous network with relays. *IEEE Transactions on Vehicular Technology*, 62(4), 1770–1784.
- Rahman, M., & Ernstrom, P. (2004). Repeaters for hotspot capacity in DS-CDMA networks. *IEEE Transactions on Vehicular Technology*, 53(3), 626–633.
- Rappaport, T. S. (1996). *Wireless communications: Principles and practice* (2). Upper Saddle River, NJ: Prentice Hall PTR.
- Rizinski, M., & Kafedziski, V. (2011, October). *Achievable rates of the amplify-and-forward strategy for the Gaussian relay channel*. Paper presented at the 2011 10th International Conference on Telecommunication in Modern Satellite Cable and Broadcasting Services (TELSIKS), Niš, Serbia.

- Sadek, A. K., Han, Z., & Liu, K. (2010). Distributed relay-assignment protocols for coverage expansion in cooperative wireless networks. *IEEE Transactions on Mobile Computing*, 9(4), 505–515.
- Salem, M., Adinoyi, A., Rahman, M., Yanikomeroglu, H., Falconer, D., Kim, Y.-D., et al. (2010). An overview of radio resource management in relay-enhanced OFDMA-based networks. *IEEE Communications Surveys & Tutorials*, 12(3), 422–438.
- Satish Kumar, D., & Nagarajan, N. (2012). A new adaptive model for throughput enhancement and optimal relay selection in IEEE 802.16j networks. *Wseas Transactions on Communications*, 11(2), 82–90.
- Scott, S., Leinonen, J., Pirinen, P., Vihriala, J., Van Phan, V., & Latva-aho, M. (2013, June). *A cooperative moving relay node system deployment in a high speed train*. Paper presented at the 2013 I.E. 77th Vehicular Technology Conference (VTC Spring), Dresden, Germany.
- Seo, H., Mok, I., & Lee, B. G. (2007). Determination of optimal transmission power in wireless relay networks with generalized error model. *IEEE Transactions on Wireless Communications*, 6(12), 4233–4237.
- Sesia, S., Toufik, I., & Baker, M. (2011). *LTE: The UMTS long term evolution*. Wiley Online Library.
- Sharma, V., & Jain, D. (2010). Multihop cellular networks: A review. *International Journal of Engineering Science*, 2(11), 6082–6091.
- Sharma, S., Shi, Y., Hou, Y. T., Sherali, H. D., & Kompella, S. (2010, March). *Cooperative communications in multi-hop wireless networks: Joint flow routing and relay node assignment*. Paper presented at the Infocom, 2010, Proceedings IEEE, San Diego, CA.
- Sui, Y., Papadogiannis, A., Yang, W., & Svensson, T. (2012b, December). *Performance comparison of fixed and moving relays under co-channel interference*. Paper presented at the 2012 I.E. Globecom Workshops (GC Workshops), Anaheim, CA.
- Sui, Y., Papadogiannis, A., & Svensson, T. (2012a, May). *The potential of moving relays-A performance analysis*. Paper presented at the 2012 I.E. 75th Vehicular Technology Conference (VTC Spring), Yokohama, Japan.
- Sui, Y., Papadogiannis, A., & Svensson, T. (2012a, May). *The potential of moving relays-A performance analysis*. Paper presented at the 2012 I.E. 75th Vehicular Technology Conference (VTC Spring), Yokohama.
- Tanghe, E., Joseph, W., Verloock, L., & Martens, L. (2008). Evaluation of vehicle penetration loss at wireless communication frequencies. *IEEE Transactions on Vehicular Technology*, 57(4), 2036–2041.
- Ullah, I. (2012). *Performance Analysis of LTE-Advanced Relay Node in Public Safety Communication*. Finland: Aalto University.
- Van Den Berg, H., Mandjes, M., & Roijers, F. (2006). Performance modeling of a bottleneck node in an IEEE 802.11 ad-hoc network. In *Ad-Hoc, mobile, and wireless networks* (pp. 321–336): New York: Springer.
- Van Der Meulen, E. C. (1971). Three-terminal communication channels. *Advances in Applied Probability*, 3(1), 120–154.
- Van Phan, V., Horneman, K., Yu, L., & Vihriala, J. (2010, December). *Providing enhanced cellular coverage in public transportation with smart relay systems*. Paper presented at the 2010 I.E. Vehicular Networking Conference (VNC), Jersey City, NJ.
- Vidal, J., Marina, N., & Host-Madsen, A. (2008, June). *Dimensioning cellular networks with fixed relay stations*. Paper presented at the International Conference on Telecommunications, 2008 (ICT 2008), St. Petersburg, Russia.
- Viswanathan, H., & Mukherjee, S. (2005). Performance of cellular networks with relays and centralized scheduling. *IEEE Transactions on Wireless Communications*, 4(5), 2318–2328.
- Wang, L. C., Su, W. S., Huang, J. H., Chen, A., & Chang, C. J. (2008, March–April). *Optimal relay location in multi-hop cellular systems*. Paper presented at the 2008. WCNC 2008. IEEE Wireless Communications and Networking Conference, Las Vegas, NV.

- Wang, H., Wang, J., & Xu, J. (2010). *A method and apparatus for load balance in a relay-based multi-hop wireless network*. Patent number WO 2,010,115,463, Applicant Nokia Siemens Networks OY.
- Wei, H. Y., & Gitlin, R. D. (2004). Two-hop-relay architecture for next-generation WWAN/WLAN integration. *IEEE Wireless Communications Magazine*, 11(2), 24–30.
- Williams, B., & Camp, T. (2002, March). *Comparison of broadcasting techniques for mobile ad hoc networks*. Paper presented at the 3rd ACM international symposium on Mobile ad hoc networking & computing, New York, NY.
- Wirth, T., Thiele, L., Haustein, T., Braz, O., & Stefanik, J. (2010, September). *LTE amplify and forward relaying for indoor coverage extension*. Paper presented at the 2010 I.E. 72nd Vehicular Technology Conference Fall (VTC 2010-Fall), Ottawa, ON.
- Wyglinski, A. M., Nekovee, M., & Hou, T. (2010). *Cognitive radio communications and networks: Principles and practice*. Chichester, England: Academic Press.
- Xu, W., Dong, X., & Lu, W.-S. (2011). Joint precoding optimization for multiuser multi-antenna relaying downlinks using quadratic programming. *IEEE Transactions on Communications*, 59(5), 1228–1235.
- Yang, Y., Hu, H., Xu, J., & Mao, G. (2009). Relay technologies for WiMAX and LTE-advanced mobile systems. *IEEE Communications Magazine*, 47(10), 100–105.
- Yongchul, K., & Sichitiu, M. L. (2011). Optimal placement of transparent relay stations in 802.16 j mobile multihop relay networks. *IEICE Transactions on Communications*, 94(9), 2582–2591.
- Yu, Y., Murphy, S., & Murphy, L. (2008). *Planning base station and relay station locations in IEEE 802.16 j multi-hop relay networks*. Paper presented at the 5th IEEE Consumer Communications and Networking Conference, CCNC 2008, Dublin, Ireland.
- Zeng, H., & Zhu, C. (2008, September). *System-Level modeling and performance evaluation of multi-hop 802.16 j systems*. Paper presented at the International Wireless Communications and Mobile Computing Conference, 2008. IWCMC'08, College Park, MD.
- Zhang, H., Hong, P., & Xue, K. (2012, January). *Uplink performance of LTE-based multi-hop cellular network with out-of-band relaying*. Paper presented at the 2012 I.E. Consumer Communications and Networking Conference (CCNC), Las Vegas, NV.
- Zhao, J., Hammerstroem, I., Kuhn, M., Wittneben, A., Herdin, M., & Bauch, G. (2007). *Coverage analysis for cellular systems with multiple antennas using decode-and-forward relays*. Paper presented at the Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65th.
- Zhao, Y., Fang, X., Huang, R., & Fang, Y. (2014). Joint interference coordination and load balancing for OFDMA multi-hop cellular networks. *IEEE Transactions on Mobile Computing*, 13(1), 11.
- Zheng, K., Lei, L., Wang, Y., Lin, Y., & Wang, W. (2011). Quality-of-service performance bounds in wireless multi-hop relaying networks. *IET Communications*, 5(1), 71–78.

LTE-A Cellular Networks

Multi-hop Relay for Coverage, Capacity and
Performance Enhancement

Yahya, A.

2017, XXII, 108 p. 52 illus., 47 illus. in color., Hardcover

ISBN: 978-3-319-43303-5