Chapter 2
LTE-A Relay Scenarios and Evaluation Methodology

LTE-A relay study item started in January 2009 and ended in December 2009. The study item began with discussions of potential deployment scenarios. Relay scenario identification provided valuable guidance for the discussion of evaluation methodology. Through proper channel modeling of the target scenarios, we can accurately assess the relay system performance, which is crucial to the technical choices and business judgment of each scenario. Considering that evaluation methodology is a specialized area that is not directly tied to the relay technology itself, we use a separate chapter discussing the evaluation parameters, with the focus on channel modeling.

2.1 Relay Scenarios

A number of potential deployment scenarios are of interest to major operators [1]. Although not all of them were prioritized for Release 10 relay specification, the discussion is helpful for scenario identification of future relay and related technologies.

2.1.1 Rural Area

As Fig. 2.1 shows, the rural service features wide coverage area and low user density. The low user density leads to rather uniform and thin distribution of users where ubiquitous coverage becomes crucial. So the first question of interest to the operators is how to lower the deployment cost. In this sense, relay would provide an efficient solution in reducing the number of macro eNBs. As the environment is primarily thermal noise limited, the issue of weak signal affects not only data
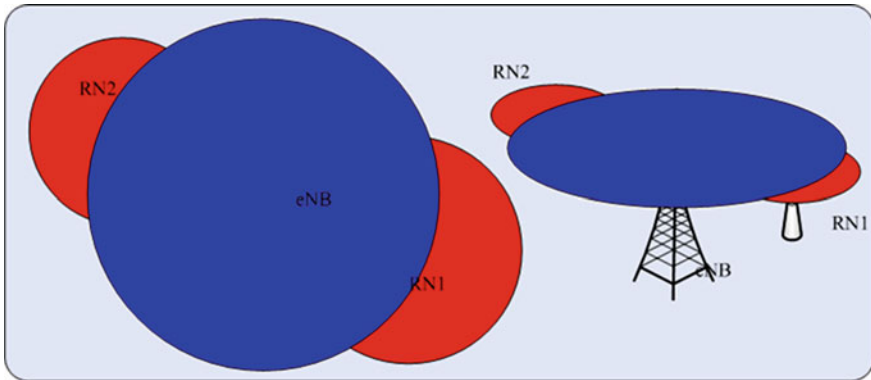
Fig. 2.1 Rural area scenario for relay

channels, but also the control channels. That is, UE within the coverage of a relay node would not be able to decode correctly the Layer 1 control signaling from eNB. Given the limited number of UEs served by each relay node (RN), the coverage, rather than the capacity improvement per RN cell would be the major concern.

The long distance between eNB and RN means low signal to noise ratio (SNR) at RN receiver. The situation prompts the need for decode and forward relay to improve the SNR at the UEs served by RNs. Amplify and forward repeater is not suitable here as the noise at RN receiver is also amplified by the repeater, i.e., no SNR improvement.

To reach out more UEs without deploying too many relay nodes, the transmit power of RN can be relatively high, and the coverage of each RN can be several kilometers. The actual coverage depends on the operating band, and the propagation environment. In general, due to the low–rise morphology, the line of sight (LOS) propagation would be dominant. NLOS is relatively rare unless the terrain is very hilly and/or covered with tall vegetations.

The high transmit power deployment favors fixed location of relay node, and the site planning is very crucial.

2.1.2 Urban Hot Spot

Urban hot spot is just opposite to rural area scenario. The user density is quite high and often non-uniformly distributed, as illustrated in Fig. 2.2. The main objective is to enhance the capacity. Therefore, the coverage of each RN is relatively small and many RNs could be deployed within a macro eNB coverage area. There could be a lot of coverage overlaps between RNs. Due to the densely deployed macro eNBs and RNs, interference scenarios become very complex and difficult to predict. HARQ is crucial to ensure reliable transmissions. The challenging interference environment makes conventional repeater unsuitable in this scenario.
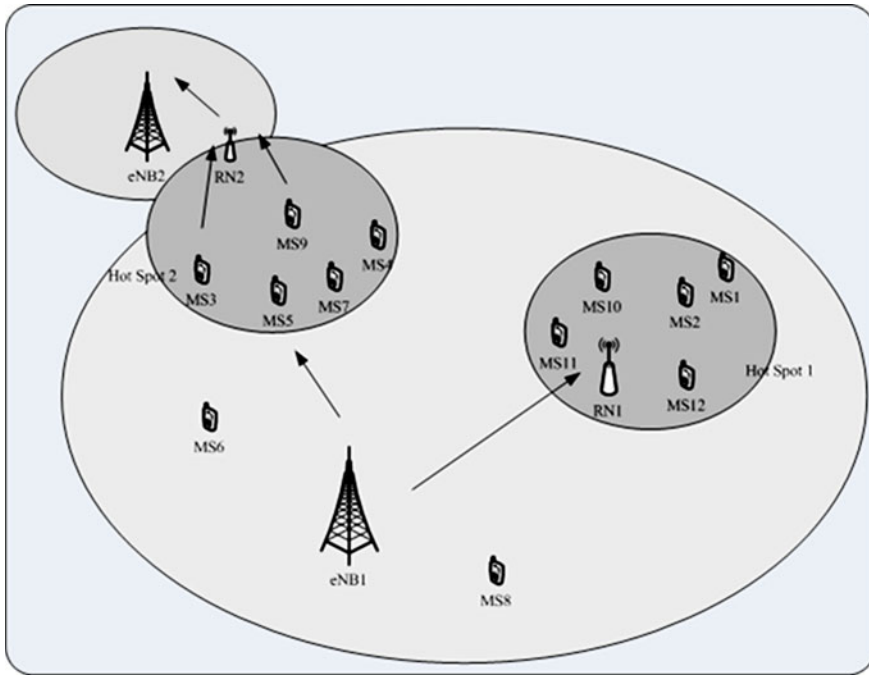
Fig. 2.2 Urban hot spot scenario for relay

Either fixed location or nomadic relay node can be deployed to alleviate the zoning regulation and renting cost for the installation. Transmit power of RN tends to be low, so that (1) the interference to neighboring cells is small; (2) RN can be made compact to allow more flexible deployment.

High–rise building in urban area results in strong non-line-of-sight (NLOS) propagation environment. Channel modeling, both for the backhaul and the access link, needs to capture dominant NLOS and the shadow fading. Note that in this scenario, the tall buildings are not yet big enough to completely block the macro eNB's signals to create coverage holes.

2.1.3 Dead Spot

In the concrete-jungle like urban terrain, quite often the height of macro eNB antennas is significantly lower than the nearby buildings, as Fig. 2.3 shows. The immerse size of surrounding high–rises can easily create dead spots in their shadows. The propagation environment may be similar to the urban hot spot, with the exception that shadow fading can have larger standard deviations. Significant building blocking creates an isolated area where signals from nearby eNBs can
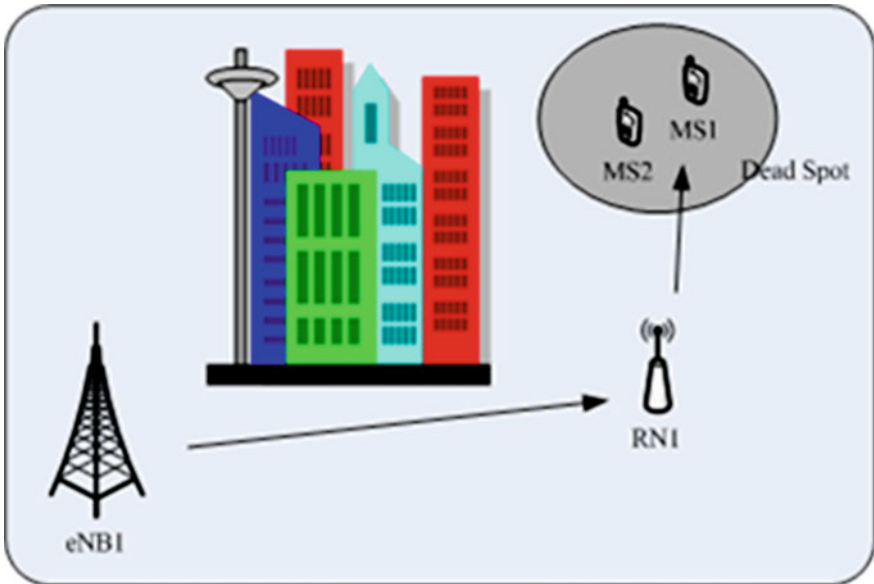
Fig. 2.3 Dead spot scenario for relay

barely reach. The interference is mainly the thermal noise where conventional repeater could be an alternative solution, in addition to the decode and forward relay.

2.1.4 Indoor Hot Spot

Relay could be used to achieve high data throughput for indoor hot spot, as Fig. 2.4 shows. This scenario is different from the urban hot spot in the sense that majority of users are indoors and stationary. The shadow fading tends to be high due to the wave reflection and refraction against the walls. The relay is supposed to provide enhanced throughputs and to serve indoor users in low coverage areas (e.g. deep indoor, or in buildings far from the donor eNB), similarly to a home eNB (femto cell). Offloading from the donor eNB may also be possible since the backhaul link is with higher quality compared to the direct link and thus requires less resource from the macro cell than the indoor UEs would. Therefore, the macro cell capacity is increased.

In the absence of wired backhaul, the indoor relay would be particularly important in the following environments:

- Far-apart houses in suburban and rural areas. Outdoor relays may not be feasible due to the extremely large number of outdoor sites needed to achieve enough good coverage.
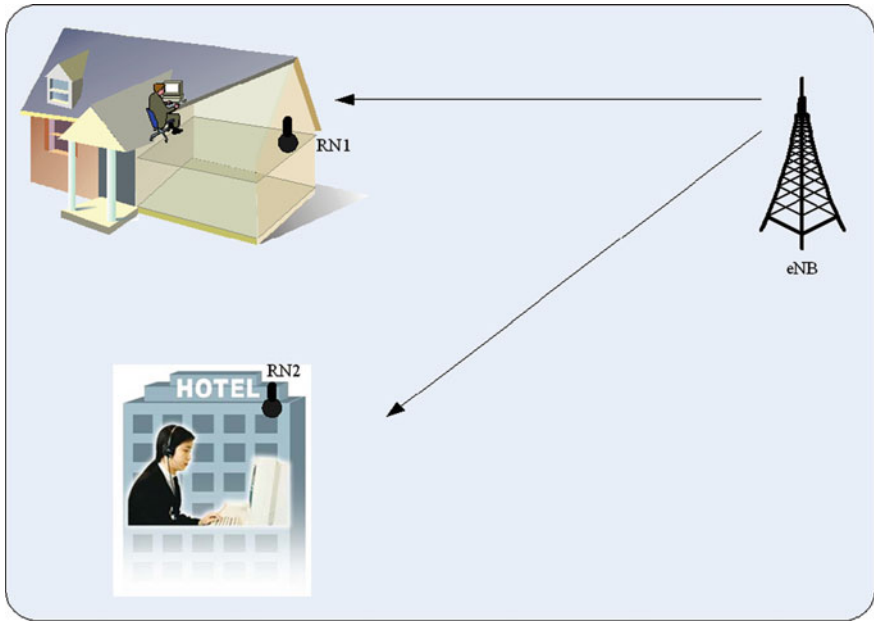
Fig. 2.4 Indoor hot spot scenario for relay

- Within high–rise buildings, users at different floors would experience vastly different channel qualities, for example, more LOS is expected at high floors, so that the signal from the serving eNB and the interference from neighboring eNBs are both strong. Thus the signal to noise and interference (SINR) would be quite poor. In this case, a directional antenna on RN pointing toward the donor eNB can effectively enhance the signal strength from the donor eNB, and suppress the interference from neighboring eNB, thus improving the SINR of the backhaul.

From the aspect of the use case, indoor relays bear a lot of similarities to femto cells. Two usages have been identified [2]:

- Residential usage: the RN serves a block of apartments or a house where the number of UEs is small, i.e., <4
- Business usage: the indoor relay serves a floor of an office building, or a shopping mall. It is expected that a large number of UEs (typically ranging from 30 to 100) would be supported by the RN

The backhaul link may suffer building penetration loss if the relay backhaul antenna is inside the building. To ensure that RN can offer better performance compared to the macro and UE connection, the RN's antenna of the backhaul link should be placed in a location that would result in good backhaul connection. A few installation methods can be considered:

1. The RN can have two distinct modules: a donor module for the backhaul connection that is placed, for example, close to a window, and a coverage module for the access link that is placed where coverage is needed, for example, in the center of a house. The two modules could be connected in a wireless way, using an outband connection (e.g. unlicensed 5 GHz band).
2. The donor antenna of RN for backhaul connection is installed above the clutter height, on the roof of a building, for instance.

It is possible that indoor RNs would serve only users belonging to the closed subscriber group (CSG), similar to femto cells.

The business case for indoor relays is as follows:

- The low transmission power and self-backhauling features allow very low-cost deployment; Self backhauling saves the need for cable installation.
- ADSL subscription may no longer be needed, nor for other cable services such as optic fibres. This provides a significant competitive edge compared to femto cells.
- The relay node is controlled by the donor eNB and operates in decode and forward mode. Its performance is expected to be much better compared to the indoor L1 repeaters that are currently installed at some homes. The network would be fully aware of any malfunctions of RNs without special Operation and Maintenance (OAM).

In this scenario, it is likely that the relay node would be self-installed as a customer premises equipment (CPE), rather than planned by the operators. Consequently, it is difficult to perform site optimization to improve the channel quality of backhaul link.

2.1.5 Group Mobility

As the penetration rate of mobile phones especially smart phones keeps increasing, users on public transportations would have more propensity to access high speed wireless services. Voice services on buses or trains are typically cacophony and the data rate is low. Battery life is shortened, in particular to overcome the penetration loss through the vehicles and the high Doppler. The battery power drain is also due to the continuous measurement carried out by on-board UEs, in both idle and active mode to accommodate the frequent handover caused by the group mobility. In such condition, UEs would experience excessive rate of broken connections since the mass number of on-board UEs frequently trigger the simultaneous handover and cause serious signaling congestions, leading to higher call-drop rate.

In such case, a relay node can be deployed on the roof-top of the moving train or bus as Fig. 2.5 shows, to serve on board passengers, and to alleviate the problem of vehicle penetration loss. The challenging link seems to be the backhaul which suffers fast fading due to the movement of the vehicle. Passengers are supposed to
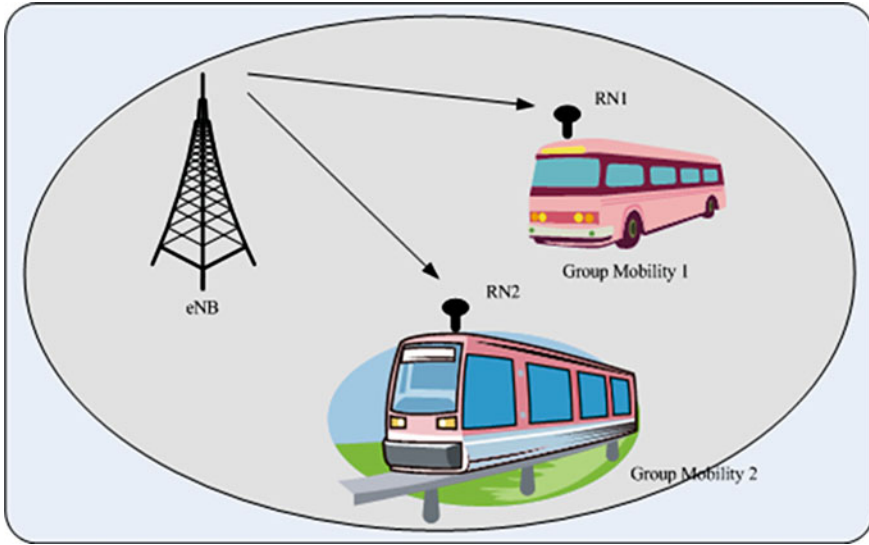
Fig. 2.5 High group mobility scenario for relay

rather stationary relative to the vehicle, so that the access link would be strong and stable.

The key usage of relay in this scenario is to "aggregate" multiple UEs' connections on a vehicle to a single access point. Obviously, it cannot be achieved by conventional repeaters that are totally transparent to on-board UEs.

Recently, relay for high speed trains has gained significant interest. Building high speed rail has become the national key projects in some countries. To provide the high speed communications for on-board passengers is also part of those national-key projects. Fast communications are crucial as passengers on high speed trains are more likely to be data-hunger professionals and would access the internet and emails when on-board. The capacity requirement for relay backhaul is expected to be very high, considering the high density of users on a train. So the demand for high data rate is high for both downlink and uplink traffic.

Backhaul channel characteristics, including pathloss, shadow fading and fast fading, would be different from those of eNB to UE connection, and some of them could be relatively benign, for example,

- Higher elevation of mobile relay antennas mounted typically on top of train roof ($\sim$5 m).
- Terrain and morphology along the rail track tend to have less scatterers, resulting in strong line of sight (LOS) propagation, except under bridges or in the tunnels.

However, the extreme high velocity poses significant challenges for the wireless backhaul transmission, even in LOS environment. A particularly difficult issue
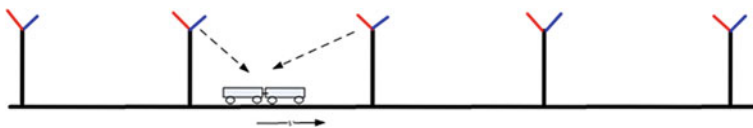
Fig. 2.6 High speed train passing a series of transmission points along the rail

Table 2.1 Parameters for high speed train scenarios

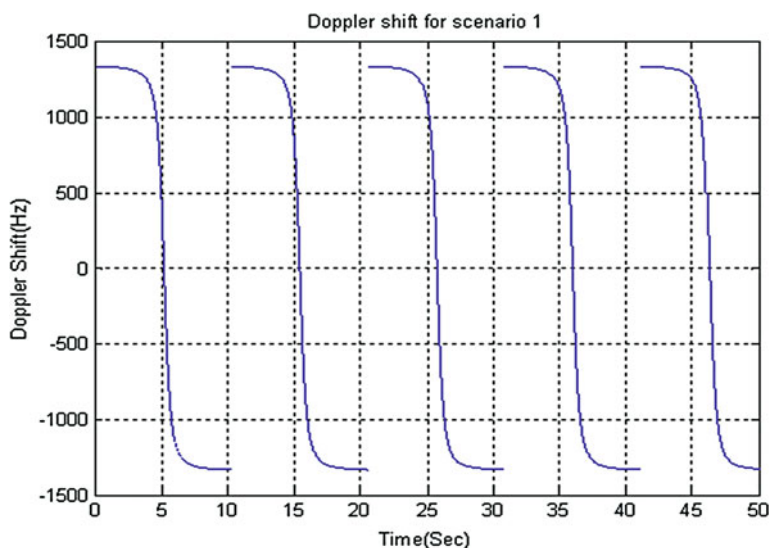| Parameter	Value	
	Scenario 1	Scenario 3
Site-to-site distance	1,000 m	300 m
Minimum track to eNB distance	50 m	2 m
Train velocity	350 km/h	300 km/h
Maximum doppler	1,340 Hz	1,150 Hz

Fig. 2.7 Doppler shift trajectory for Scenario 1 when the track to transmission point distance = 50 m

is the abrupt flip of Doppler when the train passes a transmission point as illustrated in Fig. 2.6. To show how steep the Doppler transition, let us look at an example that uses a simple LOS model [3] to describe the Doppler shift changes.

Two scenarios are considered with parameters listed in Table 2.1. In Scenario 1, the train speed is a little higher than in Scenario 2, thus leading to higher Doppler. The inter distance between adjacent transmission nodes is also longer. However, the rail track in Scenario 1 is further away from the transmit points, compared to
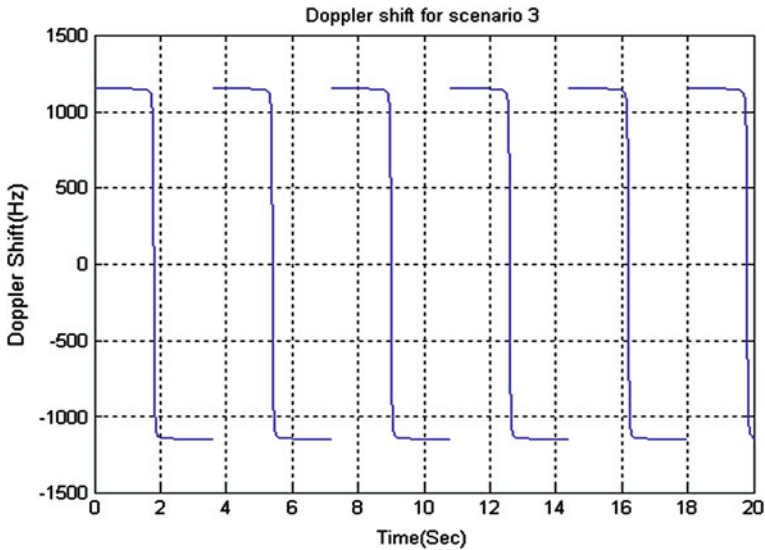
Fig. 2.8 Doppler shift trajectory for Scenario 2 when the track to transmission point distance = 2 m

Scenario 2. The changes in Doppler as a function of time are depicted in Figs. 2.7 and 2.8, respectively. It is seen that the Doppler can flip between the two extremes in a few milliseconds. Note that the transmission point switching is considered in Figs. 2.7 and 2.8.

2.1.6 Emergency or Temporary Network Deployment

The self-backhaul nature of decode and forward relay can be used to provide temporary wireless network in the case of an emergency such as natural disaster seen in Fig. 2.9, and terrorist attack, or during an event such as sport games, public gathering, outdoor concerts, etc. In either case, temporary network needs to be quickly deployed to fulfill at least the partial functionality of a full-blown network.

2.1.7 Wireless Backhaul Only

In certain rural areas, the cost of laying wired backhaul would be prohibitive, yet operators have some vacant spectrum. Therefore, relay can be deployed to act solely as the backhaul link between eNBs, without serving any UEs, as seen in Fig. 2.10. Using the vacant LTE spectrum has the benefit of tolerance against the
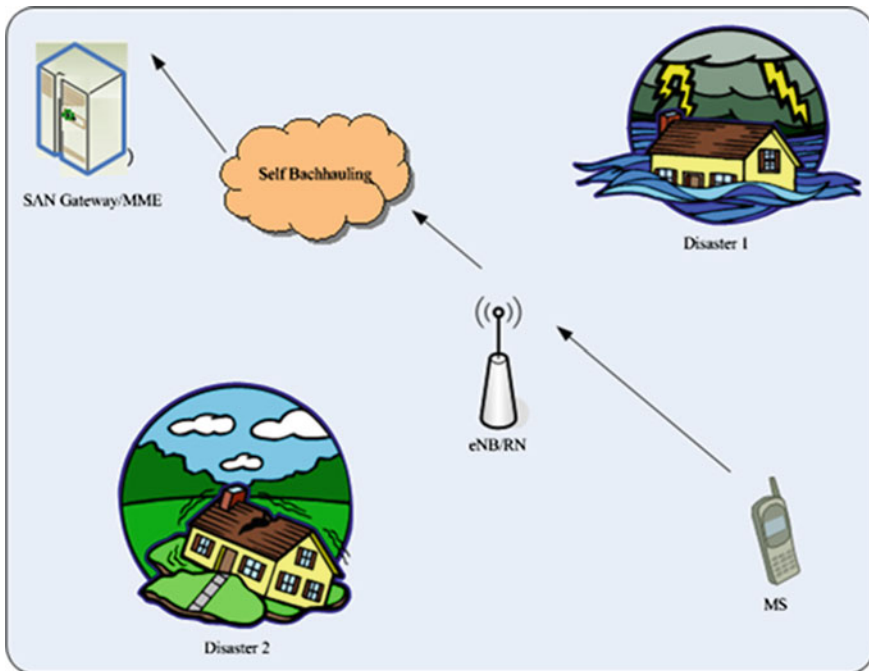
Fig. 2.9 Emergency network scenario for relay

Fig. 2.10 Relay for wireless backhaul only
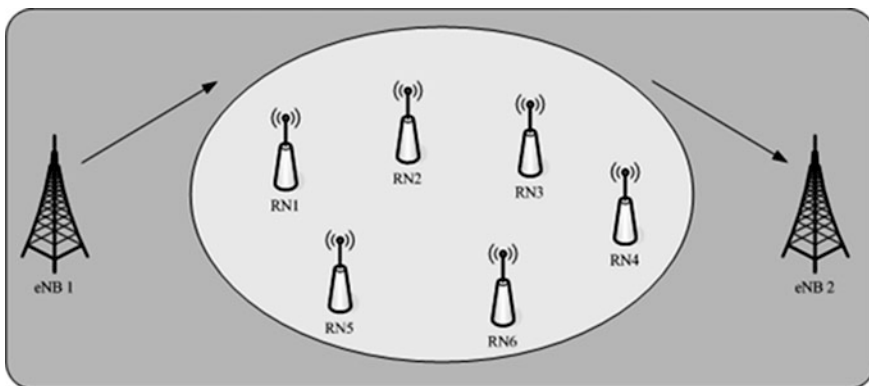
weather dependent signal attenuation, compared to using shorter wavelength microwave for point-to-point transmission. It would also save the potentially high cost of separate RF module for shorter microwave transceivers.

Relay node in this scenario is with fixed location. Hence, relay site optimization is crucial to ensure the good channel quality of the backhaul link. The transmit

power of relay node is expected to be high to guarantee high-speed transmission in the wireless backhaul.

2.2 Channel Modeling

During LTE Release 8 study, a single pathloss model was used for macro eNB to UE connection which is based on the traditional formulae for NLOS propagation environment, with minor correction to account for the contribution of LOS component. That assumption makes sense for homogeneous networks in which the site-to-site distance is constant and the topology of the entire cell grid is regular. However, using single pathloss model may not be accurate enough in heterogeneous deployment as macro eNBs and relay/pico/femto/RRH have quite different transmit powers. The antenna gains, antenna heights and down-tilts are different too. Also, cell topology becomes more diversified in HetNet, which demands more sophisticated channel models to represent the actual propagation environment.

IMT-Advanced channel model is a geometry based stochastic channel model. It was proposed for the evaluations for radio interface technologies. The framework of the primary module is based on WINNER II channel model. It is characterized by the bandwidth of 100 MHz with center frequency between 2 and 6 GHz. Five test scenarios are defined and two or three levels of randomness are introduced where the probability density functions (PDFs) are extracted from extensive measurement data.

The WINNER models are notable in the following aspects.

- The veracity of the models is justified by the extensive measurement data carried out in myriad locations, environments over long time of the observation. The statistical significance of the models is high.
- Several typical propagation environments are defined, and channel models are fine-tuned to each environment. Parameters are environment dependent.
- LOS and NLOS are separately modeled, each with its unique propagation mechanism and parameters. Mixture of two is done statistically, i.e., a UE is instantiated with either LOS or NLOS propagation at the beginning of each run or drop, with certain probability as defined in the model.

Relay is one category of low power nodes of heterogeneous networks (HetNet) which also includes remote radio head (RRH), pico node and femto node. However, their specification areas are quite different. The relay specification in RAN1 deals with wireless backhaul channel optimization, whereas the HetNet in RAN1 study primarily targets for inter-cell interference coordination (ICIC), assuming that the macro node and the low power node operate in the same carrier. For eICIC, the actual work was only started after September 2009, nine months after the relay study item had started. Simulation methodology discussion of relay, in particular for outdoor relay, was later reused for channel modeling of the pico node and RRH.

Channel modeling includes the following aspects:

- Large scale fading which is the most relevant to coverage prediction and interference analysis.
- Delay spread which captures the frequency selectivity of wideband channels
- Angle spread that reflects the spatial richness and ergodic/outage capacity of the MIMO channel.
- Cross-polarization discrimination (XPD) that is important to polarization diversity.

The last three aspects constitute small scale fading. In Release 10, new large scale fading models were proposed for relay backhaul link (eNB–RN) and access link (RN–UE). Those models were based on the real measurements reflecting the typical relay deployment. Large scale fading models were adopted for relay simulation methodology, as well as for pico/RRH in eICIC. Small scale fading models for relay backhaul and access links were proposed, however, due to the limited time, they were not agreed. Companies may use Typical Urban with fixed correlation matrix, or ITU, SCM models or their simplifications for fast fading modeling.

2.2.1 Large Scale Fading Modeling for RN–UE Connection

While WINNER models provide a rich tool for channel modeling, the original work was primarily for homogeneous deployment. WINNER indoor models can be used in some HetNet scenarios such as femto node. However, those models are not suitable for outdoor relays that serve UEs in more general application scenarios. Thus, for relay, pico and RRH, new channel models are needed. Some wireless operators such as China Mobile carried out a series of campaigns on channel measurement for low power node deployment. The vast measurement data makes sure that the derived parameters would be statistical significant. The modeling follows the same procedure as in WINNER project, e.g., LOS and NLOS are treated separately, and parameters are environment scenario dependent.

The path loss models for outdoor node generally follow the form of [4]

$$PL = A \log_{10} d[m] + B + C \log_{10}\left(\frac{f_c[GHz]}{5.0}\right)$$

where d is the distance between the transmitter and the receiver in meters. f_c is the system frequency in GHz. Parameter A, B and C are obtained by curve fitting the measured data.

Let us first look at the channel modeling for access link. Figure 2.11 shows the modeled pathloss in LOS dominant scenario where three curves are compared. The blue curve is obtained by linear fitting of the measured data to average out the perturbations due to the shadow fading. The measurement band is 2.35 GHz, and the height of the outdoor relay node antenna is 5.5 m [4]. Note that those settings are slightly different from the agreed 2.0 GHz operating band and 5 m relay height for system simulations. Some adjustments were applied to the original measured
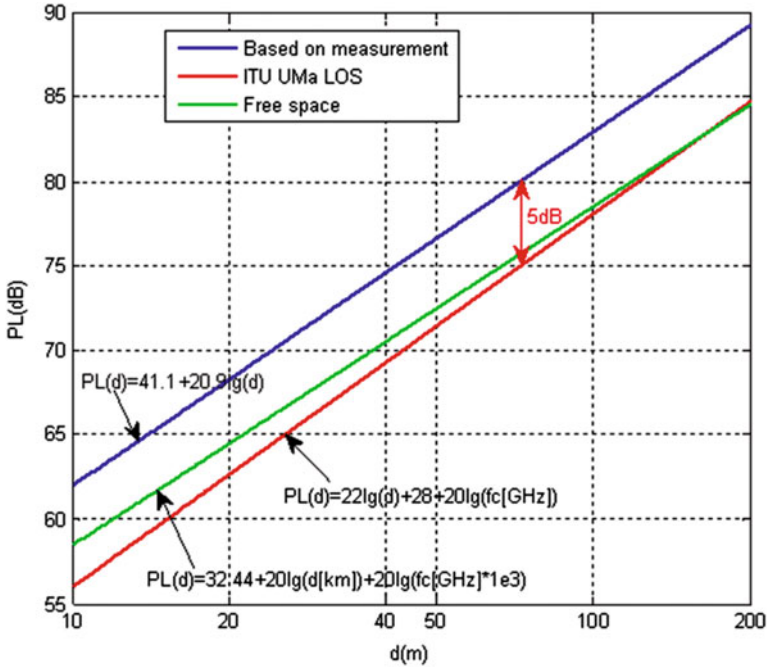
Fig. 2.11 Pathloss comparisons for outdoor relay node to UE connection in LOS dominant environment

data in order to compensate the frequency and antenna-height difference. The curve fitting is done in logarithmic domain, resulting in the following pathloss formula

$$PL(d) = 41.1 + 20.9 \log_{10} d[m] \quad \text{or} \quad PL(d) = 103.8 + 20.9 \log_{10} d[km]$$

Also plotted in Fig. 2.11 are the pathloss curves of ITU UMa LOS model and free space propagation model. The very close behaviors of these two curves indicate the rather strong free space propagation in urban macro (UMa) LOS model. The slopes of the blue curve based on the measurement and UMa LOS model are quite similar. Their difference is mainly at the vertical interception. On average, the gap is about 5 dB, which can be explained by the lower height of relay node antennas, i.e., 5.5 m, compared to 25 m typically for urban macro cells. That would bring more signal attenuation, due to the higher probability of blocking by ground vegetation, moving vehicles and other obstacles.

Measurement was also carried out for RN to UE connection under NLOS dominant environment [4]. Similar to the measurement of LOS environment, the carrier frequency is 2.35 GHz and the height of the RN antenna is 5.5 m during the measurement. Four straight curves are plotted in Fig. 2.12. The formula based on the measurement data is
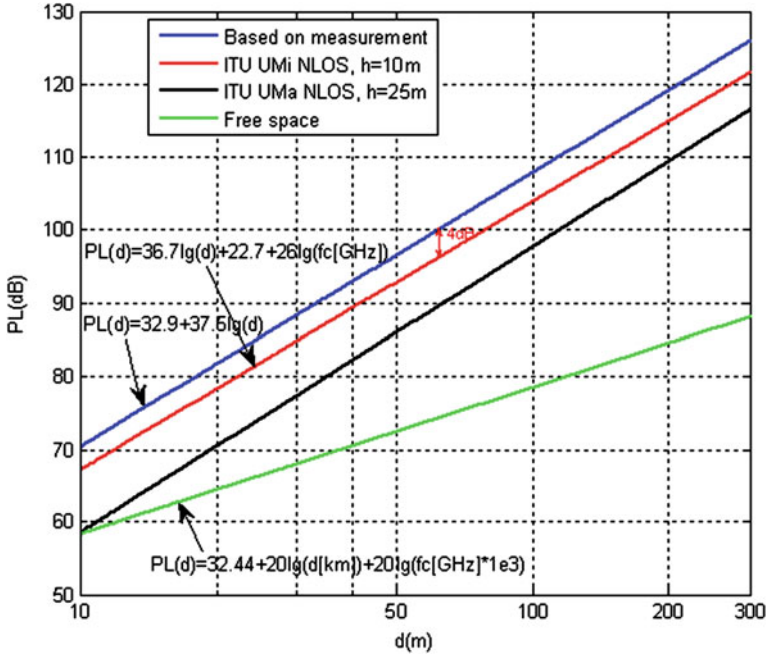
Fig. 2.12 Pathloss comparisons for outdoor relay node to UE connection in NLOS dominant environment

$$PL(d) = 32.9 + 37.5 \log_{10} d[m] \quad \text{or} \quad PL(d) = 145.4 + 37.5 \log_{10} d[km]$$

The other three curves represent the pathloss in ITU urban micro (UMi) NLOS, ITU UMa NLOS, and free space models. The slopes of NLOS curves are significantly steeper than that of the free space model which is essentially LOS. The three NLOS curves mainly differ in the vertical interceptions. The trend is similar to that in LOS, i.e., as the antenna height is reduced from 25 m in UMa, to 10 m in UMi, and further down to 5.5 m in relay node, the pathloss penalty is widened roughly from 6 to 10 dBs. All these observed from the measurement data reflect the increased probability of obstruction and scattering in the propagation path, as the antenna height is reduced.

2.2.2 LOS Probability of RN–UE Connection

We see from Figs. 2.11, 2.12 that the pathloss in LOS is significantly smaller than in NLOS. For example, at 50 m distance, the pathloss of LOS is about 77 dB, whereas the pathloss of NLOS is 97 dB. The difference is roughly 20 dB. In WINNER model, the propagation environment of a UE can be either LOS or
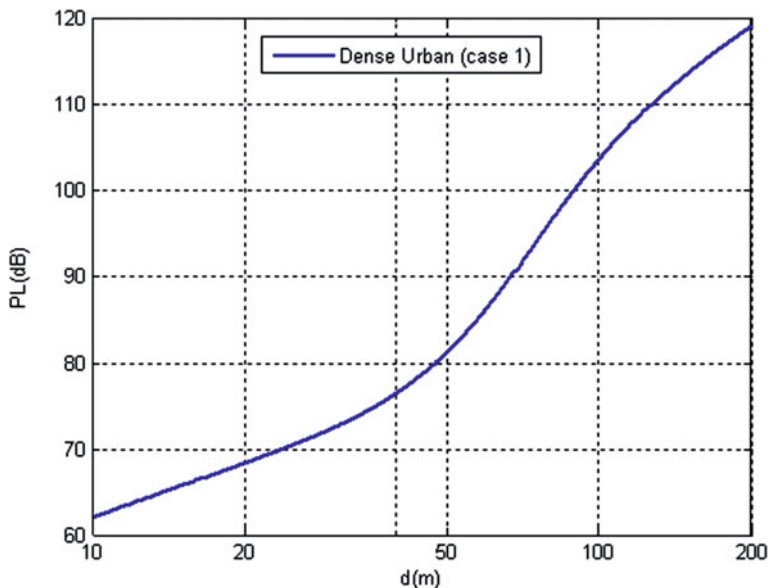
Fig. 2.13 Average pathloss vs. distance of RN–UE, considering LOS probability, Dense Urban

NLOS. The likelihood is governed by the LOS probability which is scenario and distance dependent. In general, the closer a UE is to a macro node, the more likely that the propagation between the UE and the macro is LOS. The LOS probability functions in WINNER can be useful, but they cannot directly be copied to relay scenario.

In light of this, similar formula would be used for RN to UE connection as in the case of ITU UMi, with revised parameters to reflect the smaller coverage for a typical relay node and the lower antenna height compared to ITU UMi. The modified LOS probabilities are as Dense Urban (case 1):

$$Prob(d[m]) = 0.5 - \min\left(0.5, 5\exp\left(-\frac{156}{d}\right)\right) + \min\left(0.5, 5\exp\left(\frac{d}{30}\right)\right)$$

Suburban (case 3):

$$Prob(d[m]) = 0.5 - \min\left(0.5, 3\exp\left(-\frac{300}{d}\right)\right) + \min\left(0.5, 5\exp\left(\frac{d}{95}\right)\right)$$

To get a feeling of the pathloss with LOS probability taken into consideration, we plot the

$$PL(d[m]) = Prob(d) \cdot PL_{Los}(d) + [1 - Prob(d)] \cdot PL_{NLOS}(d)$$
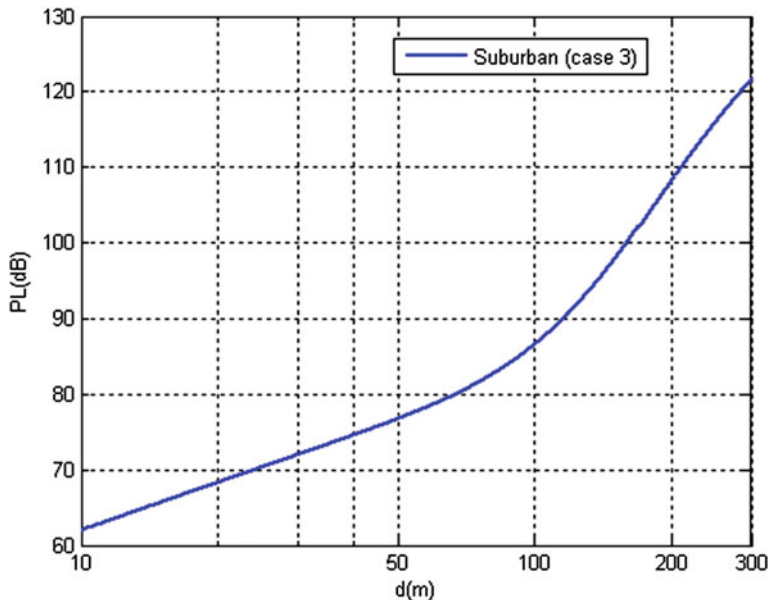
Fig. 2.14 Average pathloss vs. distance of RN–UE, considering LOS probability, Suburban

n Figs. 2.13 and 2.14 for dense urban (Case 1) and suburban (Case 3), respectively. As expected, as the UE is further away from the RN beyond 50 m (for Dense urban) and 120 m (Suburban), pathloss increases rapidly due to the environment shift from LOS to NLOS. Note that such combined pathloss is only in average sense. i.e., the expected pathloss averaged over a number of independent UE droppings. In system simulations, each UE of each drop can either be LOS, or NLOS, not both.

2.2.3 Large Scale Fading Modeling for eNB–RN Connection

We now look at the pathloss model between eNB and outdoor RN. The data were obtained from the same measurement campaign by China Mobile [5], at 2.35 GHz frequency and with 5.5 m antenna height at RN. The blue curve in Fig. 2.15 is obtained by curve fitting of the measurement data in LOS dominant scenario and has the following formula

$$PL(d) = 100.7 + 23.5 \log_{10} d[km]$$

Smaller pathloss is observed in eNB to outdoor RN connection, compared to ITU UMa LOS model and even to free space model at close distance. The reason can be
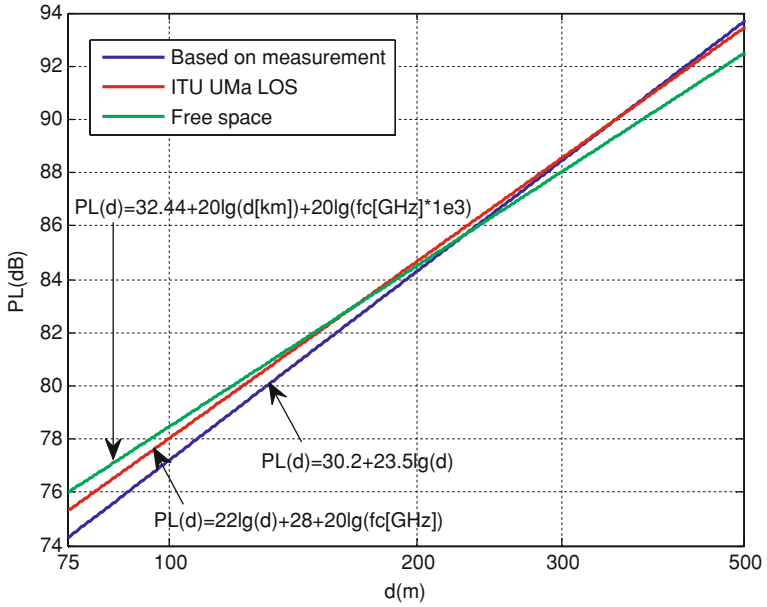
Fig. 2.15 Pathloss of eNB to outdoor relay node connection in LOS dominant environment, compared to other links
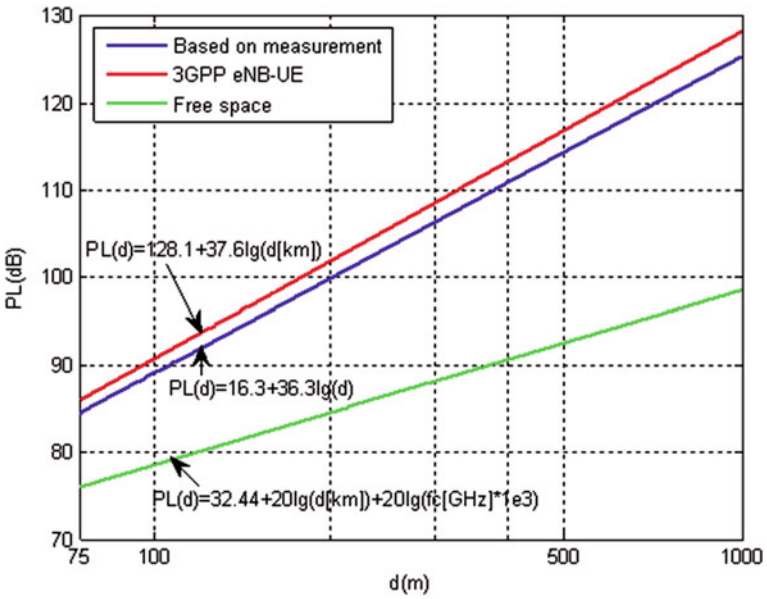

Fig. 2.16 Pathloss of eNB and outdoor relay node connection in NLOS dominant environment, compared to other links
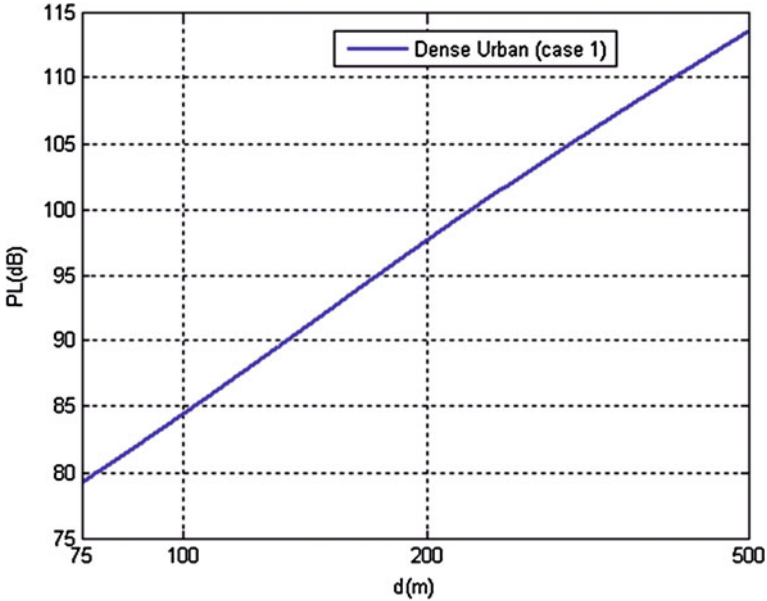
Fig. 2.17 Average pathloss vs. distance of eNB–RN, considering LOS probability, Dense Urban

explained by the higher RN antenna, i.e., 5 m height than that of UE which is assumed to be 1.5 m.

The eNB–RN pathloss in the case of NLOS are compared in Fig. 2.16. The 3GPP eNB–UE model is a NLOS model, widely used for macro cell deployment. The so called "3GPP eNB–UE model" was a model that does not distinguish LOS and NLOS (although NLOS is assumed dominant), i.e., all eNB–UE connections use the same pathloss equation. It had been used till August 2009. For the measurement data, the curve fitting leads to the following pathloss equation for eNB–RN link in NLOS dominant environment.

$$PL(d) = 125.2 + 36.3 \log_{10} d[km]$$

2.2.4 LOS Probability eNB–RN Connection

In dense urban (Case 1) environment, the LOS probability for eNB and RN connection can be based on ITU UMa model, with certain adjustment to account for the higher antenna elevation at RN compared to UE. The LOS probability is expressed as

$$Prob(d[m]) = \min\left(\frac{18}{d}, 1\right)\left(1 - \exp\left(-\frac{d}{72}\right)\right) + \exp\left(-\frac{d}{72}\right)$$
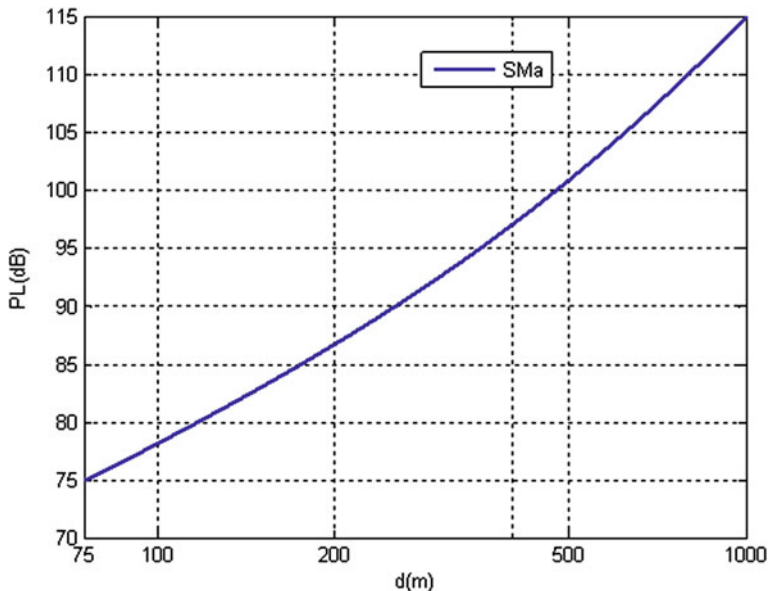
Fig. 2.18 Average pathloss vs. distance of eNB–RN, considering LOS probability, Suburban

Following the same rationale, LOS probability for suburban macro (SMa) can be adjusted to reflect the less attenuation due to the RN antenna height. The formula for suburban environment is

$$Prob(d[m]) = \exp\left(-\frac{d - 10}{1150}\right)$$

Similar to the case of RN–UE connection, we plot in Figs. 2.17 and 2.18 the average pathloss as a function of distance, taking into account of LOS probability, for Dense Urban (Case 1) and Suburban (Case 3), respectively.

Note that the LOS probabilities above simply capture the propagation environment as a function of eNB to RN distance. They do not take into account the relay site optimization which would generally improve the probabilities of LOS propagation and be favorable to the backhaul transmissions. The impacts of RN site optimization on channel modeling will be described subsequently.

As discussed in Sect. 2.1.4, the indoor relay scenario is very similar to that of femto cell deployment. In WINNER channel modeling, the elaborate indoor models already include various cases of wave propagations in different floor settings, those channel models were quickly adopted for femto study in eICIC as well as for indoor relay study. Therefore, the discussion of indoor relay channel modeling is skipped in this chapter.
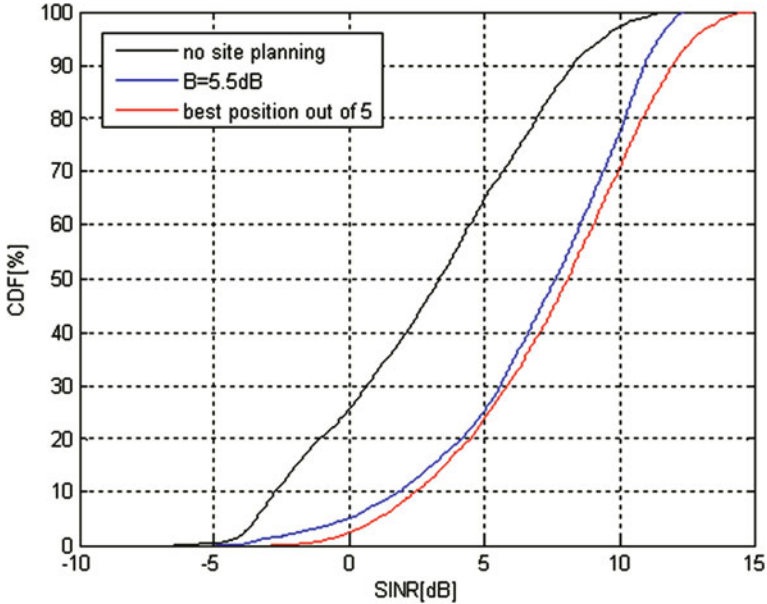
Fig. 2.19 Pathloss bonus reflecting the gain of post-site-planning geometry

2.3 Impacts of Relay Site Planning

For the discussion so far, the favorable pathloss of backhaul link is hinged on the higher antenna at relay node. In the fixed relay deployment, especially for outdoor relays, site optimization can further improve the propagation environment for the wireless backhaul communications. In 3GPP, such improvement comes from the two aspects in channel modeling: less signaling attenuation from the donor eNB, and increased LOS probability of backhaul link.

2.3.1 Less Attenuation from Donor eNB

A simple method is to add pathloss bonus directly to the connection between the eNB and a RN. Note that the bonus only applies to RNs with NLOS propagation with eNB, and only to the link to its donor eNB. In another word, a relay node of LOS propagation with its donor eNB, or of LOS/NLOS propagation with its neighboring eNBs do not enjoy such gain.

One method of choosing optimal bonus value is to compare the RN geometry curves between different bonus values to match the SINR gain due to RN site planning. For example, Fig. 2.19 compares the post-site-planning geometry curve to the RN geometry curve with B = 5.5 dB bonus, but without site planning.

Table 2.2 Site planning bonuses added on pathloss (dB), searching radius of 50 m

ISD (m)	eNB antenna beamwidth	eNB-RN distance ratio of ISD	Bonus (dB)
500	120	0.2	4.9
		0.5	4.4
		0.6	5.2
	60	0.2	2.6
		0.5	3.7
		0.6	4.2
1,732	120	0.2	4
		0.5	4.2
		0.6	4.8
	60	0.2	3.3
		0.5	3.8
		0.6	4.3

Table 2.3 Site planning bonuses added on pathloss (dB), searching radius of 30 m

ISD (m)	eNB antenna beamwidth	eNB-RN distance ratio of ISD	Bonus (dB)
500	120	0.2	3.9
		0.5	3.4
		0.6	3.7
	60	0.2	2.9
		0.5	2.9
		0.6	3.1
1,732	120	0.2	3.1
		0.5	3.3
		0.6	3.6
	60	0.2	3.1
		0.5	3
		0.6	3.1

The inter-site distance (ISD) is 500 m in the simulation. The macro to relay distance is 250 m, i.e., 0.5 ISD. Five candidate relay sites (N = 5) are considered within a searching area of 50 m radius around the virtual relay node, i.e., randomly dropped RNs. It is observed that the effect of applying 5.5 dB pathloss bonus on the backhaul link is almost equivalent to that of 5-site optimization within 50 m.

Similar exercises were carried out for different macro inter-site distances, eNB to RN distances and eNB antenna patterns [6]. The fitted bonuses are summarized in Tables 2.2 and 2.3. In some sense, site planning takes advantage of shadow fading that is random. However, there is certain distance dependent correlation btween the candidate sites. The correlation follows a circular exponential decay function. Therefore, the smaller the search area, the lower the gain of site planning. Such expectation is confirmed by the comparison between Table 2.2 of 50 m radius and Table 2.3 of 25 m radius. Similarly, wider radiation pattern, i.e., 120°, helps to include more potential relay nodes, so that site planning would bring more gains. The bous is not very senstivie to the eNB to RN distance, nor to the macro inter-site distance.
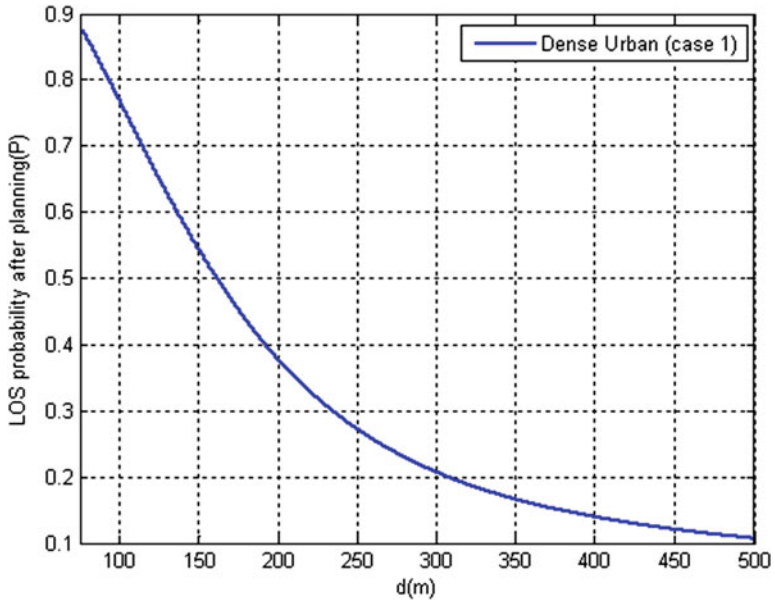
Fig. 2.20 Post site planning LOS probability vs. distance of donor eNB–RN, Dense Urban
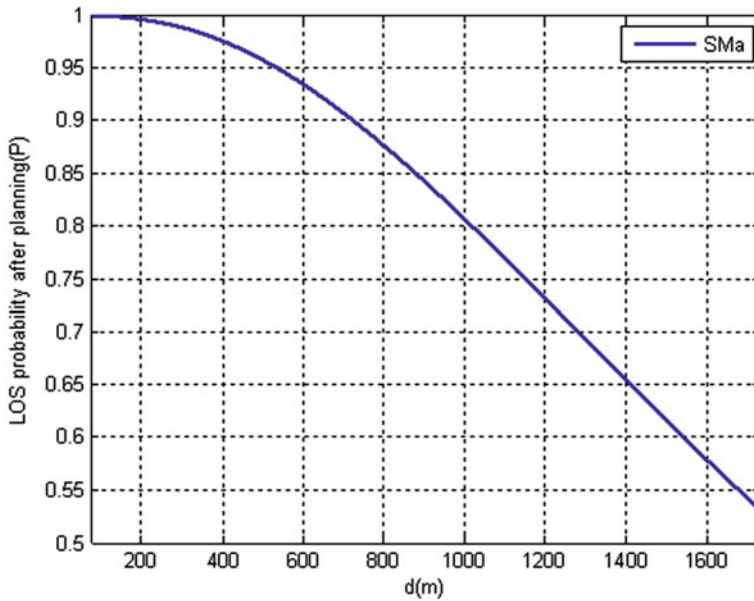

Fig. 2.21 Post site planning LOS probability vs. distance of donor eNB–RN, Suburban

Ideally, different bonuses would be applied for each individual setting. However, that would complicate the channel modeling and result in very cubersome set of parameters. Therefore, a single bonus value is perfered. From Tables 2.2 and 2.3, it is seen that using a single value could lead to approximate $1 \sim 2$ dB error when calculating the pathloss.

Alternatively, site planning can be performed in each simulation run, if a single value of bonus is considered not accurate enough to capture the actual SINR gain in the backhaul link. In this case, the following procedure can be carried out in relay system-level simulations.

The site planning optimization is a process of finding an optimal location among N candidate relay sites around the virtual relay which offers bonus to the performance.

- The relay geography locations are initialized in a system-level simulation by random dropping.
- N = 5 candidate relay sites are considered within a searching area of 50 m radius around the virtual relay.
- The best relay site is selected based on SINR criteria on the backhaul link.

2.3.2 Improvement of LOS Probability in Donor eNB–RN Connection

As the pathloss of LOS environment is significantly smaller than that of NLOS environment, a direct consequence of relay site planning is the increased chance of LOS propagation in the backhaul link.

The probability of finding a site with LOS propagation to its donor eNB depends on two factors: the LOS probability of each candidate site and the correlation between these sites. The first factor and the corresponding formulae are already discussed in previous sections. The rest is to model LOS correlation between these candidate sites. Assuming N candidate relay sites and using b_i to represent a Boolean variable indicating whether the ith candidate site is of LOS ($b_i = 1$) propagation or of NLOS ($b_i = 0$) propagation. The Boolean variable b_i can be generated from spatially-correlated Gaussian random variables g_i [7], the same way the shadow fading is generated where de-correlation distance of $d_{\text{cor\_LOS}}$ is used. The de-correlation distance captures the correlation between the two Gaussian variables at two sites. The correlation is modeled as an exponential decaying function of distance Δx. It is known that the propagation mechanisms of shadow fading and LOS are fundamentally similar, both heavily influenced by the buildings, scatterers, and/or obstacles. Therefore, we can assume that for the same eNB to RN connection, the correlation model and the de-correlation distance are similar for shadow fading and LOS probability, i.e., $d_{\text{cor\_LOS}} = d_{\text{cor\_SF}} = 50$ m. Denoting g_i as the Gaussian random variable for the ith candidate site, b_i can be calculated as follows

Table 2.4 Large scale fading parameters for outdoor relay performance evaluation

Distance-dependent path loss	Macro to relay:
	$PL_{LOS}(R) = 100.7 + 23.5log10(R)$
	$PL_{NLOS}(R) = 125.2 + 36.3log10(R)$
	For 2 GHz, R in km.
	LOS probability:
	Case 1: $Prob(R) = min(0.018/R,1)*(1-exp(-R/0.072)) + exp(-R/0.072)$
	Case 3 (*Suburban*): $Prob(R) = exp(-(R-0.01)/0.23)$
	Case 3 (*Rural/Suburban*): $Prob(R) = exp(-(R-0.01)/1.15)$
	Bonus for donor macro (from each of its sectors) to relay for optimized deployment by site planning optimization methodology.
	Higher probability of LOS shall be reflected in consideration of the height of RN antenna and site planning optimization.
	Bonus = 5 dB, for donor macro (from each of its sectors) to relay for NLOS, 0 dB for LOS
	LOS probability correction as $1-(1-Prob(R))^N$, where $N = 3$
	Relay to UE:
	$PL_{LOS}(R) = 103.8 + 20.9log10(R)$
	$PL_{NLOS}(R) = 145.4 + 37.5log10(R)$
	For 2 GHz, R in km
	Case 1: $Prob(R) = 0.5-min(0.5,5exp(-0.156/R)) + min(0.5, 5exp(-R/0.03))$
	Case 3: $Prob(R) = 0.5-min(0.5,3exp(-0.3/R)) + min(0.5, 3exp(-R/0.095))$
Shadowing standard deviation	Macro to relay
	Relay with outdoor donor antenna: 6 dB
	Relay to UE:
	Relay with outdoor coverage antenna: 10 dB

$$b = \begin{cases} 1, & \text{if } g_i < \sqrt{2} \cdot \text{erfinv}(2p-1) \\ 0, & \text{otherwise} \end{cases}$$

where p is the LOS probability for the candidate site and erfinv($\cdot$) is the inverse error function. Note b_i are correlated in space, since g_i are correlated in space. The site selection procedure from N candidate sites can be mathematically represented as max $(b_1, b_2, \ldots, b_N) = 1$ or equivalent. So after RN site planning the LOS probability becomes

$$Prob\left(\min(g_1, g_2, \ldots, g_N) < \sqrt{2} \cdot \text{erfinv}(2p-1)\right)$$

Considering five candidate sites within a circular area of radius 50 and 30 m and these sites are randomly placed in the searching area, the distribution of $\min(b_1, b_2, \ldots, b_5)$ is obtained from the simulation. Then, the post-planning LOS probability is calculated as a function of the pre-planning LOS probability. In [7] it is shown that $Prob = 1-(1-p)^{3.1}$ matches well the simulated post-planning LOS probability for 50 m search radius. To simplify the formula, the exponential "3.1"

was round-off to the nearest integer 3 in the final agreement for the modeling of post-site-planning LOS probability. Figures 2.20 and 2.21 show LOS probabilities as a function of the distance between donor eNB and RN, after site planning, for Dense Urban and Suburban environment, respectively.

2.4 Large Scale Fading Parameters

Large scale fading parameters for eNB–RN and RN–UE connections are summarized in Table 2.4. The relay here is supposed to be outdoor relay. The effect of relay site optimization is also included in Table 2.4.

Besides the pathloss, shadow fading is another important aspect for channel modeling. In WINNER channel model, the shadow fading of LOS and NLOS are different. And for indoor users in UMi, the more shadowing is applied. For relay channels, due to the lack of time for detail analysis of the measurement data, there is no differentiation between LOS and NLOS in terms of shadow fading. For macro-UE connection, the shadow fading standard deviation is often set to be 8–8.9 dB. Considering the higher antennas at RN compared to UE, smaller standard deviation is expected for backhaul link, which is modeled as 6 dB for outdoor relay [8]. On the other hand, the lower antenna height of RN compared to macro eNB leads to higher standard deviation, i.e., 10 dB for RN to UE connection.

2.5 Small Scale Fading

Most effort of channel modeling in Release 10 relay study item was focused on large-scale fading modeling which fundamentally determines the performance expectation of relay systems.

Nevertheless, fast fading is also important in the sense that:

- Delay spread, or frequency domain characteristics can only be captured by the fast fading. Frequency selective scheduling is a key feature of OFDM system which would significantly improve the system performance. Without modeling the fast fading, simulation results would only reflect the flat fading performance which effectively disables the frequency selective scheduling.
- Small scale time domain statistics are crucial to those transmission schemes that rely on the feedback of channel state information (CSI). The static channel assumption in large scale fading only simulations would exaggerate the actual performance.
- Multi-antenna technologies rely heavily on the assumptions of spatial channel characteristics, such as angle of arrival (AoA), angle of departure (AoD), angle spread, cross-polarization discrimination, which can only be obtained by fast fading modeling.

Table 2.5 Delay spread, angle spread parameters for relay-UE and macro-relay connections, compared with ITU UMa and ITU UMi

Scenarios/links	Value					
	Average delay spread (μs)		Average spread of AoD (degrees)		Average spread of AoA (degrees)	
	LOS	NLOS	LOS	NLOS	LOS	NLOS
Relay-UE	0.089	0.148	18	30	25	36
Macro-relay	0.079	0.174	23	29	35	40
ITU UMa	0.093	0.363	14	26	65	74
ITU UMi	0.065	0.129	16	26	56	69

Note that, for simplicity of modeling, absolute value of cross-correlation smaller than 0.3 is set to 0

- Link level simulations require elaborate modeling of small scale fading

Several agreed models for fast fading, such as SCM, SCM-E, or ITU UMa/UMi, could be used in the absence of well accepted models for relay backhaul and access links. But those models may not accurately represent the fast fading characteristics of eNB–RN and RN–UE links, as seen shortly after.

There were some proposals on fast fading modeling for relay-UE and eNB-relay connections as [9]. The proposed parameters were based on the data from the similar measurement campaign as for pathloss modeling discussed in Sect. 2.2. The methodology follows the same procedures of ITU fast fading modeling, i.e., using the same formulae, for example,

- The delay spread (DS) distribution is still modeled as exponential decaying function with certain mean value to represent the overall channel frequency selectivity. The standard deviation is to capture the randomness of delay profile of each UE in various locations.
- The azimuth angle spread distribution is modeled as wrapped Gaussian, for both angle of departure (AoD) and angle of arrival (AoA). In relay-UE link, the angle spreads of AoD and AoA reflect the spatial richness from the aspects of relay access link antennas, and UE antennas, respectively. In macro-relay link, the angle spreads of AoD and AoA capture the characteristics scatterers from the aspects of macro antennas and relay backhaul link antennas, respectively.
- The composite parameters for delay spread, azimuth angle spread and shadow fading (SF) are correlated. Six cross-correlation coefficients are used: angle spread of departure (ASD) to delay spread, angle spread of arrival (ASA) to delay spread, ASD to shadowing, ASA to shadowing, ASD to ADA, delay spread to shadowing.

The above fast fading parameters for relay-UE and macro-relay links are proposed in [10] to better match the channel measurement data. Tables 2.5 and 2.6 highlight some key parameters, compared with those of ITU UMa and ITU UMi.

In Table 2.5, the average delay spread for LOS does not differ much between relay channels and ITU macro and micro channels. However, For NLOS, the delay spread of ITU UMa is significantly longer that other channels. It is also observed

Table 2.6 Cross correlations between delay spread, angle spread parameters for relay-UE and macro-relay connections, compared with ITU UMa and ITU UMi

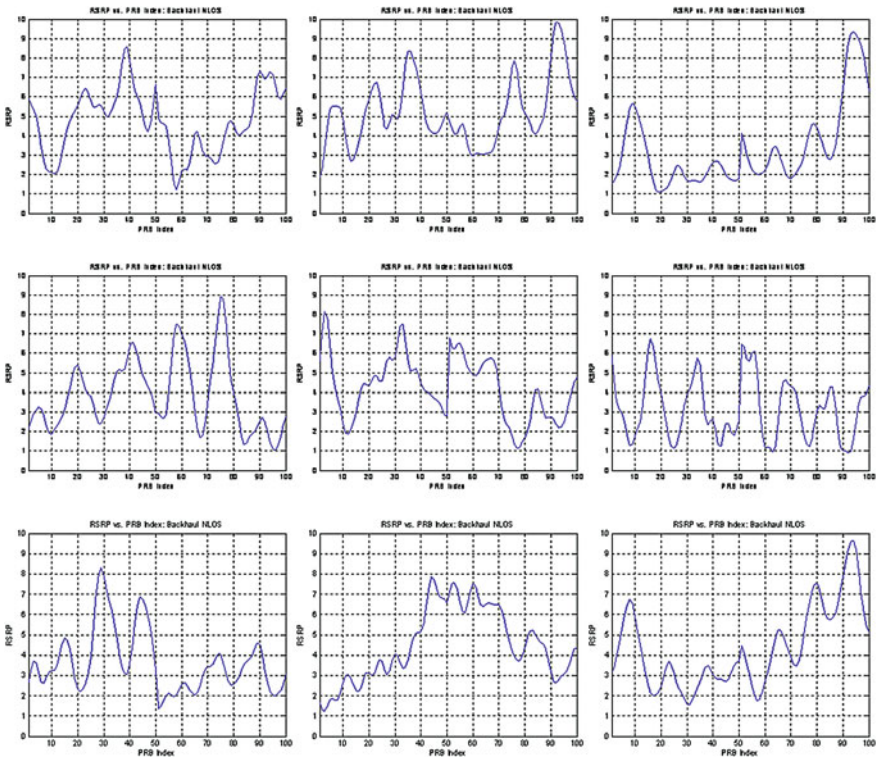| Scenarios/ links	Cross correlation										
	ASD to DS		ASA to DS		ASA to SF		ASD to SF		DS to SF		ASA to ASD	
	LOS	NLOS	LOS	NLOS	LOS	NLOS	LOS	NLOS	LOS	NLOS	LOS	NLOS
RN–UE	0.3	0.3	0.5	0	0	0	0	0	−0.8	−0.8	0	0.5
eNB-RN	0	0.6	0.3	0	−0.3	0	0	0	−0.3	−0.3	0	0
ITU UMa	0.4	0.4	0.8	0.6	−0.5	0	−0.5	−0.6	−0.4	−0.4	0	0.4
ITU UMi	0.5	0	0.8	0.4	−0.4	-0.4	−0.5	0	−0.4	−0.7	0.4	0

Fig. 2.22 RSRP vs. PRB index of backhaul channels in NLOS scenario

that due to the higher elevation of relay antennas compared to UE antennas, angle spread of AoA of backhaul link is noticeably narrower than that of ITU UMa and ITU UMi, which means from relay backhaul antenna point of view, less scatterers are seen. It is interesting to see that angle spread of AoA of access link is narrower than that of ITU UMa and ITU UMi, which may be explained by the wave-guide
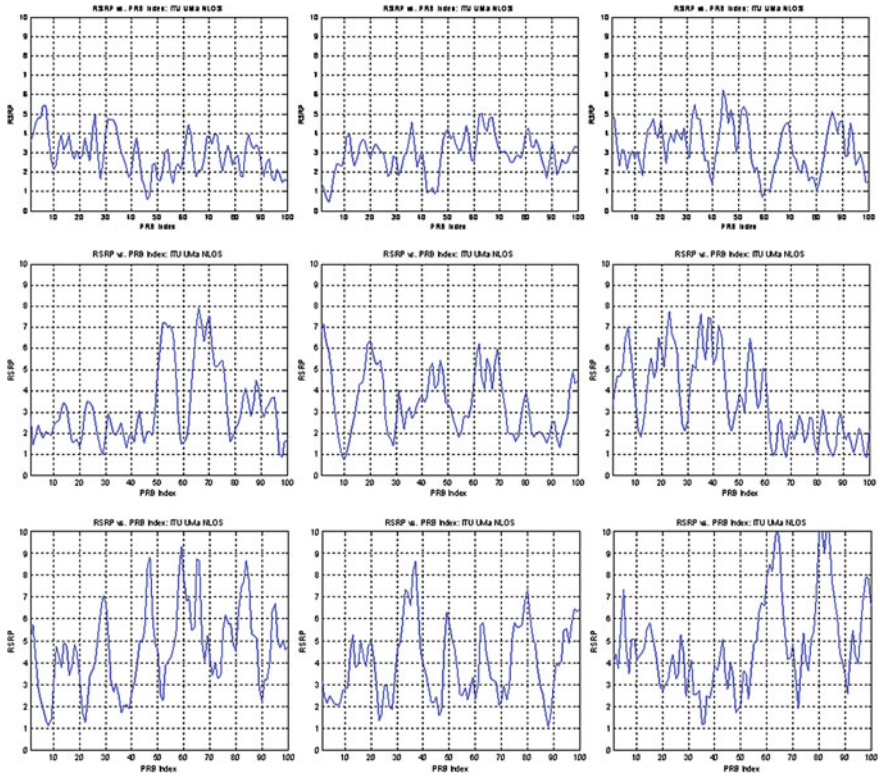
Fig. 2.23 RSRP vs. PRB index of ITU UMa channels in NLOS scenario

effect, caused by the lower RN antenna height than macro or micro eNB. Also observed is the slightly broader angle spread of AoD in eNB–RN link of LOS propagation. Possible reason is that eNB–RN link would receive signals from far-away scatters than RN–UE and eNB–UE links.

Table 2.6 shows that in all the four scenarios/links, angle spread and delay spread are moderate-high positive correlated, and delay spread and shadow fading are moderate-high negative correlated. In ITU UMa and ITU UMi, the angle spread and shadow fading are moderate-high negative correlated. However in RN–UE and eNB–RN links, the correlation between the angle spread and shadow fading is small.

The parameters in Table 2.5 may look obscure to people who are not familiar with spatial channel modeling or ITU fast fading channel models. To get a feeling of what the channel looks like with Table 2.5, we plot a few frequency domain response of the backhaul channel using those parameters.

We randomly generate 9 fast fading realizations and plot linear-scale reference signal received power (RSRP) as a function of physical resource block (PRB) index. The operating bandwidth is 20 MHz, and there are 100 PRBs in

Table 2.7 Other key parameters for outdoor relay system simulations

Parameter	Assumption/value
Cell layout	Hexagonal grid, 19 macro eNB cell sites, 3 cells per site, wrapped around
Inter-site distance (macro)	500 m (Case 1), 1,732 m (Case 3)
Penetration loss	Macro to UE: 20 dB, macro to RN: 0 dB, RN to UE: 20 dB
Antenna pattern (azimuth)	Relay-UE link (Case 1):
	5dBi antenna gain, omni $A(\theta) = 0$ dB
	2 transmit, 2 receive antenna configuration
	Relay-UE link (Case 3):
	5dBi antenna gain,
	omni $A(\theta) = 0$ dB
	or
	directional pointing away from the donor cell
	$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3db}}\right)^2, A_m\right]$
	$\theta_{3dB} = 70$ degrees, $A_m = 20$ dB.
	2 transmit, 2 receive antenna configuration
	Macro-Relay link (Case 1 and Case 3)
	7dBi, directional
	$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3db}}\right)^2, A_m\right]$
	$\theta_{3dB} = 70$ degrees, $A_m = 20$ dB.
	2 transmit, 2 receive antenna configuration,
	or 4 transmit, 4 receive antenna configuration
	Use of antenna downtilt and vertical antenna FFS
Total transmit power of RN	Case 1: 30 dBm @ 10 MHz bandwidth
	Case 3: 30 or 37 dBm @ 10 MHz bandwidth
Mini dist. between UE and outdoor RN	10 m
Mini dist between RN and marco	35 m
Num of UEs per macro cell	25

the plots. RSRPs in each figure are the averaged values over resource elements of common reference signal (CRS) in each PRB. Figure 2.22 corresponds to backhaul NLOS scenario. Figure 2.23 is for ITU UMa NLOS scenario. It is seen that in NLOS scenario the backhaul channel frequency response is smoother than ITU UMa channels, indicating that the backhaul channel is less frequency selective than ITU UMa channel. This is reasonable according to Table 2.5 where the average delay spread of macro-RN channel is 0.174 μs, compared to 0.363 μs for ITU UMa.Due to the limited time of the simulation verification, no new fast fading models were agreed for relay study. Nevertheless, the parameters proposed in [10] would be a useful reference for future study of relay, and even for pico cell (access link).

2.6 Other Settings

Relay system simulation reuse many parameters for homogeneous network simulations. But there are some exceptions such as the transmit power of RN, minimum distance between UE and RN, between RN and macro, etc. Some key parameters are listed in Table 2.7.

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