MSc Thesis

Evaluation of Relay-Enhanced LTE-Advanced Networks

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Originality Statement

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at TU Delft or any other educational institution, except where due acknowledgment is made in the thesis. Any contribution made to the research by others, with whom I have worked at TU Delft or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation and linguistic expression is acknowledged.

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Dedicated to my beloved mother and father, for planting the magic inside me and uplifting my spirit by supporting me all the way along...

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Abstract

The Third Generation Partnership Program's Long-Term Evolution Advanced (3GPP LTE-Advanced) group is developing a new standard for mobile broadband access that will meet the throughput and coverage requirements of a fourth generation cellular technology. The key goals for this evolution are increased data rate, improved spectrum efficiency, improved coverage and reduced latency. The ultimate results of these goals are significantly improving service provisioning and reduction of operator costs for different traffic scenarios. One of the main challenges faced by the developing standard is providing high throughput at the cell edge. Cell edge performance is becoming more important as cellular systems employ higher bandwidths with the same amount of transmit power and use higher carrier frequencies with infrastructure designed for lower carrier frequencies. One solution to improve coverage is to use the fixed relays to transmit data between the Base Stations and the Mobile Stations or User Equipments through multi hop communication. For this reason, relay technologies have been actively studied and considered in the standardization process of next-generation mobile broadband communication system. As a next-generation 3GPP standard, LTE-Advanced exclusively takes the relay technology into account. This thesis focuses the relay technologies for the LTE-Advanced systems and evaluates the performance of the relay-enhanced LTE-Advanced network. The approach for this work is to design several environments for LTE-Advanced networks involving relays. Incorporating the channel model from the *Wireless World Initiative New Radio* (WINNER) project, four environments were designed among which one environment considers no relay at all and the rest of the environments considered relay deployments. And the performances of all the environments are evaluated in terms of Symbol Error Rate (SER) versus the Signal to Noise Ratio (SNR), under several different scenarios defined in WINNER project. As an outcome, the simulation results from the simulator show that relay technologies can effectively improve service performance.

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List of Abbreviations

3G	3rd Generation
3GPP	3rd Generation Partnership Project
4G	4th Generation
AoA	Angle of Arrival
AoD	Angle of Departure
ARQ	Automatic Repeat reQuest
AWGN	Additive white Gaussian Noise
B3G	Beyond 3rd Generation
BER	Bit Error Rate
BS	Base Station
CDL	Clustered Delay Link
CoMP	Coordinated Multi Point
CP	Cyclic Prefix
DFT	Discrete Fourier Transform
DL	Down Link
EDGE	Enhanced Data rates for GSM Evolution
eNB	evolved Node B
FCS	Far Cluster Scatterers

FDMA	Frequency Division Multiple Access
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
FSTD	Frequency Shift Transmit Diversity
GSM	Global System for Mobile communication
HSPA	High Speed Packet Access
IFFT	Inverse Fast Fourier Transform
IMT	International Mobile Telecommunications
IMT-A	International Mobile Telecommunications Advanced
ITU	International Telecommunication Union
LOS	Line Of Sight
LSP	Large Scale Parameter
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
MATLAB	MATrix LABoratory
MBSFN	Multicast Broadcast Single Frequency Network
MIMO	Multiple Input and Multiple Output
MMSE	Minimum Mean Square Error
MPC	Multi Path Component
NLOS	Non Line Of Sight
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PAPR	Peak to Average Power Ratio
QoS	Quality of Service

QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RAN	Radio Access Network
RN	Relay Node
RX	Receiver
SCFDMA	Single Carrier Frequency Division Multiple Access
SCME	Spatial Channel Model Extended
SER	Symbol Error Rate
SFBC	Space Frequency Block Coding
SISO	Single Input and Single Output
SNR	Signal to Noise Ratio
TDD	Time Division Duplex
TDSCDMA	Time Division Synchronous Code Division Multiple Access
TX	Transmitter
UE	User Equipment
UL	Up Link
UMTS	Universal Mobile Telecommunications System
VoIP	Voice over Internet Protocol
WCDMA	Wideband Code Division Multiple Access
WINNER	Wireless World Initiative New Radio
WLAN	Wireless Local Area Network

Chapter 1

Introduction

This thesis involves a study for evaluating the performance of relay-enhanced LTE-Advanced networks which is formally submitted as a candidate of 4G system to ITU in late 2009 [25] with the incorporation of the WINNER channel model [25] in LTE-Advanced standard. WINNER channel model and LTE-Advanced will be discussed in details later. The main purpose of this chapter is to describe the background motivation of this work, the main objectives and the general overview of the thesis.

1.1 Thesis Background

LTE-Advanced [10] is considered to be the next big leap in the mobile communications world. The target of LTE-Advanced is to reach and surpass the ITU requirements. LTE-Advanced should be backward compatible and should share the frequency bands with the previous releases of LTE. One of the important LTE-Advanced benefits is the ability to take advantage of advanced topology networks; optimized heterogeneous networks with a mix of macros with low power nodes such as picocells, femtocells and new relay nodes [29]. The next significant performance leap in wireless networks will come from making the most of topology, and brings the network closer to the user by adding many of these low power nodes, which improves the capacity and coverage, and ensures user fairness. LTE-Advanced also introduces multi-carrier to be able to use ultra wide bandwidth, up to 100 MHz of spectrum supporting very high data rates [28], which makes LTE-Advanced a worthy standard for 4G. A single ubiquitous radio access system is required which is adaptable to a comprehensive range of mobile communication scenarios from short range to wide area and supports the challenging requirements of systems beyond 3G. The radio channel plays an important role in the evaluation of transceiver parameters such as modulation, coding, link adaptation, channel equalization, multi-user scheduling, etc in terms of, e.g. bit-error-rate (BER), system throughput etc. The European WINNER project [26] has developed a new radio concept for Beyond-3G (B3G) wireless communication system which uses a channel bandwidth of up to 100 MHz for one radio link [25], and radio frequencies most likely between 2 and 6 GHz [25]. As a result, new channel models were developed during the WINNER project, based on existing literature and channel measurements [35], which covers more detailed network scenarios. The channel models developed in WINNER project become very much competent for the 4G wireless communication as well as LTE-Advanced. A communication model utilizing both LTE-Advanced standard and WINNER channel model is necessary to advancement towards the 4G. This thesis was initiated from the necessity of modeling relay-enhanced LTE-Advanced network with the incorporation of WINNER channel.

1.2 Thesis Purpose

The LTE-Advanced system will support peak data rates of 100 Mb/s in high mobility environment (up to 350 km/h) [6] and 1 Gb/s in stationary and pedestrian environments (up to 10 km/h) [7]. The transmission bandwidth of LTE-Advanced system will be scalable and can change from 20 to 100 MHz, with down link and up link spectrum efficiencies in the ranges of 1.1 b/s/Hz to 15 b/s/Hz and 0.7 b/s/Hz to 6.75 b/s/Hz [6], respectively. There will be a minimum requirement on voice over IP (VoIP) capacities in high- and low-mobility environments of around 30 and 50 active users/sector/MHz. The latency for control and user planes should be less than 100 ms and 10 ms, respectively, in unloaded conditions [10]. Still by deploying IMT-Advanced standard and enhancements in radio link technology will not solve the basic problem related to propagation loss, that is coverage and capacity at the cell border remain relatively small due to low Signal-to- Noise-Ratio (SNR). A very promising solution to overtake this problem is to use Relay Nodes (RN) in the network. Deploying RNs near the cell edge will help to increase the capacity or alternatively to extend the cell coverage area [3][13].

For this, relay technologies have been actively studied and considered in the standardization process of next-generation mobile communication systems, such as 3GPP LTE-Advanced. Relay transmission can be seen as a kind of collaborative communications, in which a Relay Node (RN) helps to forward the data-information from a local eNode-B or Base Station (BS) to the neighboring user equipment (UE). As a result, a RN can effectively extend the signal and service coverage of an eNB and enhance the overall throughput performance of a wireless communication system and solve the above mentioned low SNR problem. A part from this, Relaying technology can also be integrated in normal base station platforms which is cost efficient and easy to deploy as it does not require additional back haul [13].

This thesis focuses on evaluating the performance of an LTE-Advanced network with Relay Nodes. For that we explore the idea and theory of LTE-Advanced and WINNER channel model to create a simulation model which is capable of evaluating the performance of relay deployment in an LTE-Advanced utilizing the WINNER channel model. The performance is evaluated by analyzing the Symbol Error Rate (SER) for a certain range of SNRs. For the simplicity of the simulation environment a number of maximum two Relay Nodes have been considered in this model as well as a simulator for transmitting and receiving data bits has also been designed. To the author knowledge, there is not any model for relay-enhanced LTE-Advanced network incorporating the WINNER channel model for academic purpose, which is free and open sourced. This model can lead the researchers to enhance and modify an academic simulation model for the further researches.

The model has been simulated on MATLAB completely. No actual devices or instruments are involved in this evaluation. So the outcome results are more *theoretical* rather than *practical*. Apart from this, a Free and Open sourced channel model was necessary to design a LTE-Advanced simulator. But except WINNER channel model, other models are closed sourced and restricted by the developer(s). So this thesis utilizes only the free and open sourced WINNER channel model for designing the simulator.

1.3 Summary of Contribution

In this thesis, our primary focus is to develop a simulator for LTE-Advanced, which will allow the deployment of relays and can evaluate the Symbol Error Rate of the deployed system. We designed such a simulator, by maintaining the requirements of 3GPP [23] so that further research on LTE-Advanced can be continued based on this model.

1.4 Thesis Overview

This thesis is organized as follows:

In Chapter 2, we give a general overview of LTE-Advanced technology. We discuss the current scenario of LTE and then compare that with the ITU proposed LTE-Advanced. Some of the main key features of LTE and LTE-Advanced has been discussed there. Apart from this, the relay technologies in IMT-Advanced as well as LTE-advanced standard are studied in this chapter.

In Chapter 3, WINNER II channel model from the European WINNER project [25] which has been chosen as the radio channel for this thesis is discussed. The channel parameters, the path loss models for different scenarios involved in WINNER II as well as the applicability of the radio channel model are summarized. Also the network layout and delay lines for the channel model has been discussed briefly.

In Chapter 4, we discuss the general design of the work, stating the main components used in this work. Then we present the design concepts of the simulator as well as the algorithms of the designed simulator.

In Chapter 5, the results from each scenarios and environments of the simulator are presented. Then an analysis of interpretation and deduction of the results of each scenarios and environments are presented in this chapter.

In Chapter 6, the conclusions that have been drawn from all the results obtained in the course of this thesis work has been presented. Recommendations for the further future research involving this thesis are also proposed in this chapter.

Chapter 2

Long Term Evolution Advanced (LTE-Advanced)

Broadband with the standards definitions now available for LTE, the Long Term Evolution of the 3G services, eyes are now turning towards the next development, that of the truly 4G technology named IMT-Advanced. The new technology being developed under the auspices of 3GPP to meet these requirements is often termed LTE-Advanced. In this chapter, some of the key concepts of LTE (Release 8) will be addressed and then the major differences between LTE and LTE-A will be provided. Later we will discuss some of the advantages and key features of LTE-advanced.

2.1 3G Wireless Systems

Long Term Evolution (LTE) based on the radio access technology, is a 3G (third generation) wireless system's partnership project. LTE is taking momentum and continuing to grow at an accelerated pace. However, it is necessary to further develop the future demands for mobile broadband services through higher data rates, shorter delays, and even greater capacity. In parallel to these activities related to the evolution of current 3G wireless technologies, there is also an increased research effort on future radio access, referred to as fourth-generation (4G) radio access. Such future radio access is anticipated to take the performance and service provisioning of wireless systems a step further, providing data rates up to 100 Mbps with wide-area coverage and up to 1 Gbps with local-area coverage, fulfilling the requirements for Beyond IMT-2000 systems[18][19]. To meet the challenges of major enhancements to LTE-Advanced which will be introduced in release 10, 3GPP has initiated the study item on LTE-A, aiming at achieving additional substantial leaps in terms of service provisioning and cost reduction[20][21].

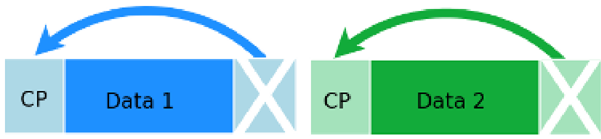

Figure 2.1: OFDM Symbols with Cyclic Prefix

2.2 LTE – An Overview

To set the background for LTE-Advanced, it is necessary to briefly describe the existing LTE system, known as LTE Release 8.In the following, a brief overview of the first release of LTE is given.

2.2.1 Transmission Scheme

The core of the LTE down link radio transmission is the Orthogonal Frequency Division Multiplexing (OFDM) with data being transmitted on a large number of parallel narrow-band sub carriers,. Due to the use of relatively narrow band sub carriers in combination with a cyclic prefix, OFDM transmission is inherently robust to time dispersion on the radio channel without having to resort to advanced and often relatively complex receiver-side channel equalization. Also in an OFDM symbol the cyclic prefix, transmitted during the guard interval, consists of the end of the OFDM symbol as shown in the following Figure 2.1.

The guard interval is used so that the receiver will integrate over an integer number of sinusoid cycles for each of the multipath when it performs OFDM demodulation with the FFT. For the down link, this is an attractive property as it simplifies the receiver base band processing with a reduced terminal cost and power consumption as consequences. This is especially important taking into account the wide transmission bandwidths of LTE and even more so in combination with advanced down link multi-antenna transmission such as spatial multiplexing.

For the up link, where the available transmission power is significantly lower than for the down link, the situation is somewhat different. Rather than the amount of signal processing in the receiver, one of the most important factors in the up link design is to allow for highly power efficient transmission. This will improve coverage and reduce terminal cost and power consumption at the transmitter. For this reason, to improve the RF transmission power efficiency in the UE, single-carrier transmission based on DFT-precoded OFDM, sometimes referred to as Single-Carrier FDMA, is used for the LTE up link. SC-FDMA has similar performance and essentially the same overall structure as those of an OFDMA system. One prominent advantage of SC-FDMA over OFDMA is that the SC-FDMA signal has lower peak-to-average power ratio (PAPR). In the up-link communications low PAPR greatly benefits the User Equipment (UE) in terms of transmit power efficiency [18].

Guard intervals with cyclic repetition are introduced between blocks of symbols as in OFDM explained earlier. In OFDM, FFT is applied on the receiver side on each block of symbols, and IFFT on the transmitter side. In SC-FDMA, both FFT and IFFT are applied on the transmitter side, and also on the receiver side. However SC-FDMA requires transmissions in consecutive bands, and thus introduces restrictions on the frequency domain packet scheduling for individual users compared to OFDMA.

2.2.2 Spectrum Flexibility

Depending on regulatory aspects in different geographical areas, radio spectrum for mobile communication is available in different frequency bands, of different sizes, and comes as both paired and unpaired bands. Paired frequency bands implies that up link and down link transmissions are assigned separate frequency bands, while in case of unpaired frequency bands up link and down link has to share the same frequency band. Also, at least in an initial migration phase, different radio access technologies often need to be able to operate jointly in the same overall spectrum. Spectrum flexibility, enabling operation under all these conditions, is one key feature of the LTE radio access.

LTE is not only able to operate in different frequency bands but can also be deployed with different bandwidths in order to be able to operate in spectrum of different size as well as allow for efficient migration of other radio access technologies to LTE. More specifically, LTE allows for an overall system bandwidth ranging from as small as 1.4 MHz up to 20 MHz, where the latter is needed to provide the highest LTE data rates [23]. All terminals will support the widest bandwidth. A unique LTE possibility is the possibility to use different up link and down link bandwidths, allowing for asymmetric spectrum utilization. Furthermore, as already mentioned, LTE enables operation in both paired and unpaired spectrum by supporting both Frequency-Division Duplex (FDD) and Time-Division Duplex (TDD) operation with a single radio-access technology.
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2.2.3 Multi-Antenna Solutions

Multiple Input Multiple Output (MIMO) is the major feature used to improve the performance of the LTE system, it allows in improving the spectral efficiency and data throughput. MIMO consists of multiple antennas on the receiver and transmitter to utilize the multipath effects. This reduces the interference and leads to high throughputs. Multipath occurs when the different signals arrive at the receiver at various times intervals. MIMO divides a data stream into multiple unique streams, transmits data streams in the same radio channel at the same time. The receiving end uses an algorithm or employs special signal processing

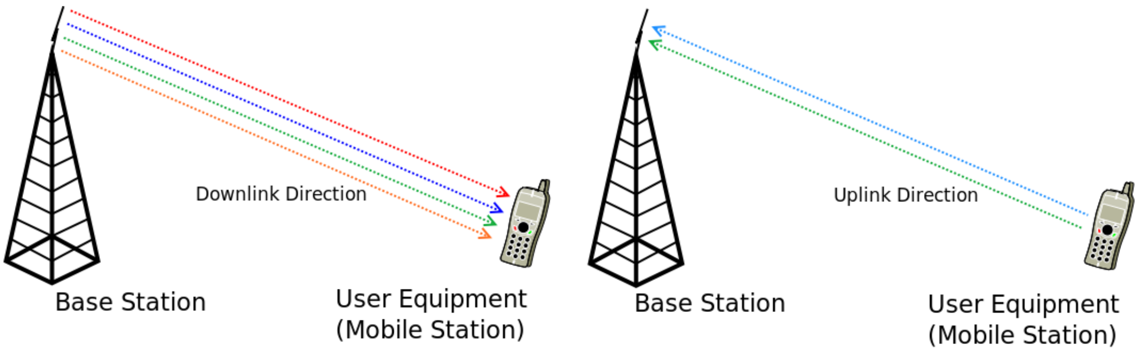

Figure 2.2: LTE T_x and R_x Schemes (4×2 MIMO)

to generate one signal that was originally transmitted from the multiple signals [22].

This multi-antenna transmission technique is an integral part of LTE from the first release and the channel quality measurements for link adaptation and scheduling are designed to cater for this. The fact that all terminals support at least two receive antennas is important, as it allows the networks to be planned assuming at least the presence of down link receive diversity. More advanced multi-antenna schemes are also supported by LTE, including transmit diversity, spatial multiplexing (including both so-called single-user MIMO as well as multi-user MIMO), and beam-forming. Which of the scheme (or which combination of schemes) to use depends on the scenario. In the up link, both open and closed-loop transmit antenna selection are supported as optional features.

LTE transmit diversity is based on so called Space Frequency Block Coding (SFBC), complemented with Frequency Shift Transmit Diversity (FSTD) in case of four transmit antennas. Transmit diversity is primarily intended for common down link channels to provide additional diversity for transmissions for which channel dependent scheduling is not possible. However, transmit diversity can also be applied to user-data transmission, e.g. to Voice-over-IP (VoIP), where the relatively low user data rates may not justify the additional overhead associated with channel-dependent scheduling. In case of spatial multiplexing, up to four antennas at both the transmitter (base station) and the receiver (terminal) side are used to provide simultaneous transmission of multiple parallel data streams, also known as layers, over a single radio link, thereby significantly increasing the peak data rates that can be provided over the radio link. As an example, with four base-station transmit antennas, and a corresponding set of (at least) four receive antennas at the terminal side, up to four data streams can be transmitted in parallel over the same radio link, effectively quadrupling the data rate.

2.2.4 Inter-Cell Interference Coordination

LTE provides orthogonality between users within a cell in both up link and down link, i.e. at least in principle there is no interference between transmissions within one cell (no intra-cell interference). Hence, LTE performance in terms of spectrum efficiency and available data rates is, relatively speaking, more limited by interference from other cells (inter-cell interference) compared to WCDMA/HSPA, especially for users at the cell edge. Means to reduce or control the inter-cell interference can therefore, potentially, provide substantial benefits to LTE performance, especially in terms of the service (data rates, etc.) that can be provided to users at the cell edge. Up link power control is one of the mechanisms in LTE used for this purpose. It is used not only to control the received signal strength in the intended cell, but also to control the amount of interference in neighboring cells.

Inter-cell interference coordination is a scheduling strategy, used to control the inter-cell interference in both up link and down link. A simple method to improve cell edge data rates is to statically restrict the usage of parts of the bandwidth, e.g., through a reuse larger than one. Such schemes improve the signal-to-interference ratios of the used frequencies. However, the loss due to a reduced bandwidth availability is typically larger than the corresponding gain due to higher signal-to-interference ratio, leading to an overall loss of efficiency. The LTE standard therefore provides tools for inter-cell interference coordination of the scheduling in neighbor cells such that cell-edge users in different cells are preferably scheduled on complementary parts of the spectrum when needed. Note that a major difference from static reuse schemes is that LTE still allows for the total available spectrum to be used in all cells. Bandwidth restrictions are only applied when traffic and radio conditions motivate this.

To aid up link inter-cell coordination, LTE defines two indicators that can be exchanged between base stations:

- the high-interference indicator, providing information to neighboring cells about the part of the cell bandwidth upon which the cell intends to schedule its cell-edge users;

- the overload indicator, used to indicate the experienced interference level in each part of the bandwidth to neighboring cells.

2.3 Evolution of LTE-Advanced

Although the term LTE-Advanced is used frequently, it is important to stress that this is not a new radio-access scheme but rather the evolution of LTE to further improve the performance. LTE-Advanced is thus a name for a future release of the LTE standard, currently predicted to release-10. Being an evolution of LTE, LTE-Advanced should be backwards compatible in the sense that it should be possible to deploy LTE-Advanced in spectrum already occupied by the first release of LTE with no impact on existing LTE terminals. A direct consequence of this requirement is that, for an LTE terminal, an LTE-Advanced-capable network should appear as an LTE network. Such spectrum compatibility is of critical

Table 2.1: ITU and 3GPP Requirements [23]

Quantity		IMT-Advanced	LTE-Advanced
Peak Data Rate	UL		1 Gbit/s
	DL		500 Mbit/s
Spectrum Allocation		up to 40 MHz	up to 100 MHz
Latency	User Plane	10 ms	10 ms
	Control Plane	100 ms	50 ms
Spectrum Efficiency (4 ant BS, 2 ant terminal)	Peak	15 bit/s/HZ DL	30 bit/s/HZ DL
		6.75 bit/s/HZ UL	15 bit/s/HZ UL
	Average	2.2 bit/s/HZ DL	2.6 bit/s/HZ DL
		1.4 bit/s/HZ UL	2.0 bit/s/HZ UL
	Cell Edge	0.06 bit/s/HZ DL	0.09 bit/s/HZ DL
		0.03 bit/s/HZ UL	0.07 bit/s/HZ UL

importance for a smooth, low-cost transition to LTE-Advanced capabilities within the network and is similar to the evolution of WCDMA to HSPA.

In addition to the fundamental requirement of being an evolution of LTE and thus backwards compatible, the 3GPP has defined a set of targets [23] to be fulfilled by LTE-Advanced. These requirements are a super-set of the IMT-Advanced requirements, i.e., LTE-Advanced will fulfill, and sometimes even surpass, the IMT-Advanced requirements. For example, the spectrum efficiency requirements are significantly higher for LTE-Advanced than for IMT-Advanced as illustrated in Table I. In fact, many of the IMT-Advanced requirements are close to be fulfilled already with the first release of LTE.

As can be seen in Table 2.1, requirements are set not only on the peak spectral efficiency, but also on the average and cell-edge spectral efficiency. The latter are, in most practical deployments, more important than the peak rates and [23] therefore explicitly states that "special focus should be put on improving the cell edge performance" to provide a reasonably homogeneous user experience across the cell. LTE-Advanced will also provide further enhanced spectrum flexibility beyond the capabilities of LTE Release 8 and be capable of exploiting spectrum allocations up to 100 MHz.

The link performance of current LTE is already quite close to the Shannon limit. From a pure link-budget perspective, the very high data rates targeted by LTE-Advanced require a higher SNR than what is typically experienced in wide-area cellular networks. Although some link improvements are possible, e.g. using additional bandwidth as a means to improve the coding/modulation efficiency, it is necessary to find tools for improving the SNR,e.g. by means to allow for a denser infrastructure at reasonable cost. In the following subsections, some examples of technologies considered for LTE-Advanced are outlined.

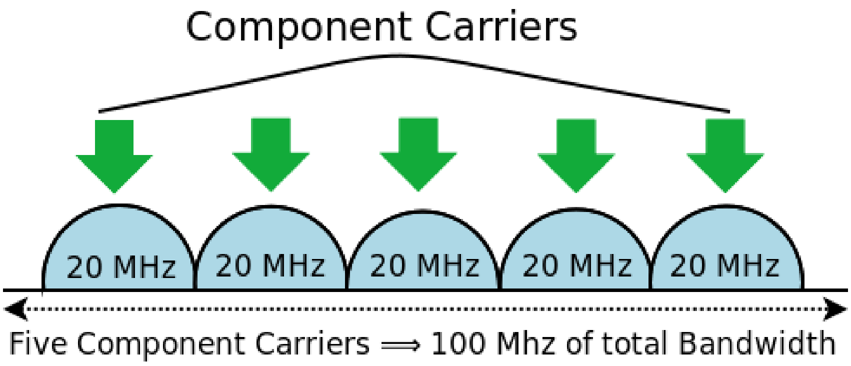

Figure 2.3: Example of Carrier Aggregation

2.3.1 Wider-band transmission and spectrum sharing

Already the first release of LTE radio-access specification provides extensive support for deployment in spectrum allocations of various characteristics. Thus, LTE can be deployed in spectrum allocations of different size, with transmission bandwidths ranging from around 1.25 MHz, suitable for initial migration of e.g. cdma2000/1xEV-DO systems, up to around 20MHz, needed to provide the highest LTE data rates of 300 Mbit/s. Furthermore, LTE allows for operation in both paired and unpaired spectrum by providing a single radio-access technology supporting Frequency-Division Duplex (FDD) as well as Time Division Duplex (TDD). In TDD mode-of-operation, LTE also achieves full spectrum compatibility with the current 3GPP TDD-based TD-SCDMA radio-access technology.

The very high peak-data rate targets for LTE-Advanced can only be fulfilled in a reasonable way with a further increase of the transmission bandwidth, compared to what is supported with the first release of LTE, and transmission bandwidths up to 100 MHz have been discussed in the context of LTE-Advanced. At the same time, such a bandwidth extension should be done while preserving spectrum compatibility. This can be achieved done with so called carrier aggregation, where multiple LTE "component carriers" are aggregated on the physical layer to provide the necessary bandwidth. Carrier aggregation is illustrated in Figure 2.3. To an LTE terminal, each component carrier will appear as an LTE carrier, while an LTE-Advanced terminal can exploit the total aggregated bandwidth.

In Figure 2.3, the case of contiguous component carriers is illustrated although, from a baseband perspective, this is not a prerequisite. Access to large amounts of contiguous spectrum, in the order of 100 MHz, may not always be possible. LTE-Advanced could therefore allow for aggregation of non contiguous component carriers in, possibly, separate spectrum (spectrum aggregation) to handle situations where large amounts of contiguous spectrum are not available. However, it should be noted that aggregation of non-contiguous spectrum is challenging from an implementation perspective. Thus, although spectrum aggregation would be supported by the basic specifications, the actual implementation will be strongly constrained, including specification of only a limited number of aggregation scenarios and aggregation over dispersed spectrum only being supported by the most advanced terminals.

For a component carrier to be accessible by an LTE terminal, synchronization signals and broadcast channels need to be present. On the other hand, for an LTE-Advanced terminal capable of receiving multiple component carriers, it is sufficient if these signals are available on one of the component carriers only. Hence, an operator can, by enabling/disabling synchronization signals, control which part of the spectrum that should be accessible to LTE terminals. Whether carrier aggregation is used or not, and which component carriers to aggregate, is provided to the LTE-Advanced terminals as part of the system information. Finally, note that access to higher transmission bandwidths is not only useful from a peak-rate perspective, but also, and probably more important, as a tool for extending the coverage of medium data rates. As an example, assume a data rate requiring the use of higher order modulation and/or high code rates in LTE. With access to higher bandwidths, the same data rate may be possible to provide with power-efficient QPSK modulation and/or lower code rate, both impacting the link budget favorably.

One key issue for LTE-Advanced is the availability of radio spectrum. Increased data bandwidth comes at the cost of requiring wider transmission bandwidths. Even though the spectrum can be used more efficiently using techniques such as MIMO and beam forming, it is still necessary to have greater levels of available spectrum. As a result some new bands were identified for use by IMT/IMT Advanced technologies at the World Radio Conference in 2007. Possible bands included:

- 450-470 MHz
- 698-862 MHz
- 790-862 MHz
- 2.3-2.4 GHz
- 3.4-3.6 GHz

These allocations are not yet confirmed and they may not be available on a worldwide basis. In addition to this, it is recognized that LTE-Advanced may need to use non-contiguous spectrum, and send data over transmission in different frequency bands.

2.3.2 Enhanced Multi-antenna solutions

Multi-antenna technologies, including beam-forming and spatial multiplexing, are key technology components already of LTE and can safely be expected to continue

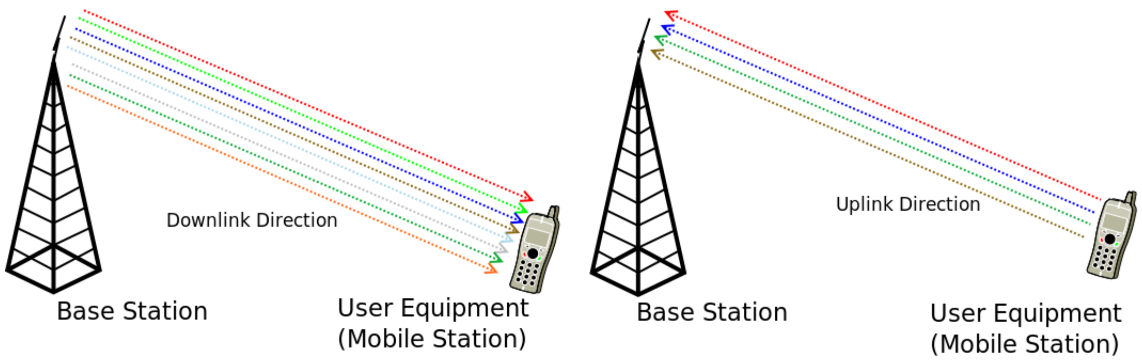

Figure 2.4: LTE_Advanced T_x and R_x Schemes (8×4 MIMO)

to play an even more important role as part of LTE-Advanced. The current LTE multi-antenna design supports up to four antenna ports with corresponding cell-specific reference signals in the down link, in combination with code book-based precoding.

This structure supports both spatial multiplexing of up to four layers, implying peak-data rates of 300 Mbit/s, as well as (code book-based) beam-forming. Together with a total bandwidth of 100 MHz, the current LTE spatial multiplexing schemes would result in a peak rate of 1.5 Gbit/s, well beyond the LTE-Advanced requirement. As a minimum, support for spatial multiplexing on the up link is anticipated to be part of LTE-Advanced. The reason for this is that even by just considering the ITU requirements, up link spatial multiplexing is, in practice, needed to fulfill the peak spectral-efficiency targets.

Increasing the number of supported down link transmission layers beyond four is possible, and can be used as complement to a peak-rate increase through bandwidth expansion. However, spatial multiplexing of a large number of transmission layers to a single terminal is mainly useful in high-SNR scenarios found in close proximity to a base station or in specific scenarios such as small cells or fixed wireless deployments. At the same time, a more relevant target is to improve the wide-area data rates. Hence, improved support for beam-forming as a tool to increase the SNR at the receiver and to employ spatial multiplexing within the beam is in many situations more important than increasing the number of transmission layers alone. Code book-based beam-forming with cell-specific reference signals may result in excessive overhead if more than four antennas are used and improved support for UE-specific reference signals may therefore be attractive for LTE-Advanced.

2.3.3 Coordinated multi-point transmission

The data rates targeted by LTE-Advanced require a (significant) improvement in the SINR at the terminal. Beam-forming is one possibility. Already in current networks, multiple, geographically dispersed antennas connected to a central baseband processing unit are used as a cost-efficient way of building networks.

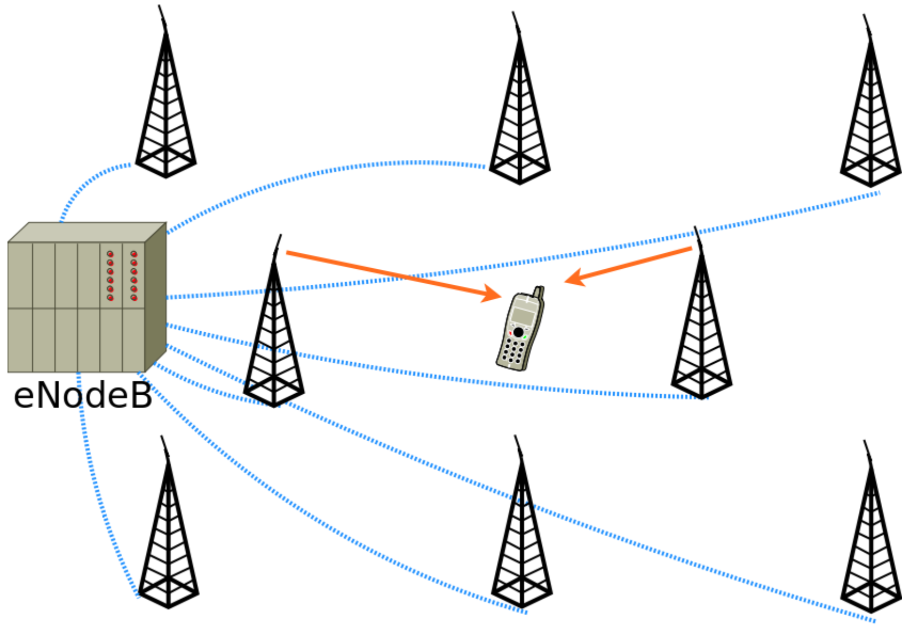

Figure 2.5: Coordinated Multi point Transmission

Such structures open up new transmission strategies. With the base band processing located in a single node, coordinated multi-point transmission/reception (CoMP), illustrated in Fig. 2.5, can be deployed. In the down link it implies coordination of the transmissions from multiple transmission points. Depending on to what extent the terminals are aware of transmissions originating from multiple points, three different alternatives, A, B, C, can be envisioned.

In alternative A, the terminals are not aware of the transmission originating from multiple, geographically separated points. The same receiver processing and measurement reporting as for single-point transmission is used. Hence, in principle, the introduction of multi-point transmission can be made in a backwards compatible way, benefiting also existing LTE terminals. The network can, e.g. based on existing path loss measurements, determine from which transmission points to transmit to a specific terminal. As the terminals are not aware of the presence of multi point transmission, UE-specific reference signals, available already in the first release of LTE, has to be used for channel estimation. In this setting, coordinated multi-point transmission provide diversity gains similar to those found in single frequency broadcast networks and results in improved power amplifier utilization in the network, especially in a lightly loaded network where otherwise some power amplifiers would be idle.

In alternative B, the terminals provide channel-status feedback to the network for all down link channels visible to a particular terminal while the receiver processing remains the same as for single-point transmission. At the network side, as all processing is located in a single node, fast, dynamic coordination of the transmission activity at the different transmission points is possible. One possibility is to do spatial profiteering of the signal transmitted to a particular terminal to reduce inter-user interference, possibly also complemented by dirty paper coding [24]. This type of coordinated multi-point transmission can in principle provide similar benefits as alternative A above but, in addition to improving the strength of the desired signal, it also allows for coordinating the inter user interference to further improve the SNR. Since the terminal is not aware of the exact processing in the network, UE-specific reference signals are needed.

In alternative C, the channel-status reporting is the same as in approach B. However, unlike approach B, the terminals are provided with knowledge about the exact coordinated transmission (from which points, with what transmission weights etc). This information can be used for received signal processing at the terminal side, but comes at a cost of increased down link overhead. For the up link, coordinated multi point reception is mainly a question of applying the relevant signal processing at the receiver. In many respects, this is similar to macro diversity, used already today in many cellular systems.

2.3.4 Relays and Repeaters

The very high data rates targeted by LTE-Advanced requires, as already mentioned, a tighter infrastructure. Coordinated multi point transmission, described above, is one possibility for deploying a denser infrastructure. Another possibility for providing a denser infrastructure from a link-budget perspective is to deploy different types of relaying solutions. In essence, the intention is to reduce the transmitter-to-receiver distance, thereby allowing for higher data rates. Depending on the scheme applied, different types of relaying solutions can be envisioned, although they all share the basic property of relaying the communication between the donor cell and the terminal. The donor cell may, in addition to serving one or several relays, also communicate directly with other terminals.

Two types of Relays (RN) have been defined in 3GPP LTE-Advanced standards, Type-I and Type-II, and non-transparency and transparency [13]. Specifically, a Type-I (or non-transparency) RN can help a remote UE unit, which is located far away from an BS, to access the BS. So a Type-I RN needs to transmit the common reference signal and the control information for the BS, and its main objective is to extend signal and service coverage. Type-I RNs mainly perform IP packet forwarding in the network layer (layer 3) and can make some contributions to the overall system capacity by enabling communication services and data transmissions for remote UE units. On the other hand, a Type-II (or transparency) RN can help a local UE unit, which is located within the coverage of an BS and has a direct communication link with the BS, to improve its service quality and link capacity. So a Type-II RN does not transmit the common reference signal or the control information, and its main objective is to increase the overall system capacity by achieving multipath diversity and transmission gains for local UE units.

The simplest form of relay is a repeater, which simply amplify and forward the received analog signals. Repeaters and are used already today, e.g. for handling coverage holes. Traditionally, once installed, repeaters continuously

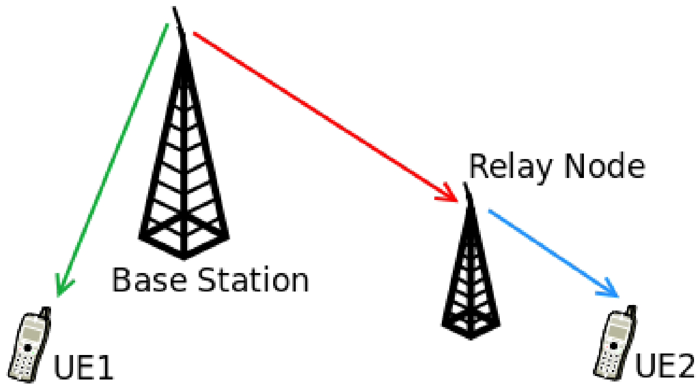

Figure 2.6: Deploying relay

forwards the received signal regardless of whether there is a terminal in its coverage area or not. Such repeaters are invisible to both the terminal and the base station. More advanced repeater structures can also be considered, e.g. schemes where the network can control the transmission power of the repeater and, for example, activate the repeater only when users are present in the area handled by the repeater in order to increase the supported data rates in the area. Irrespective of these mechanisms, as they simply amplify-and-forward the received signal, repeaters are backwards compatible in the sense that they are invisible to the terminal and hence also can serve Rel-8 terminals. All radio-resource management functions such as mobility, scheduling, retransmission mechanism are handled by the base station.

The intermediate relay node may also decode and re encode any received data prior to forwarding it to the served users. This is often referred to as decode-and forward relaying. As the intermediate node decodes and re-encodes received data blocks a significant delay is introduced, longer than the LTE sub frame duration of 1 ms. However, no noise or interference is forwarded by the relay node and rate adaptation may be performed individually for each link. As for repeaters, many different options exist depending on supported features (e.g. support of more than two hops, support of mesh structures). Although very similar in their basic characteristics (e.g. introduction of delays and avoidance of noise amplification), different relaying structures have different properties depending on which functions that are controlled by the relay. A straightforward relaying solution is to let the relay perform the same functions as normally handled by the base station, e.g. hybrid-ARQ retransmissions, scheduling, and mobility functions. In essence, the relay is, from a functional perspective, a base station and therefore there is no need to define new functions for mobility. This relaying solution is sometimes referred to as self-back hauling or “layer-3” relaying. Since the relay from a logical perspective is identical to a base station, it will be capable of handling Rel-8 terminals, which is highly beneficial from a backwards compatibility perspective. Naturally, although the relay acts as a base station from a functional perspective, its physical implementation may still be different, e.g. lower output power and smaller size than a regular base station.

Another possibility is to only keep part of the radio resource control in the relay, e.g. hybrid-ARQ retransmissions and scheduling, while keeping other functions, e.g. mobility handling, in the base station. Such relaying schemes, sometimes referred to as “layer-2” relaying, may require new mobility mechanisms to be defined, e.g. relay-to-base-station handover, in which case they will not be backwards compatible with Release 8. It is also questionable if there are any gains with this type of relaying compared to self back hauling. Regardless of the decode-and-forward relaying solution, there is a need for anchor-to-relay communication, preferably operating in the same spectrum as communication to/from the terminals. Simultaneous reception from the donor cell and transmission to terminals by the relay can be troublesome due to interference from the relay down link transmitter to the relay down link receiver. Similarly when the relay is transmitting in the up link to the donor cell, it may be troublesome to receive up link transmissions from terminals.

Hence, it is necessary to operate the relay such that the relay is not transmitting in the down link when it is supposed to receive data from the donor cell, i.e. to create gaps in the relay-to-terminal transmission. Note that, if the relay is to serve Rel-8 terminals as well, the mechanisms to create the gaps must be present already in Rel-8. Otherwise, the terminals would expect down link transmission, at least in the form of cell-specific reference signals, in each (down link) sub frame. Such a mechanism is actually included already in the first release of LTE in the form of MBSFN (multi cast broadcast single frequency network) sub frames, originally introduced for single-frequency broadcasting transmissions. In an MBSFN sub frame, the terminal will not expect down link transmission, except for the first OFDM symbols. Consequently, the remaining part of the MBSFN sub frame can be used for donor-to-relay communication.

2.3.4.1 Pairing schemes for relay selection

Consider a network with multiple RNs and multiple UE units in each cell. One of the key challenges is to select and pair nearby RNs and UE units to achieve the relay/cooperative gain. The selection of relay partners (i.e., with whom to collaborate) is a key element for the success of the overall collaborative strategy. Practically, it is very important to develop effective pairing schemes to select appropriate RNs and UE units to collaborate in relay transmissions, thus improving throughput and coverage performance for future relay-enabled mobile communication networks. This pairing procedure can be executed in either a centralized or distributed manner. In a centralized pairing scheme, an BSs will serve as a control node to collect the required channel and location information from all the RNs and UE units in its vicinity, and then make pairing decisions for all of them. On the contrary, in a distributed pairing scheme, each RN selects an appropriate UE unit in its neighborhood by using local channel information and a contention-based medium access control (MAC) mechanism. Generally speaking, centralized schemes require more signaling overhead, but can achieve better performance gains, than their distributed counterparts.

Some centralized and distributed pairing schemes have been developed for multiple-RN-single-UE and single-RN-multiple-UE scenarios [13], aiming at optimizing the throughput performance of a single two hops link (or a single UE unit). Only limited work has been reported in the literature for the more general multiple-RN-multiple-UE scenario [9, 10]. Specifically, a centralized pairing scheme based on a min-max criterion and the bipartite graph theory is proposed in [9], which can minimize the maximal outage probability of all the UE units while guaranteeing fairness among them. In [10] another centralized pairing scheme is developed to enable every UE unit to measure the channel qualities toward its neighboring UE units and then identify a list of relay-capable neighbors by using a predefined threshold. This information will be sent to the BS, which will make pairing decisions by sorting the orders in those lists from different UE units. To the best of our knowledge, no distributed pairing scheme has been published for the multiple-RN-multiple-UE scenario yet. In this section we develop and evaluate both centralized and distributed pairing schemes for achieving multipath diversity and optimizing the overall system performance in a realistic multiple-RN-multiple-UE scenario.

2.3.4.2 Centralized Pairing Scheme

In a centralized pairing scheme, each RS identifies a set of UE units it can serve in its vicinity and checks the channel condition (service quality) for the links between the RN and the BS and between the RN and every UE unit in this service set. This information needs to be periodically updated and reported to the local BS to capture dynamic changes of neighborhood and channel conditions at each RN. After receiving timely updates from all the RNs in the same cell, the corresponding BS will generate a two dimensional matrix $C = [c_{i,j}]$ with its rows and columns corresponding to UE IDs and RNs IDs, respectively. In matrix C the element $c_{i,j} (c_{i,j} \geq 0)$ represents the achievable data rate over a two hops relay transmission when the ith UE is served by the jth RN. If the ith UE is not in the service set of the jth RNs, $c_{i,j}$ is set to zero. Otherwise, $c_{i,j}$ can be calculated based on the instantaneous channel conditions between the ith UE and the jth RN, and between the jth RN and the BS. Under the condition that each RN can serve only one UE unit at a time, the optimization objective of a centralized pairing scheme is to maximize the number of served UE units. Specifically, the BS will manipulate matrix C by keeping as many non-zero rows as possible (i.e., at least one positive element exists in each of these rows), while maintaining at most one nonzero element in each column because one RN cannot serve more than one UE unit simultaneously. To achieve the optimization objective, the BS first searches and keeps those rows with only one non-zero element; that is, the UE units with only one RN in their vicinities are given high priority to be paired with their only RN. If several such high-priority UE units are sharing the same RN, the one with the maximal achievable data rate will be selected; as a result, the rows corresponding to the other UE units will be eliminated from matrix C. Once an RN is selected for a UE unit, it cannot be used by any other UE units (if any) in its service set. Thus, the BS will clear the values (i.e., set to zeros) along the column where the selected RN is located, except for the row corresponding to the paired UE. Following the same criteria, the BS will iteratively check and keep the remaining rows, starting with those having fewer non-zero elements, and then continuously update the matrix C by setting zeros into the corresponding column each time an appropriate RN is paired with a new UE unit. Finally, all the columns contain only one non-zero element (i.e., the paired UE and RN), and this complete pairing result will be broadcast to all the RNs and UE units in the same cell. The overall throughput for the served UE units can be calculated by adding these nonzero values together.

2.3.4.3 Distributed Pairing Scheme

To reduce periodic information exchange and signaling overhead in the centralized pairing scheme, a simple distributed pairing scheme based on a contention-based MAC mechanism has been proposed in [13]. Specifically, a common slotted communication channel is shared by all the RNs in the same cell. Every N slots are grouped into a pairing section, and a complete pairing procedure contains M pairing sections. In practice, these parameters N and M can be tuned according to the densities of RNs and UE units in each cell, thus to achieve a better performance trade off between collisions and delay in the proposed distributed pairing procedure. In the distributed pairing scheme, each RN first identifies its service set of neighboring UE units. It also evaluates the channel conditions between itself and the BS, as well as those UE units in the service set. Then, in the first pairing section of the distributed pairing procedure, those RNs with a single-UE service set each randomly selects a time slot from the N slots in this pairing section to broadcast its served/paired UE ID. If multiple RNs choose the same time slot to announce their served UE units, a pairing collision occurs, and those RNs involved will try again in the next pairing section. Other RNs with a service set consisting of more than one UE unit will listen to the broadcast messages in the first pairing section and then update their service sets by removing those announced/paired UE units. The second pairing section is for those collided RNs (if any) in the first pairing section and some additional RNs, each having a newly updated service set of only one UE unit. These RNs will independently select their own time slot to announce their served/paired UE units in the second pairing section. Pairing collisions may occur, and the remaining RNs (with a service set of more than one UE unit) will update their service sets accordingly after hearing the successfully announced UE IDs. The same process continues in the following pairing sections, until the last (i.e., the Mth) section, wherein each remaining (unpaired) RN will select a UE unit from its current service set and announce its final pairing choice at a random time slot. Pairing collisions in this last section will not be resolved, and a new pairing procedure will start over again when an RN's neighborhood is changed due to user mobility or dynamic channel conditions. By introducing high priority for the RNs with a single-UE service set in the pairing procedure, the proposed distributed pairing scheme can effectively reduce pairing collisions, increase successful pairing probability, and thus achieve the objective of serving as many UE units as possible in a multiple-RN-multiple-UE scenario.

2.4 Advantages and Key Features Of LTE- Advanced

2.4.1 Advantages

Some advantages that are applicable to the 4th Generation mobile communications are also applicable to LTE-Advanced. With average download speeds of 400 Kbps to 700 Kbps, the network offers enough bandwidth to enable cell phone users to surf and download data from the Internet. LTE-Advanced should significantly lower the bit-cost for the end-users and the total cost of ownership for the operators. At the same time, LTE-A should meet new emerging challenges such as energy-efficient Radio Access Network (RAN) design, increase the flexibilities of network deployments, and off load networks from localized user communications. Regardless of the actual technology, the forthcoming technology will also be able to allow the complete interoperability among heterogeneous networks and associated technologies, thus providing clear advantages in terms of:

- Coverage: The user gets best QoS and widespread network coverage as there is network availability at any given time.
- Bandwidth: Sharing the resources among the various networks will reduce the problems of spectrum limitations of the third generation.

2.4.2 Key Features

- Various concepts for relay nodes
- UE Dual TX antenna solutions for SU-MIMO and diversity MIMO
- Scalable system bandwidth exceeding 20 MHz, Potentially up to 100 MHz
- Local area optimization of air interface
- Nomadic / Local Area network and mobility solutions
- Flexible spectrum usage
- Cognitive radio
- Automatic and autonomous network configuration and operation
- Enhanced precoding and forward error correction
- Interference management and suppression
- Asymmetric bandwidth assignment for FDD

- Hybrid OFDMA and SC-FDMA in up link
- UL/DL inter BS coordinated MIMO

Apart from this the Heterogeneous Services (Services that are heterogeneous in nature; for example, different types of services such as audio, video etc.) such as quality and accessibility may not be the same due to the heterogeneity of the network. For instance, a user in proximity of the shopping mall but out of the coverage of a LAN can still receive pop-up advertisements using the Miltie-hop adhoc network setup in his surrounding. Therefore the dynamics of the network environment can change the number of users, terminals, topology, etc.

2.5 Comparison between LTE and LTE-advanced

A summary comparison of performance requirements of LTE with some of the current agreements of LTE Advanced [23] are:

Table 2.2: Comparison between LTE and LTE-Advanced [23]

Technology	LTE	LTE-Advanced
Peak Data Rate Down link	150 Mbit/s	1 Gbit/s
Peak Data Rate Up link	75 Mbit/s	500 Mbit/s
Transmission Bandwidth Down link	20 MHz	100 MHz
Transmission Bandwidth Up link	20 MHz	40 MHz (as defined by ITU)
Mobility	Optimized for low speeds (<15 km/hr), High performance as speeds up to 120 km/hr, Maintain links at speeds up to 350 km/hr	Same as in LTE
Coverage	Full Performance up to 5 Km	(a) Same as LTE requirement (b) should be optimized or deployment in local areas/micro cell environments
Scalable Bandwidths	1.3, 3, 5, 10, and 20 MHz	up to 20-100 MHz
Capacity	200 active users cell in 5 MHz	3 times higher than that in LTE

Chapter 3

WINNER II Channel Model

The goal of WINNER was to develop a single ubiquitous radio access system adaptable to a comprehensive range of mobile communication scenarios from short range to wide area. This will be based on a single radio access technology with enhanced capabilities compared to existing systems or their evolutions. WINNER II is a continuation of the WINNER I project, which developed the overall system concept. WINNER II has developed and optimized this concept towards a detailed system definition. The novel features of the WINNER-II models are its parametrization, using of the same modeling approach for both indoor and outdoor environments, new scenarios like outdoor-to-indoor and indoor-to-outdoor, elevation in indoor scenarios, smooth time (and space) evolution of large-scale and small-scale channel parameters (including cross-correlations), and scenario-dependent polarization modeling. The models are scalable from a single single-input-single-output (SISO) or multiple-input-multiple-output (MIMO) link to a multi-link MIMO scenario including polarization among other radio channel dimensions. In this chapter we describe the key features and mathematical model of WINNER channel model in brief.

3.1 Channel Model

WINNER channel model is a geometry based stochastic model. Geometry based modeling of the radio channel enables separation of propagation parameters and antennas. The channel parameters for individual snapshots are determined stochastically, based on statistical distributions extracted from channel measurement.

Antenna geometries and field patterns can be defined properly by the user of the model. Channel realizations are generated with geometrical principle by summing contributions of rays (plane waves) with specific small scale parameters like delay, power, AoA and AoD. Superposition results to correlation between

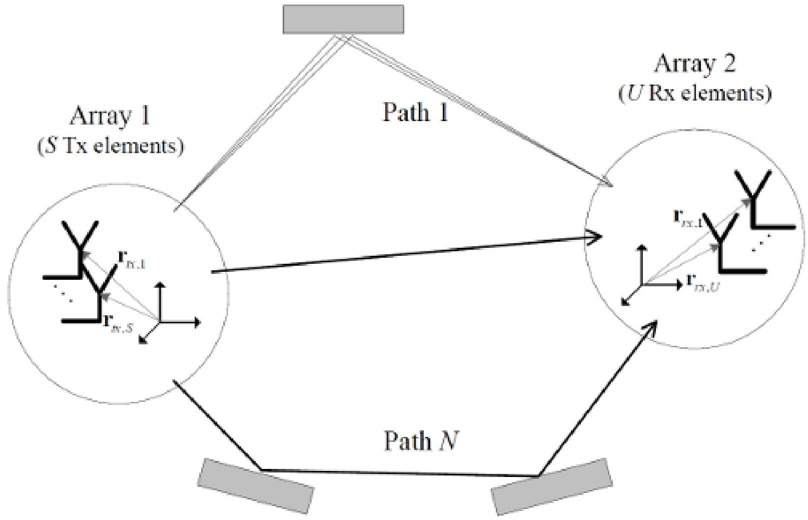

Figure 3.1: The Channel Model [25]

antenna elements and temporal fading with geometry dependent Doppler spectrum. A number of rays constitute a cluster. Elements of the MIMO channel, i.e. antenna arrays at both link ends and propagation paths, are illustrated in Figure 3.1.

Transfer matrix of the MIMO channel is [25]:

$$\mathbf{H}(t;\tau) = \sum_{n=1}^{N} \mathbf{H}_n(t;\tau) \tag{3.1}$$

It is composed of antenna array response matrices F_{tx} for the transmitter, F_{rx} for the receiver and the propagation channel response matrix h_n for cluster n as follows [25]:

$$\mathbf{H}_{u,s,n}(t;\tau) = \iint \mathbf{F}_{rx}(\varphi)\,\mathbf{h}_n(t;\tau,\phi,\varphi)\,\mathbf{F}_{tx}^{T}(\phi)\,d\phi d\varphi \tag{3.2}$$

The channel from T_x antenna element s to R_x element u for cluster n is as follows [25]:

$$\mathbf{H}_{u,s,n}(t;\tau) = \sum_{m=1}^{M} \begin{bmatrix} F_{rx,u,V}(\varphi_{n,m}) \\ F_{rx,u,H}(\varphi_{n,m}) \end{bmatrix}^{T} \begin{bmatrix} \alpha_{n,m,VV} & \alpha_{n,m,VH} \\ \alpha_{n,m,HV} & \alpha_{n,m,HH} \end{bmatrix} \begin{bmatrix} F_{tx,s,V}(\phi_{n,m}) \\ F_{tx,s,H}(\phi_{n,m}) \end{bmatrix}$$

$$\times \exp\left(j2\pi\lambda_0^{-1}\left(\overline{\varphi_{n,m}} \cdot \overline{r_{rx,u}}\right)\right) \exp\left(j2\pi\lambda_0^{-1}\left(\overline{\varphi_{n,m}} \cdot \overline{r_{rx,u}}\right)\right)$$

$$\times \exp\left(j2\pi\upsilon_{n,m}t\right)\delta\left(\tau - \tau_{n,m}\right) \tag{3.3}$$

where,

$F_{rx,u,V}$ and $F_{rx,u,H}$ are the antenna element u field patterns for vertical and horizontal polarizations respectively

$\alpha_{n,m,VV}$ and $\alpha_{n,m,VH}$ are the complex gains of vertical-to-vertical and horizontal-to-vertical polarizations of ray n, m respectively

λ_0 is the wave length of carrier frequency

$\overline{\phi_{n,m}}$ is AoD unit vector

$\overline{\varphi_{n,m}}$ is AoA unit vector

$\overline{r_{tx,s}}$ and $\overline{r_{rx,u}}$ are the location vectors of element s and u respectively

$\upsilon_{n,m}$ is the Doppler frequency component of ray n, m

If the radio channel is modeled as dynamic, all the above mentioned small scale parameters are time variant, i.e. function of t.

3.2 Channel Parameters

Parameters used in the WINNER II Channel Models have been listed and shortly explained below. The first set of parameters is called large scale (LS) parameters, because they are considered as an average over a typical channel segment i.e. distance of some tens of wave-lengths. First three of the large scale parameters are used to control the distributions of delay and angular parameters. And the second set is known as the Support Parameters.

Large Scale Parameters :

- Delay spread and distribution
- Angle of Departure spread and distribution
- Angle of Arrival Spread and distribution
- Shadow Fading standard deviation
- Ricean K-factor

Support Parameters:

- Scaling parameter for Delay distribution

- Cross-polarization power ratios
- Number of clusters
- Cluster Angle Spread of Departure
- Cluster Angle Spread of Arrival
- Per Cluster Shadowing
- Auto-correlations of the LS parameters
- Cross-correlations of the LS parameters
- Number of rays per cluster

All of these parameters have been specified from the measurement results or, in some cases, found from literature. Number of rays per cluster has been selected to be 20. Analysis of the measurement data for the different parameters has been described in the Part II document of this deliverable. In the WINNER Channel Models the parameters are assumed not to depend on distance. Although this assumption is probably not strictly valid, it is used for simplicity of the model. The parameter values are given in paragraph 4.4 and represent expected values over the applicability range. In the basic case the Angles of Arrival and Departure are specified as two-dimensional, i.e only azimuth angles are considered. For the indoor and outdoor-to-indoor cases the angles can also be understood as solid angles, azimuth and elevation, and the modeling can be performed also as three-dimensional.

3.3 Network Layout

WINNER MIMO radio channel model enables system level simulations and testing. This means that multiple links are to be simulated (evolved) simultaneously. System level simulation may include multiple base stations, multiple relay stations, and multiple mobile terminals as in Figure 3.2. Link level simulation is done for one link, which is shown by blue dashed ellipse. The short blue lines represent channel segments where large scale parameters are fixed. System level simulation consists of multiple links. Both link level and system level simulations can be done by modeling multiple segments, or by only one (CDL model).

A single link model is shown in Figure 3.3. The parameters used in the models are also shown in the figure. Each circle with several dots represents scattering region causing one cluster. The number of clusters varies from scenario to another.

In spatial channel model the performance of the single link is defined

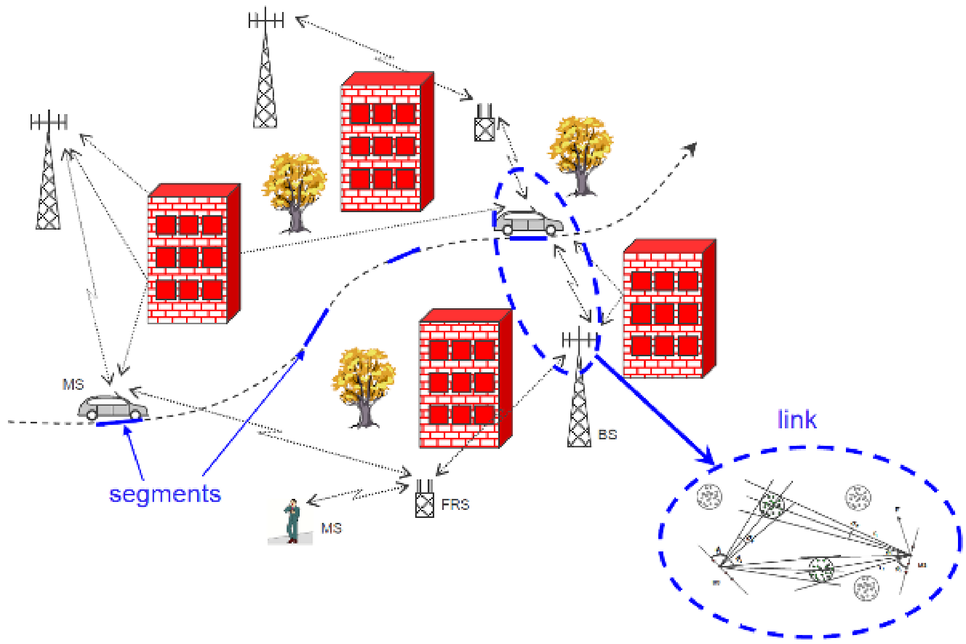

Figure 3.2: System level approach, several drops [25]

by small-scale parameters of all MPCs between two spatial positions of radio-stations. According to this, if only one station is mobile (MS), its position in space-time is defining a single link. The more complex network topology also includes multi hop links and cooperative relaying, however more complex peer-to-peer connections could be easily described as collections of direct radio-links. Large-Scale Parameters (LSP) are used as control parameters , when generating the small-scale channel parameters. If we are analyzing multiple positions of MS (many MSs or multiple positions of the single MS) we have a multiple-link model for system level simulations. It can be noted that different MSs being at the same spatial position will experience same LSP parameters. For multi-link simulations some reference coordinate system has to be established in which positions and movement of radio-stations can be described. A term network layout is designating complete description of the relative positions of the system elements, as well as vectored description of their movements (speeds). In general, positions (coordinates) of scatterers are unknown. Only exceptions are related to far cluster scatterers (FCS) that are actually positioned in the same coordinate system as radio-stations. In multi-link simulations spatial correlations of channel parameters are important. In order to establish correlations between links at system level the LSPs have been generated with the desired correlation properties.

3.4 Reduced Complexity Models

A need has been identified for reduced-complexity channel models that can be used in rapid simulations having the objective of making comparisons between systems alternatives at link-level (e.g. modulation and coding choices). In this report, such models are referred to as reduced-complexity models, and have the

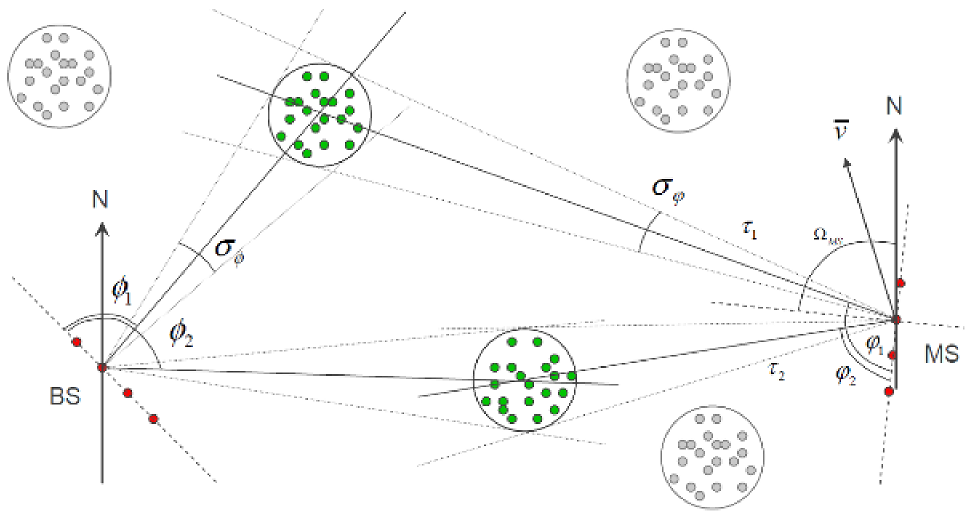

Figure 3.3: Single link [25]

Table 3.1: Ray offset angles within a cluster, given for 1° RMS angle spread [25]

Ray number m	Basis vector of offset angles α_m
1,2	±0.0447
3,4	±0.1413
5,6	±0.2492
7,8	±0.3715
9,10	±0.5129
11,12	±0.6797
13,14	±0.8844
15,16	±1.1481
17,18	±1.5195
19,20	±2.1551

character of the well-known tapped delay line class of fading channel models. However, to address the needs of MIMO channel modeling, temporal variations at the taps are determined by more detailed information than that required for the specification of relative powers, envelope fading distributions, and fading rates, which are typical inputs to traditional tapped delay line models.

Specifically, multipath AoD and AoA information is inherent in the determination of tap fading characteristics. For these reasons, the reduced complexity models reported herein are referred to as Cluster Delay Line (CDL) models. A cluster is centered at each tap. In general, each cluster is comprised of the vector sum of equal-powered MPCs (sinusoidal), all of which have the same or close to same delay. Each MPC has a varying phase, but has fixed AoA and AoD offsets. The latter depend on the angular spreads at the MS and the BS, respectively, as shown in Table 3.1.

The values in this table were chosen to realize a specified Laplacian PAS for each cluster, appropriate to the scenario being modeled. In cases where there is a desire to simulate Ricean-like fading, an extra MPC is added, which is given a power appropriate to the desired Rice factor, and zero angular offset. The powers and delays of the clusters can be non-uniform, and can be chosen to realize the desired overall channel RMS delay spread. Doppler information is not specified explicitly for CDL models. This is because Doppler is determined by the AoAs of the MPCs, MS speed and direction, and the specified antenna patterns at the MS and BS, upon which there are no restrictions, except in fixed feeder link scenarios.

3.4.1 Cluster Delay Line models for mobile and portable scenarios

Cluster delay line (CDL) models for all mobile scenarios have been generated from the corresponding generic models by selecting typical values from a set of random channel realizations. The CDL models consist of the average power, mean AoA, mean AoD, and angle spreads at the BS and MS associated with each cluster within the cluster delay line models. Although AoA and AoD values are fixed, it is recommended to have directional variation for e.g. beam forming simulations by adding network layout related angle parameter Ω_{MS} and Ω_{BS} to all tabulated angles.

3.4.2 Cluster Delay Line models for fixed feeder links

Only CDL models have been created for fixed feeder links (B5 scenarios). Some of the model parameters have been created by applying models generated in WINNER. As for the mobile and portable scenarios, any desired antenna patterns can be chosen. However, for scenarios B5a and B5b, at distances greater than 300 meters, the 3 dB beam width of the antenna at one end of the link should be less than 10 degrees, while that at the other end of the link should be less than 53 degrees. Different parameters are specified in the cited tables for scenarios B5a, b, c, and d. For fixed link scenarios B5a, B5b, B5d and B5f, Doppler shifts are independent of AoAs. Instead, they are derived from considerations concerning the movement of interacting objects. One interacting object per cluster is modeled as having motion, while the others are fixed. Associated Doppler frequencies are specified in CDL tables. For the scenario B5c, two whole cluster are moving with random velocity.

3.5 Path loss models

Path loss models for the various WINNER scenarios have been developed based on results of measurements carried out within WINNER, as well as results from the open literature. These path loss models are typically of the following form [25]

$$PL = A \log_{10}(d) + B + C \log_{10}\left(\frac{f_c}{5.0}\right) + X \qquad (3.4)$$

where d is the distance between the transmitter and the receiver in [m].

f_c is the system frequency in [GHz].

A the fitting parameter which includes the path-loss exponent.

B is the intercept, it is a fixed quantity based on empirical observations. It is determined by the free space path loss to the reference distance and an environment dependent constant.

C describes the path loss frequency dependence.

X is an optional, environment-specific term (e.g., wall attenuation in the A1 NLOS scenario).

The models can be applied in the frequency range from 2 – 6 GHz and for different antenna heights. The processing of measuring the values from empirical observation of the variables A, B, C and X of Equation 3.5 are described in [25]. The free-space path loss, PL_{free}, can be written as follows

$$PL_{free} = 20 \log_{10}(d) + 46.4 + 20 \log_{10}\left(\frac{f_c}{5.0}\right) \qquad (3.5)$$

The path loss models used in different scenarios of WINNER channel model are based on measured data obtained mainly at 2 and 5 GHz. These models have been extended to arbitrary frequencies in the range from 2 – 6 GHz with the aid of the path loss frequency dependencies *(C)* and the path loss intercept *(B)* defined in [25].

3.6 CDL Models

Although the clustered delay line (CDL) model is based on similar principles as the conventional tapped delay line model, it is different in the sense that the fading process for each tap is modeled in terms of a sum of sinusoidal rather than by a single tap coefficient. The CDL model describes the propagation channel as being composed of a number of separate clusters with different delays. Each cluster, in turn, is composed of a number of multipath components (rays) that have the same delay values but differ in angle-of-departure and angle-of-arrival. The angular spread within each cluster can be different at the BS and the MS. The offset angles represent the Laplacian PAS of each cluster. The average power, mean AoA, mean AoD of clusters, angle-spread at BS and angle-spread at MS of each cluster in the CDL represent expected output of the stochastic model with parameters listed in WINNER II documentation [25]. Exceptions are the fixed feeder link models in scenario B5, for which no stochastic models have been defined.

3.7 Applicability

3.7.1 Environment dependence

Different radio-propagation environment would cause different radio-channel characteristics. Instead of attempt to parametrize environment directly (e.g. street widths, average building height etc.) WINNER models are using (temporal and spatial) propagation parameters obtained from channel measurements in different environments. In this context, environments in which measurements are conducted to observe radio-channel characteristics are called propagation scenarios. For each scenario measured data is analyzed and complemented with results from literature to obtain scenario-specific parameters. After this point, same generic channel is used to model all scenarios, just by using different values of channel parameters.

Usually, even for the same scenario, existence of LOS component substantially influences values of channel parameters. Regarding to this property, most WINNER scenarios are differentiating between LOS and NLOS conditions. To enable appropriate scenario modeling, transition between LOS and NLOS cases have to be described. For this purpose distance dependent probability of LOS is used in the model.

3.7.2 Frequency dependence

Dependence on carrier frequency in WINNER model is found in path-loss models. All the scenarios defined by WINNER support frequency dependent path-loss models valid for the ranges of 2 – 6 GHz. The path-loss models are based on measurements that are mainly conducted in 2 and 5 GHz frequency range. In addition the path-loss models are based on results from literature, like Okumura-Hata, which have been extended to the desired frequency range.

From WINNER measurement results and literature survey it was found that [25][35] model parameters DS, AS and Ricean K-factor do not show significant frequency dependence. For that reason these parameters show only dependence on environment (scenario).

For modeling of systems with time-division-duplex (TDD) all models are using same parameters for both up link and down link. If system is using different carriers for duplex (FDD), then (additionally to path loss) random phases of scatterer contributions between UL and DL are modeled as independent. For the WINNER purposes it is required that channel model supports bandwidths up to 100 MHz. Following the approach described in (for indoor propagation modeling) and further with SCME, WINNER II model introduces intra-cluster delay spread as a mean to support 100 MHz bandwidth and to suppress frequency correlation. Instead of zero-delay-spread-cluster approach of Phase I model, the two strongest clusters with 20 multipath components (MPCs) are subdivided into 3 zero-delay sub-clusters. Thus we keep the total number of MPCs constant, but introduce four additional delay taps per scenario.

Chapter 4

Case Design

In this chapter, we describe the main objective that is being studied, our approach towards the solution to this objective and the general design of the case we are considering. We then discuss the setup of the design environment of the simulator with WINNER channel model (that have been discussed in Chapter 3). Furthermore we discuss the parameters and specifications of the designing.

4.1 The Case Statement

Currently, LTE is the latest standard in the mobile network technology tree that produced the GSM/EDGE and UMTS/HSPA network technologies.[14][15] The current generation of mobile telecommunication networks are collectively known as 3G. Although LTE is often marketed as 4G, first-release LTE does not fully comply with the IMT Advanced 4G requirements. The pre-4G standard is a step toward LTE Advanced, a 4th generation standard (4G) of radio technologies designed to increase the capacity and speed of mobile telephone networks. LTE Advanced is backwards compatible with LTE and uses the same frequency bands, while LTE is not backwards compatible with 3G systems. Being described as a 3.9G (beyond 3G but pre-4G) technology the first release LTE does not meet the IMT Advanced requirements for 4G (also called IMT Advanced) as defined by the International Telecommunication Union, such as peak data rates up to 1 Gbit/s. LTE Advanced should be compatible with first release LTE equipment, and should share frequency bands with first release LTE. The mobile communication industry and standardization organizations have therefore started to work on 4G access technologies such as LTE Advanced. As stated in Chapter 2, one of the key features of LTE-Advanced is the capability of relaying. Relaying can be used to increase the coverage area of base stations, increase the capacity, and cover shadowed areas. Also deploying relay can allow cost efficient and flexible system deployment. So a LTE model with Relaying technology should do the trick for LTE-Advanced.

This thesis work investigates the feasibility of deploying relay node(s) within a LTE network, while obeying the specific regulatory conditions which ensures that the specifications of IMT and 3GPP [19] for LTE-Advanced are obeyed. As stated earlier, as a channel model WINNER is considered here. After designing the simulator, a comparative test between a criterion with relay nodes and a criterion without relay nodes were run to compare the performance of the both criteria. As case scenario,s we have chosen the built-in scenarios of WINNER channel model.

4.2 Components Description

WINNER channel model deliver the model only in Physical Layer. So the designed simulator is a physical level simulator. The main components that are used to design this simulator are the Scenario, the Base Station (BS), the Relay Node (RN) and the User Equipment (UE). These components are discussed briefly below:

4.2.1 The Scenarios

In Chapter 2, we learned that WINNER II comes with 14 different scenarios. The scenarios cover some typical cases. They are not intended to cover all possible environments and conditions: e.g. the mountainous or even hilly rural environments have not been covered. Similarly the antenna heights do not cover all values that could be seen reasonable. Actually, the environments are such that are found in urban areas of European and North- American countries. The environments can be grouped into two groups. Firstly, most of the scenarios use the ordinary way placing the transmitters and receivers, so that the only location parameter is the distance between transmitter and receiver, called non-grid-based models. Secondly, the other group of the scenarios is grid-based. This means that there is a grid of streets or a building layout or both, where the transmitters and receivers can be located e.g. by Cartesian coordinates. This latter group of scenarios include the indoor environment and micro cells [25][26]. Other scenarios belong to the first group.

4.2.2 The Base Station

The Base Stations used in this design are 3 sectored omnidirectional antenna. Which means, the antenna pattern that has been used at the Base Station is 3-sector antenna used for each sector. The channel model docent depend on the base station. So other antenna patterns (1-sector antenna and 2-sector antenna) can also be used. For our consideration, only one BS is used in the simulator.

4.2.3 The User Equipment

The User Equipment is an one sectored directional antenna. The UE does not affect the Channel Model, which means the channel model is independent of the UE. For our simulator we consider the UE to be static (the velocity is zero).

4.2.4 The Relay Node

Relays used in this simulator are conventional Amplify and Forward Relays (AF). These relays provide best benefit in noise limited system deployment. These relays are constructed using a UE in the receiving terminal and a BS in the transmitting terminal. It is considered that no scheduling is involved in the relay as well as no time delay occurred by the relays.

4.3 Designing the Simulator

In this part we will discuss the design procedure of the LTE-Advanced simulator with the simulation parameters in details.

4.3.1 Simulation Parameters

The simulation are performed in a network that is represented by a regular hexagonal cellular layout with one BS, one RN and one UE. Simulation setup follows the assumption of WINNER II [25][26]. the RN height is chosen in between the heights of BS and UE. Only the down link is simulated. The transmit power is considered as 1 Watt. The simulation parameters are summarized below:

- Carrier Frequency is 2 GHz
- Channel Bandwidth is 20 MHz
- Number of Cell is 1
- Channel Model used is WINNER II
- Full Buffer Down link is used
- BS height: 32m
- Number of BS sector: 1
- BS antenna per sector: 1

- BS transmitted power: 1 W
- BS elevation and antenna gain: 14 dBi
- BS noise figure: 5 dB
- RN height: 25 m
- RN numbers: 1
- RN antennas: 1
- RN transmitted power: 1 W
- RN elevation and antenna gain: 9 dBi
- RN noise figure: 7 dB
- UE height: 1.5m
- UE numbers: 1 (single user)
- UE antennas: 2 (cross polarized)
- UE elevation and antenna gain: 0 dBi
- UE noise figure: 7 dB

4.3.2 Designing the Environments

By default the WINNER channel model comes with no relay. As a standard LTE model, it consists of only BSs and UEs which are distributed randomly. The locations of the BS and the UE can be anywhere within the cell. Which means the distance between BS and UE will be set up randomly. For only one BS and one UE the simulation environment will look like the Figure 4.1.

If we introduce a Relay Node in between the BS and UE, we have to fix the distance between BS and UE. Otherwise there may some situation where the distance between BS and UE is less than the distance between BS and RN. If we put the Relay Node in between the BS and UE, the environment will look like the Figure 4.2.

After putting the relay node, the BS can communicate with UE in two ways (Figure 4.3):

- BS can communicate with UE via the RN (indirect communication). It's

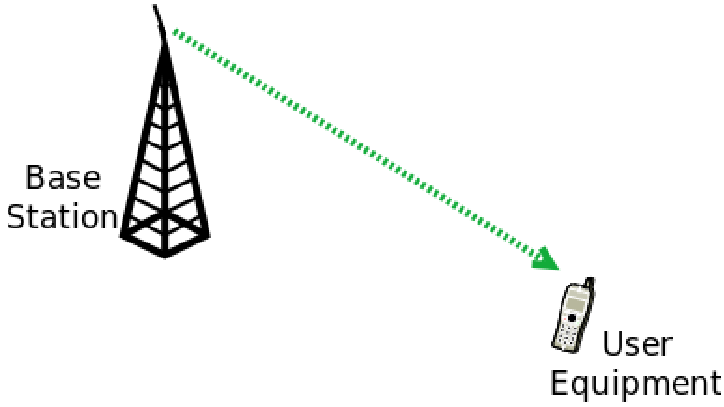

Figure 4.1: Simulator Environment without any Relay Node

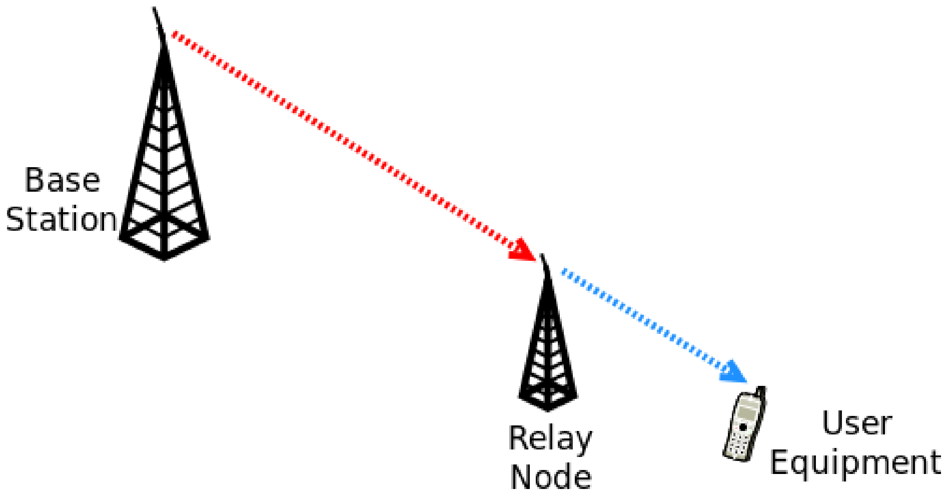

Figure 4.2: Simulator Environment with Relay Node

a two hops communication. First hop uses the Relay link and the second hop uses the Direct link.

- BS can communicate with UE without the RN (direct communication). It/s a single hop communication.

Based on this approach, we can describe three different environments for the simulation:

- Without Relay Environment: Where there is no relay in between the BS and UE. The only way of communication is the direct way from the BS to the UE. (Figure 4.1)

- Non co-operative Environment: It is a two hop communication between the BS and the UE. A RN is introduced in between the BS and UE. So the BS communicates via the RN with the UE. (Figure 4.2)

- Co-operative Environment: In this environment (Figure 4.3), the BS can communicate with the UE using both direct link and indirect link (via RN).

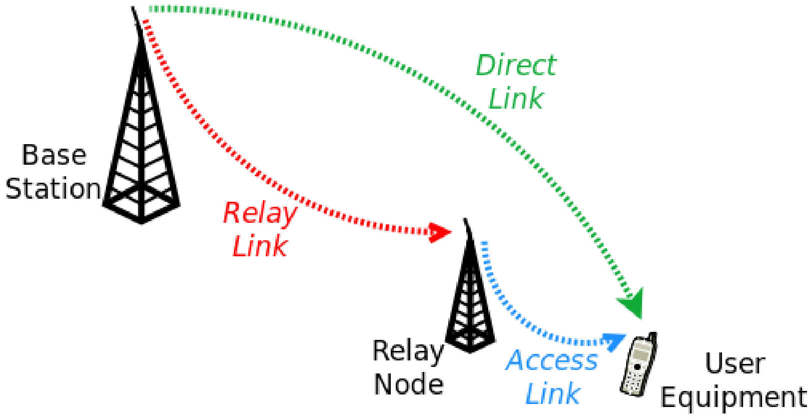

Figure 4.3: Simulator Environment in co-operative mode with one relay

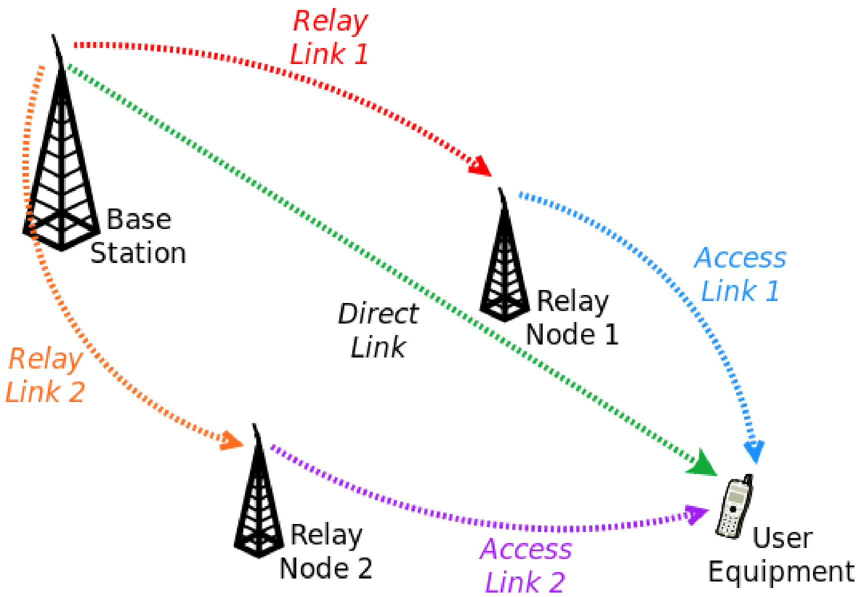

Figure 4.4: Simulator environment in co-operative mode with 2 relays

The link between the BS and the UE is referred to the Direct Link, the link between BS and the RN is referred to the Relay Link and the link between the RN and the UE is referred to the Access Link.

- Co-operative Environment with 2 relays: Instead of one relay, two relays are deployed in this environment. Figure 4.4 shows the general idea of this environment. As there are two relays, so the number of relay link and access link will be two in each case, which leads the environment to have total 5 links.

The simulator should be designed in a way so that it works in the above four environments.

4.3.3 Fixing the Distance

To obtain the effect of RN, all the three nodes (BS, RN and UE) should be placed in the fixed locations. We define the 3D antenna configuration and pattern as well as the 3D co-ordinates of the nodes. For the simulation purpose, we consider the distance between the UE and BS is 1000m and the RN is deployed just in the middle of those two nodes. Which makes the RN to be situated in a distance of 500m both from the UE and BS. This setup is shown in Figure 4.5 and covers the *without relay environment, non co-operative environment* and *co-operative environment.*

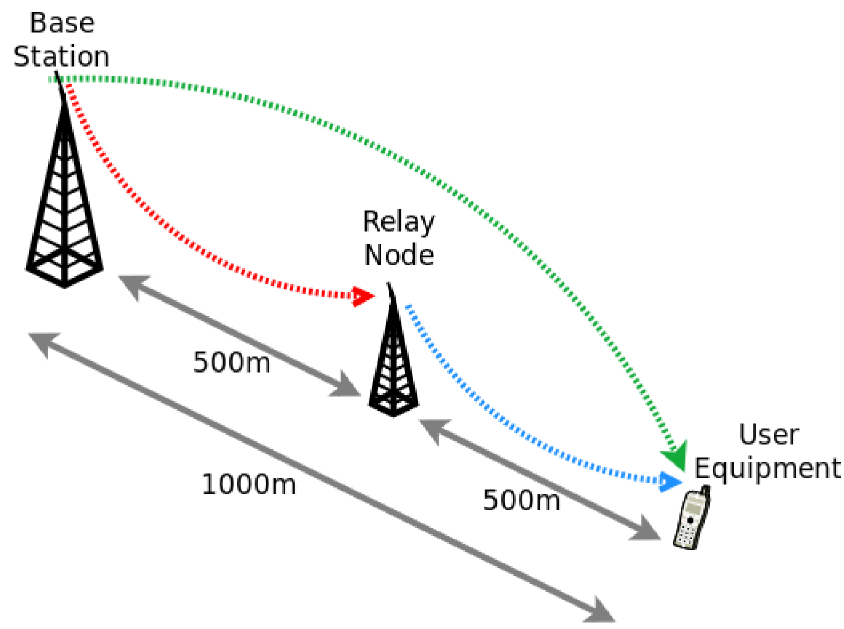

Figure 4.5: Simulation Environment (after fixing the distances)

For *co-operative environment with 2 relays environment*, the distance between the BS and UE remains the same, which is 1000m. Both the RNs are placed in such a way so that they have the same distance from BS and and UE. So RN1 is 559m away from BS as well as UE. And RN2 is also placed 559m away from the BS and UE. The general setup is visualized in Figure 4.6.

4.3.4 Relay Deployment

For our simulator, it is necessary to implement a multi hop environment, where a relay is employed in between the BS and the UE. Relay transmission can be seen as a kind of collaborative communications, in which a Relay Node (RN) helps to forward user information from neighboring user equipment (UE) to a local eNode-B or Base Station (BS). The relay itself is a combination of a UE (the receiving part) and a BS (the transmission part). So deploying relay means deploying a pair of BS and UE in the environment. As in Figure 4.7, there are two Base Stations denoted as BS1, BS2 and two Mobile Stations denoted as UE1

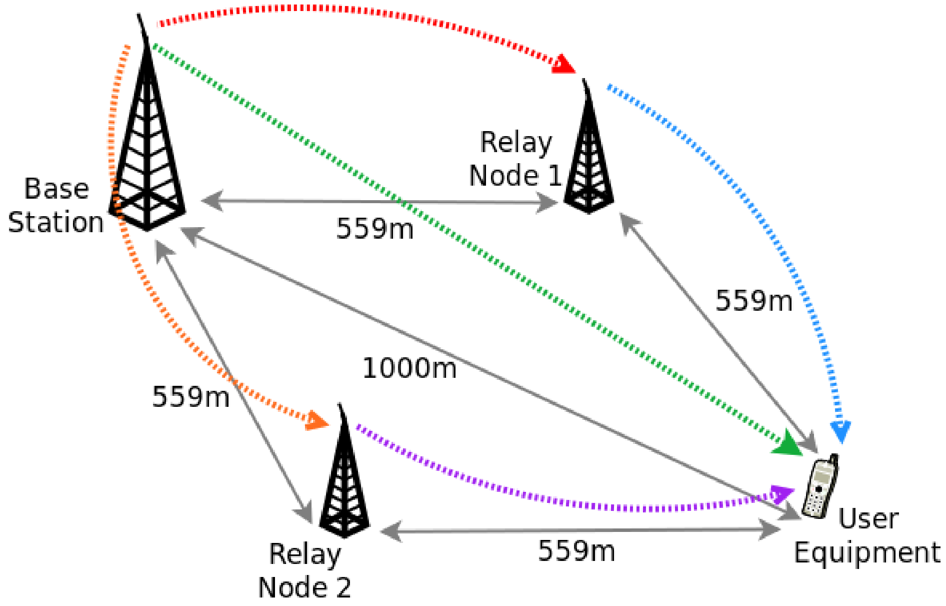

Figure 4.6: Simulation Environment for co-operative environment with 2 relays

and UE2. The pair of UE1 and BS2 constructs the Relay Node. The link between BS1 and UE1 is referred to Relay Link, whereas the link between BS2 and UE2 is referred to Access Link. And the link between BS1 and UE2 is considered as a direct link.

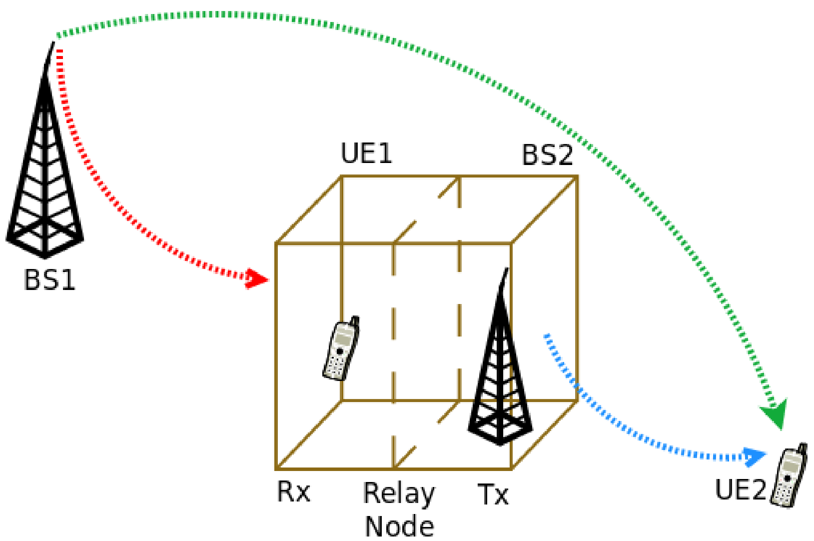

Figure 4.7: Deploying Relay Node with a combination of a BS and a UE

In this case, the signal from BS1 to UE2 is transmitted via UE1 and BS2; who act as a relay for BS1. So for multi hop network, multiple pair of BS-UE can be introducing in the position of the Relay. To deploy the Relay Node, following procedure was followed:

1. First the positions and antenna array orientations of the Base Station BS1 was set.

2. Then the positions and antenna array orientations of the Mobile Station UE2 was set.

3. Now to deploy Relay Node, Mobile Station UE1 and Base Station BS2 were added according to Figure 4.5. The array orientations and array characteristics of both UE1 and BS2 were maintained exactly same.

4. Now we defined a UE×BS Pairing Matrix. A pairing matrix defines the way how the UE and BS pairing up to construct a Relay Node. In case of co-operative environment (with single relay), the general form [25] of the pairing matrix, A is: $A = \begin{bmatrix} BS_1UE_1 & BS_1UE_2 \\ BS_2UE_1 & BS_2UE_2 \end{bmatrix}$. So in our design(Figure 4.7) only BS2 and UE1 make the pair. There are no pairing between BS1 and UE1; or BS1 and UE2; or BS2 and UE2 for constructing the Relays. So the desired paired matrix will be: $A = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}$. We consider BS1 as node 1, UE1 as node 2, BS2 as node 3 and UE2 as node 4. From Figure 4.5, we can see that, node 1 is linked with node 3 for the Relay link, node 2 is linked with node 4 for the Access link and node 1 is connected to the node 4 for the Direct link. The pairing matrix will be $A = \begin{bmatrix} 1 & 2 & 1 \\ 3 & 4 & 4 \end{bmatrix}$. This matrix is defined on line 24 of the MATLAB code in Appendix B.1. In the same way the pairing matrix for the co-operative environment with 2 relays will be $A = \begin{bmatrix} 1 & 1 & 2 & 1 & 3 \\ 6 & 4 & 6 & 5 & 6 \end{bmatrix}$.

5. Then all the radio links are generated at once.

6. Finally, all channel segments were simulated.

4.4 The Output Results

The output of the above simulation returns some parameters as the result. Lets say, in the simulation there are K number of links and N number of paths in each links and M number of sub paths in each path. Then the output parameters of the simulation is as following:

- Delays: A $K \times N$ matrix of the path delays can be measured in seconds.
- AODs - angles of departure in degrees over -180^o to 180^o.
- AOAs - angles of arrival in degrees over over -180^o to 180^o.
- Path Losses - A $K \times 1$ matrix of Path losses for the scenario. This Path loss values are measured using the formula described in Chapter 3.5. It is a coefficient by which the transmitted power is multiplied.

- Path Powers: $A\ K \times N$ matrix of path powers can be measured. This power is the clustered path powers of each paths of each links. It is a coefficient by which the transmitted power is multiplied.

- Station Distance - The distances between the stations can be measured in meters, which is a $K \times 1$ matrix.

- Shadow Fading - A $K \times 1$ matrix of shadow fading losses in linear scale can be measured. It is a coefficient by which the mean path-loss is multiplied.

A sample output of the above parameters are shown in Appendix C.

4.5 Evaluating the Symbol Error Rate

The link level simulation for evaluating Symbol Error Rate (SER) in three different environments (as discussed in 4.3.2) of the simulator is illustrated here. For the multipath channel, we consider the Path Powers generated in 4.3.4 with additive white Gaussian noise (AWGN) as suggested in [16].

Table 4.1: Simulation parameters for evaluating SER

System bandwidth	5 MHz
Sampling rate	5×10^6 samples/s
Data modulation format	QPSK
Pulse shaping	none
Cyclic prefix	20 samples ($4\mu s$)
Transmitter IFFT size	512
Sub carrier (tone) spacing	9.765625 kHz (= 5 MHz/512)
Channel estimation	Perfect
Equalization	Minimum Mean Square Error (MMSE)
Channel coding	none
Detection	Hard Decision
Number of iterations	$> 10^5$

As a multiplexing techniques Orthogonal Frequency Division multiplexing (OFDM) is used. Since the system sampling rate is set to 5 mega-samples per second, the channel delay was quantized to the nearest multiples of 200 nsec ($= 5 \times 10^{-6}$). Also, the length of the cyclic prefix (CP) is chosen as $4\mu s$ (20 samples) considering the maximum channel delay of the Vehicular A channel, which is $2.51\mu s$. Table 4.1 summarizes the simulation assumptions and parameters that were used throughout this simulation for evaluating SER.

The algorithm for OFDM simulator is illustrated in Figure 4.8. For certain SNR, first the data block of size 512 is generated. Then Inverse Fast Fourier Transform (IFFT) is applied on that data block and Cyclic Prefix (CP) is added. Then the data was transmitted through the channel by channel filtering

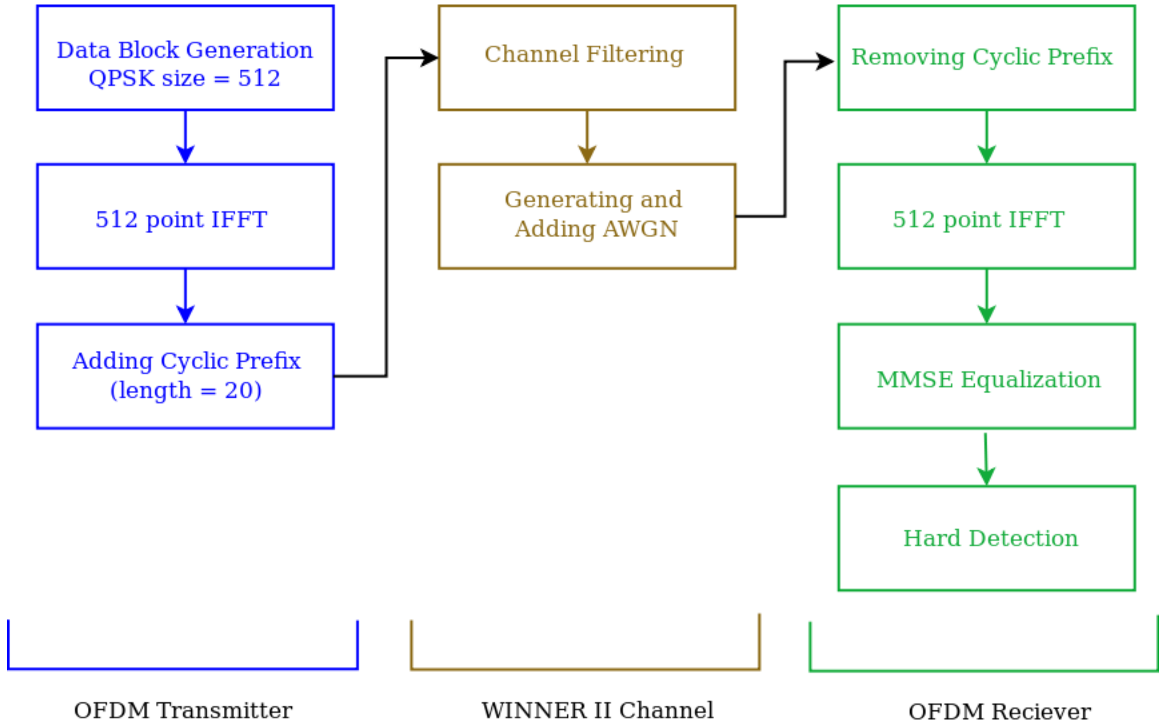

Figure 4.8: Block diagram of OFDM simulator

and adding Additive white Gaussian noise (AWGN). After receiving the data at receiver the Cyclic Prefix is removed and IFFT applied again. Then MMSE equalization is done. After that the hard detection is performed to evaluating the Symbol Error Rate. This process is iterate for all the SNR of the given range

For relaying, this OFDM simulator has been design slightly differently. For certain SNR, first the data block of size 512 is generated. After that like the previous method, Inverse Fast Fourier Transform (IFFT) is applied on that data block and Cyclic Prefix (CP) is added. The resultant data was transmitted through the relay channel with channel filtering. Then Additive white Gaussian noise (AWGN) was added. Now the receiver end of this data will be the receiving end of the relay. After receiving the data at the receiver of the relay, the Cyclic Prefix is removed, IFFT is applied and MMSE equalization is done. Then the IFFT is applied on the equalized data and the Cyclic Prefix (CP) is added. Then the data is transmitted through the access channel with channel filtering and adding Additive white Gaussian noise. At this point the received end is the receiver of the UE. Cyclic Prefix is removed from the received data, IFFT is applied and MMSE equalization is done. After that the hard detection is performed to evaluating the Symbol Error Rate.

Same method is applied when 2 relays are deployed in the co-operative environment, except now instead of two links the receiver is now fed by the combined signal of one direct link (from the BS) and two access links from two separate relays. The same signal is transmitted from the BS with the three links. First the data block of size 512 is generated, then Inverse Fast Fourier Transform (IFFT) is applied on that data block, Cyclic Prefix (CP) is added and the data is transmitted through the relay link 1 and relay link 2, with channel filtering and adding Additive white Gaussian noise (AWGN) separately. At this stage, the receiver end will be the receiving end of the relays. After receiving the data at the receiver of the relays, the Cyclic Prefix is removed, IFFT is applied and MMSE equalization is done. These are done separately in each relay nodes. After that, IFFT is applied again on the equalized data and the Cyclic Prefix (CP) is added in each relays. Then the data is transmitted through the respective access links of the associated relays. With channel filtering and adding Additive white Gaussian noise the data is received at the receiver end. At this point the received end is the receiver of the UE. The signals from three different links are combined here, then Cyclic Prefix is removed from the combined received data, IFFT is applied and MMSE equalization is done. Finally the hard detection is performed to evaluating the Symbol Error Rate.

4.6 Simulator Algorithm

The overall algorithm of the simulator is illustrated at Figure 4.9. The code of this algorithm can be found in Appendix B.

From the Figure 4.9, it can be seen that, in the first block, the antenna arrays and orientations of BSs and UEs are defined. In the Appendix B.1, the antenna arrays are initiated in line 6 and the antenna orientations of BSs and UEs are declared in line 10 and 11 for the without relay, non co-operative and co-operative environments. For co-operative environment with two relays, the BSs and UEs are declared in line 106 of Appendix B.1. The orientation of BSs and UEs are maintained in such a way that in the relay node the orientations of the BS and UE must be same in order to function as a single node.

In the second block of the algorithm, the WINNER II scenarios and scenario related all the layout parameters are specified. WINNER II specifies all the scenarios with corresponding numbers. By choosing the appropriate number for the desired scenario in line 13 of the code, the simulation scenarios can be selected. With the combination of BSs and UEs orientation information and scenario data, the layout parameters for the desired scenario is generated.

The next block of the algorithm declared the positions of all the BSs and UEs and RNs in the selected layout. All the positions are defined in a three dimensional Cartesian Coordinate System. So with origin O and axis lines X, Y and Z, position of each node is defined with the height.

Then the Pairing Matrix for the Relay Node is defined. Generation of the pairing matrix was elaborately discussed in Section 4.3.4. In short, this pairing matrix defines how the BSs and UEs are linked with each other for the relay layout. In line 21 of the code, the pairing matrix for the scenarios are defined.

At this point of the simulation, all the required configuration and param-

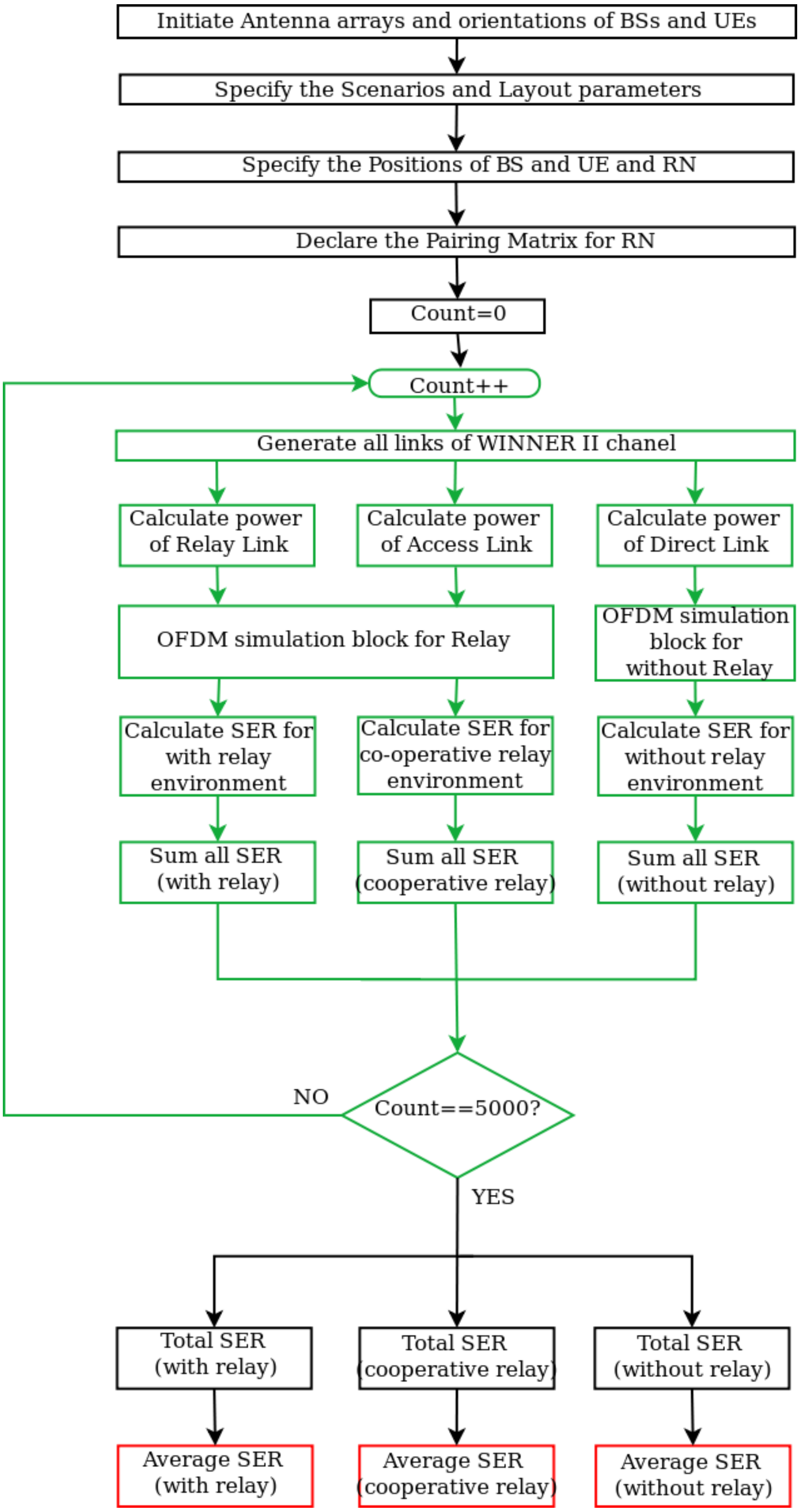

Figure 4.9: Simulator Algorithm

eters are initiated. Now we have to generate all the links of this simulation. To generate all the links at once, WINNER II channel model has a default command. Using that command the links are generated and simulated in line 31 of the code. The output parameters after generating all the links are discussed in Section 4.4. From those parameters, the Path Power gives the output of the power of each paths of the each links. For the multipath channel, we consider this Path Powers as the channel parameters. As there are three links involved in this simulation, and as we get powers of every link, this includes separate path powers for the relay link, the access link and the direct link. These power are considered for the OFDM simulator for channel filtering.

The next block is the OFDM simulator. This simulator block is discussed elaborately in Section 4.5. This block takes the Path Powers from the previous step and utilize it for the channel filtering. As we have three different environments, for each of the environments we have different OFDM block. For Without Relay Environment, the OFDM simulator works just as mentioned in Section 4.5. For Non Co-operative environments, as data is transmitted in two steps (from BS to RN and then RN to UE), the simulator works in two steps too (the steps are marked in Appendix B.3). For Co-operative Environments, the receiver gets the signal in two ways - one is through the direct link (without relay environment) and the other is through the relay link and access link (non co-operative environment). The simulator sums up the data transmitted of both direct link and relay-to-access link at the receiver end.

Then the Symbol Error Rates (SER) for three different environments are calculated. Each time WINNER II model generate different path powers depending on multi paths and cluster combinations. This effect was discussed in Section 3.3. So as a result, from generation of all links to calculation of SERs, the whole process is iterate for several times (in our case 5000 times exactly). Each time the calculated SERs are added with the previous SERs of the respective environments. After the completion of the iteration cycle, total SER is calculated, from which the average value is calculated.

These average values of SERs for each environments are then represented on graph for each corresponding SNR values. In the graph, the X-axis represents the SNRs and the Y-axis represents the corresponding SER values.

Chapter 5

Evaluation And Results

In the previous chapter, we introduced the case design where we described the cases involved and general properties of the network and technologies being considered. In this chapter, we therefore discuss and evaluate the results which was performed for the different environments as well as different scenarios. The results of the performed simulations are presented here, where interpretation and deductions of the results are also discussed.

5.1 Simulation Scenarios and Environments

From Chapter 2 We have learned that there are fourteen scenarios involved in WINNER II model. The details of those scenarios will be found in Appendix A. Out of those fourteen scenarios, we consider six scenarios for our simulation. The selected scenarios are:

1. Indoor to outdoor
2. Typical urban micro-cell
3. Bad urban micro-cell
4. Suburban
5. Typical urban macro-cell
6. Bad urban macro-cell

The default BS and UE distances are 1000m (1km) in all of the above cases (unless the distance is depicted otherwise). The reason for proposing this model is the following: It is very near the model for LOS probability defined in [31] at small distances. In addition it does not go to zero at the cell boundary, so that it can be used in the system-level modeling of interference. As discussed in Chapter 4.3.2, all the scenarios that are used in this simulation, are involved with three links- a relay link, an access link and a direct link. Depending on those links, each scenarios has three different environment:

- Without Relay: in this environment only direct link from BS to UE is considered. No relay is involved in this environment.

- Non co-operative: in this environment relay link and access link - both are considered. Signal is transmitted through relay link from BS to RN first, then finally from RN to UE through the access link.

- Co-operative: in this environment, signal from BS reaches to UE using two paths. First path is the *Direct link*. The second one uses both the *Access link* and *Relay link*. The UE receives two resultant signals of the two previously discussed environments - without relay environment and non co-operative environment.

- Co-operative (with 2 relays): in this environment, UE receives the signals from the BS and two RNs (Figure 5.2). So signal transmitted to the UE from the BS via three paths. One is the direct link where BS transmit the signal directly to the UE. In the case where *Relay node 1* is involved, signal first from the BS first transmitted to the RN1 via *Relay link 1* then transmitted to the UE from the RN1 via *Access link 1.* And the other path involves with *Relay Node 2,* where signal is first transmitted to the RN2 with *Relay link 2* from the BS and then via *Access link 2* the signal is transmitted from RN2 to the UE.

5.2 Case Scenario - Indoor to outdoor

In indoor-to-outdoor scenario the MS antenna height is assumed to be at 1 – 2 m, and BS antenna height at 2 – 2.5 m + floor height. The floor is considered to be the ground floor. The corresponding outdoor and indoor environments are B1 an A1 (for details see Appendix A), respectively. It is assumed that the floors 1 to 3 are used in simulations, floor 1 meaning the ground floor. The path loss equation for this scenario is in Equation (5.2).

$$PL = \left(10\log_{10}(d) + 9.45 - 17.3\log_{10}(h_{BS}) - 17.3log_{10}(h_{UE}) + 2.7\log_{10}\left(\frac{f_c}{5}\right)\right)\times d + 14(15(1-\cos\theta))^2 + 0.5d \qquad (5.1)$$

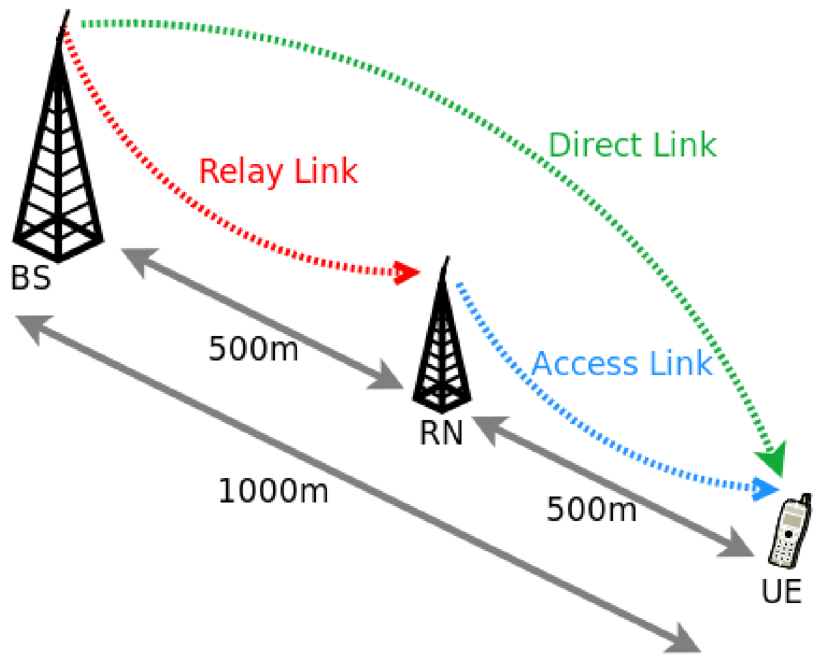

Figure 5.1: Simulation setup for *without relay, non co-operative* and *co-operative (single relay)* environments

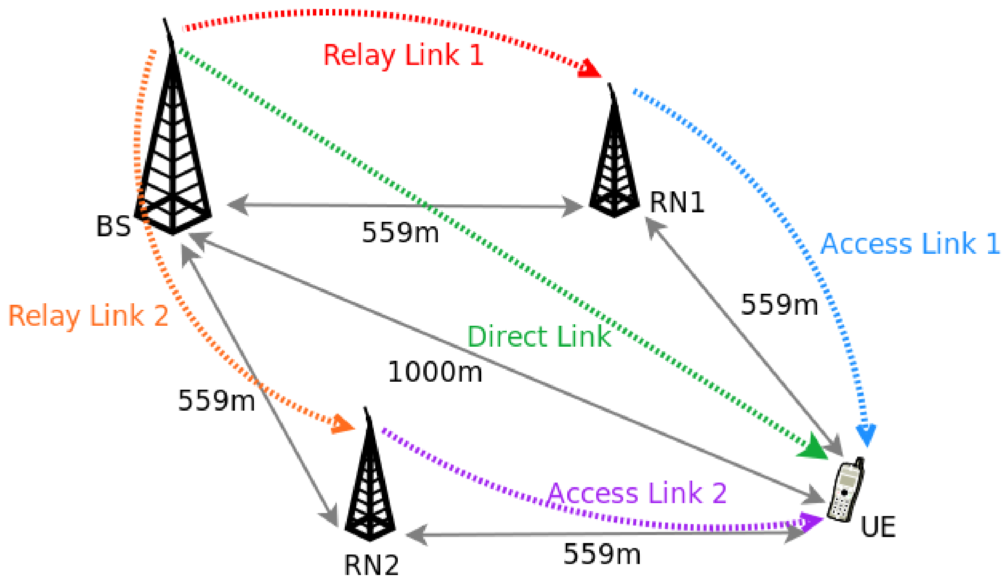

Figure 5.2: Simulation setup for *co-operative (2 relays)* environment

where,

d is the distance between transmitter and the receiver

h_{BS} is the height of the base station

h_{UE} is the height of the mobile station

f_c is the carrier frequency

θ is the antenna aperture angle

For this scenario, the SNR vs Symbol Error Rate curve for this scenario is shown in Figure 5.2.

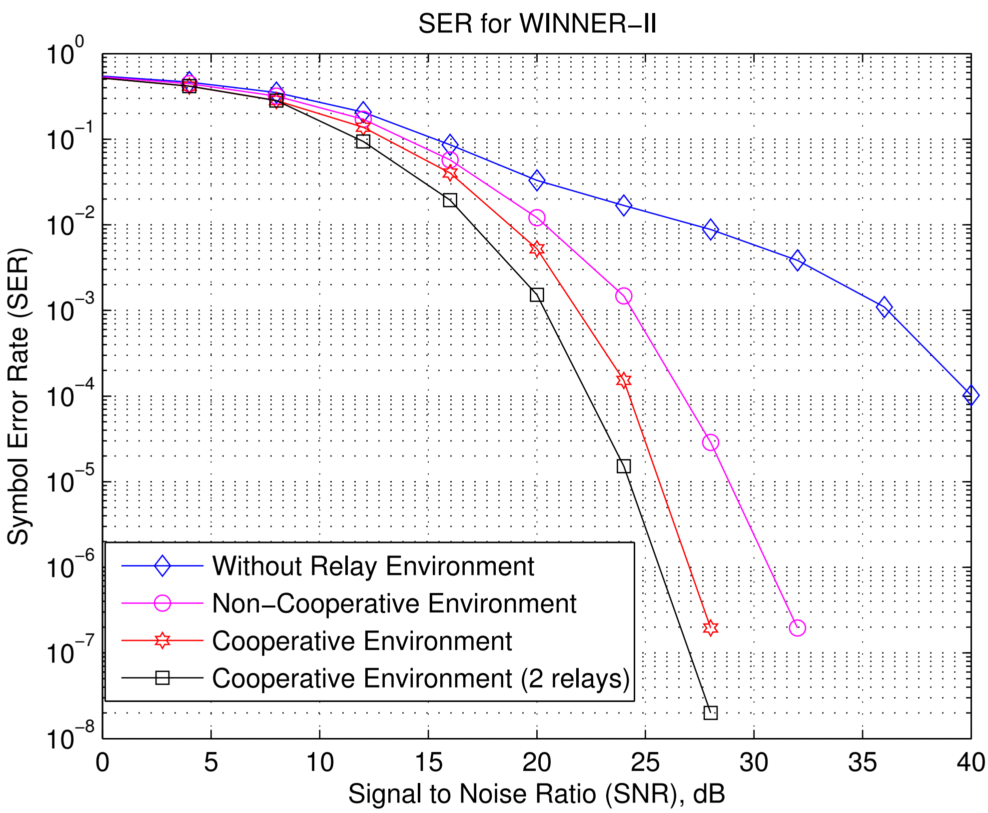

Figure 5.3: SNR vs. SER (indoor to outdoor)

From Figure 5.3, the Without Relay environment exhibits that Symbol Error Rate is much higher in the high SNR. Also it is clear that, we get the better performance in Co-operative environment compared to the other environments as the SER is much lower in co-operative environment. And when we deploy two relays the, results becomes even better. Which concludes that, all the relay environments perform much better than the without relay environment.

5.3 Case Scenario -Typical urban micro-cell

In this scenario, both antennas are assumed to be outdoors in an area where streets are laid out in a Manhattan-like grid. The streets in the coverage area are classified as “the main street”, where there is the LOS from all locations to the BS, with the possible exception in cases where the Line of sight is temporarily blocked by traffic (e.g. trucks and buses) on the street. Streets that intersect the main street are referred to as perpendicular streets, and those that run parallel to it are referred to as parallel streets. Cell shapes are defined by the surrounding buildings, and energy reaches streets as a result of the propagation around corners, through buildings, and between them. The path loss equation for this scenario is in Equation (5.3).

$$PL = 10\log_{10}(d) + 9.45 - 17.3\log_{10}(h_{BS}) - 17.3log_{10}(h_{UE}) + 2.7\log_{10}\left(\frac{f_c}{5}\right) \quad (5.2)$$

where,

d is the distance between transmitter and the receiver

h_{BS} is the height of the base station

h_{UE} is the height of the mobile station

f_c is the carrier frequency

For this scenario, the SNR vs Symbol Error Rate curve is shown in Figure 5.4. Though both of the relay environments performs better than the without relay environment, up to 15dB of SNR, co-operative relay and Non-cooperative relay environments exhibit almost the same curve. Up to 8 dB, all the three relay environments (non co-operative, co-operative and co-operative with 2 relays) exhibit almost same SER. But at the higher SNR, co-operative environment with two relays performs the best.

5.4 Case Scenario - Bad urban micro cell

Bad urban micro-cell scenarios are identical in layout to Urban Micro-cell scenarios, as described above. However, propagation characteristics are such that multipath energy from distant objects can be received at some locations. This energy can be clustered or distinct, has significant power (up to within a few dB of the earliest received energy), and exhibits long excess delays. Such situations typically occur when there are clear radio paths across open areas, such as large

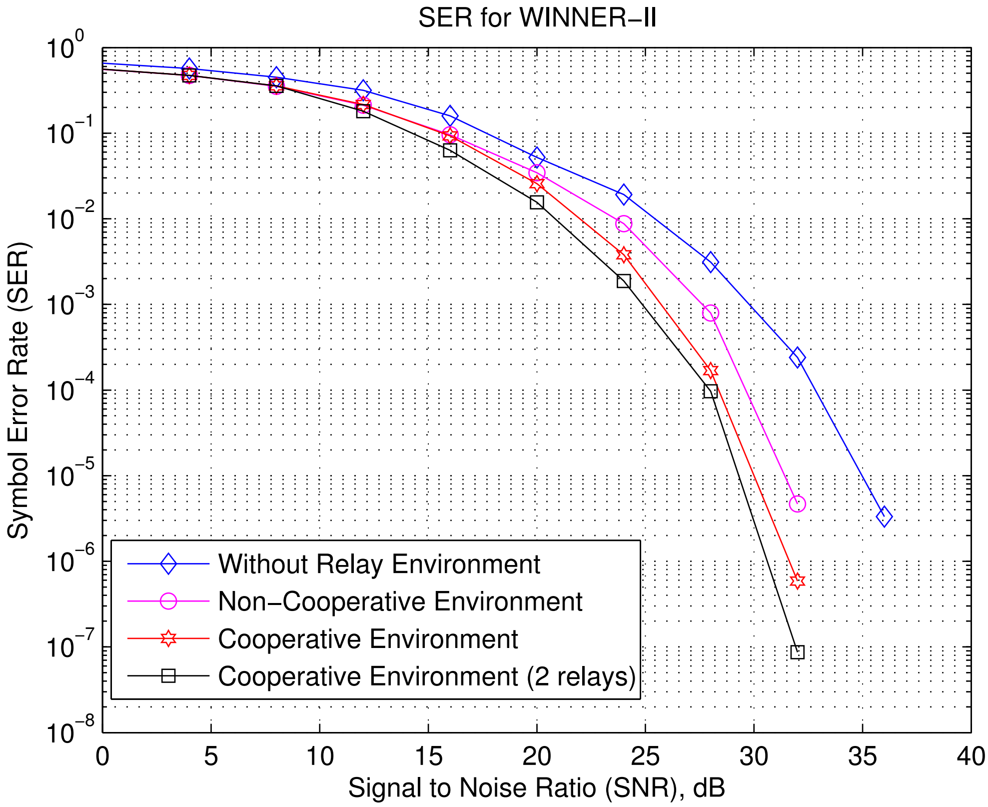

Figure 5.4: SNR vs SER (typical urban micro cell)

squares, parks or bodies of water. The path loss equation for this scenario is in Equation (5.4).

$$PL = 13.9\log_{10}(d) + 64.4 + 20\log_{10}\left(\frac{f_c}{5}\right) \tag{5.3}$$

where,

d is the distance between transmitter and the receiver

f_c is the carrier frequency

The SNR vs Symbol Error Rate curve for this scenario is shown in Figure 5.5. In this scenario it is clear that in the higher signal to noise ratio, both Co-operative environments perform much better than the rest of the two. Without Relay Environment exhibits the worst performance. Up to a 8 dB SNR, both the co-operative environments exhibit the same SER, but as the SNR increases the co-operative environment with 2 relays performs better than the co-operative environment with one relay.

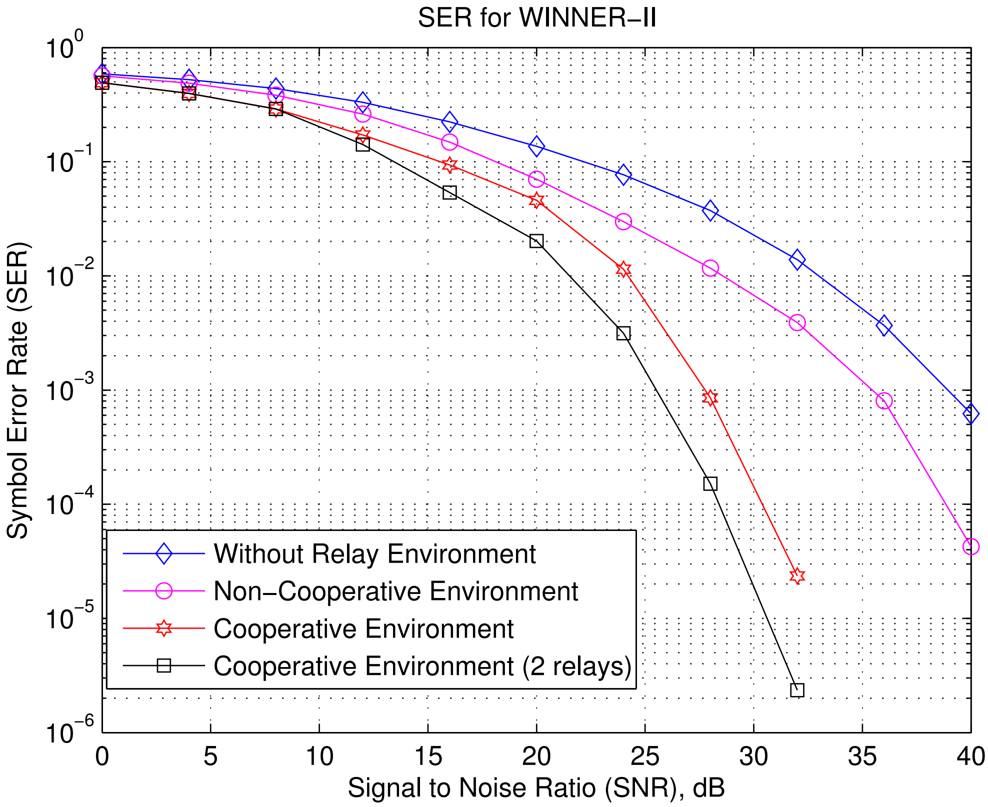

Figure 5.5: SNR vs. SER (bad urban micro cells)

5.5 Case Scenario - Suburban macro-cell

In suburban macro-cells base stations are located well above the rooftops to allow wide area coverage, and mobile stations are outdoors at street level. Buildings are typically low residential detached houses with one or two floors, or blocks of flats with a few floors. Occasional open areas such as parks or playgrounds between the houses make the environment rather open. Streets do not form urban-like regular strict grid structure. Vegetation is modest. The path loss equation for this scenario is in Equation (5.5)

$$PL = 40\log_{10}(d) + 11.65 - 16.2\log_{10}(h_{BS}) - 16.2\log_{10}(h_{UE}) + 3.8\log_{10}(\frac{f_c}{5}) \quad (5.4)$$

where,

d is the distance between transmitter and the receiver

h_{BS} is the height of the base station

h_{UE} is the height of the mobile station

f_c is the carrier frequency

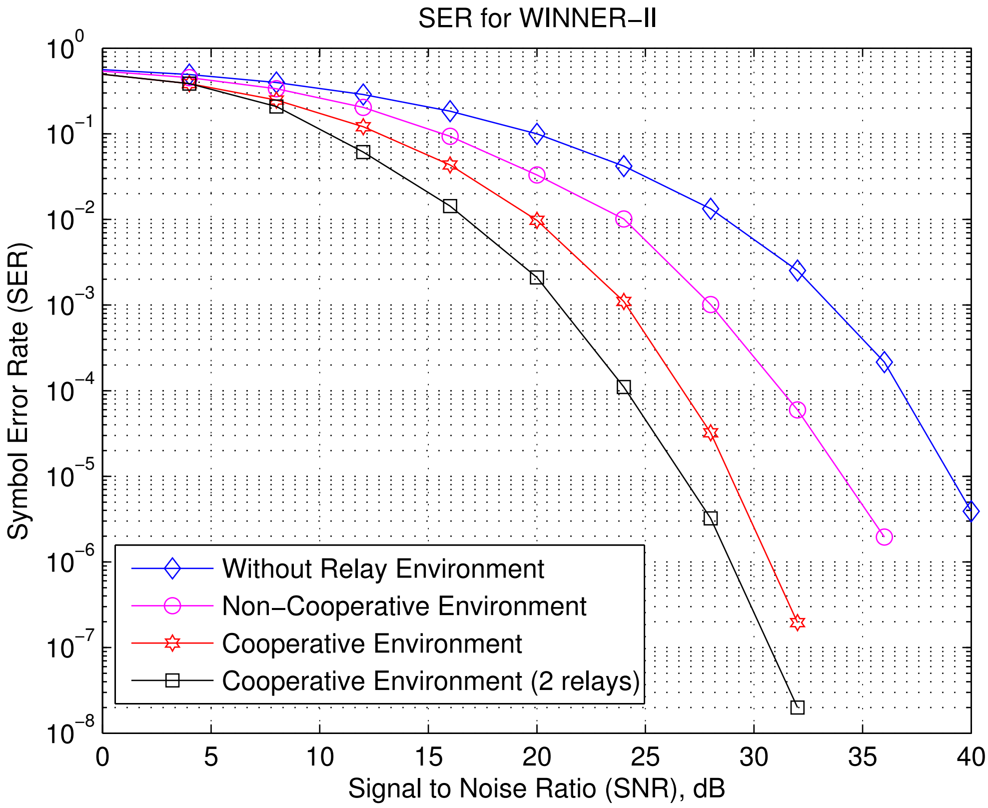

Figure 5.6: SNR vs SER (suburban macro-cell)

For this scenario, the SNR vs Symbol Error Rate curve for this scenario is shown in Figure 5.6. In this scenario, it is clear that without relay environment exhibits the poorest performance compared to the other relay environments. In the higher SNR values, Co-operative environment with two relays, performs much better than the non co-operative environment and co-operative environments with single relay.

5.6 Case Scenario - Typical urban macro-cell

In typical urban macro-cell mobile station is located outdoors at street level and fixed base station clearly above surrounding building heights. As for propagation conditions, non- or obstructed line-of-sight is a common case, since street level is often reached by a single diffraction over the rooftop. The building blocks can form either a regular Manhattan type of grid, or have more irregular locations. Typical building heights in urban environments are over four floors. Buildings height and density in typical urban macro-cell are mostly homogeneous. The path loss equation for this scenario is in Equation (5.6)

$$PL = 10\log_{10}(d) + 13.47 - 14\log_{10}(h_{BS}) - 14\log_{10}(h_{UE}) + 6\log\left(\frac{f_c}{5}\right) \quad (5.5)$$

where,

d is the distance between transmitter and the receiver

h_{BS} is the height of the base station

h_{UE} is the height of the mobile station

f_c is the carrier frequency

For this scenario, the SNR vs Symbol Error Rate curve for this scenario is shown in Figure 5.7. Though both of the relay environments performs better than the without relay environment, up to approximately 20dB of SNR, co-operative environments (both single and two relays) and Non-cooperative relay environment exhibit almost the same curve. For larger SNR than 20 dB, the co-operative environment with 2 relays performs better than the rest of the environments.

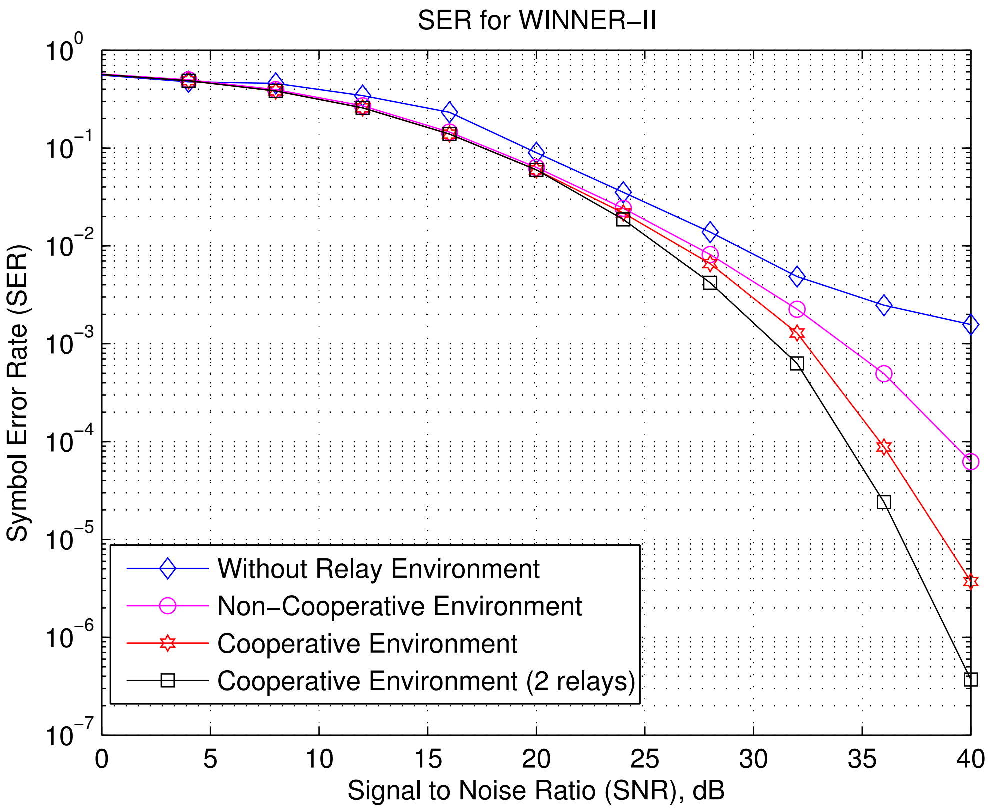

Figure 5.7: SNR vs SER (typical urban macro-cell)

5.7 Case Scenario - Bad urban macro-cell

Bad urban environment describes cities with buildings with distinctly inhomogeneous heights or densities, and results to a clearly dispersive propagation environment in delay and angular domain. The inhomogeneities in city structure can be e.g. due to large water areas separating the built-up areas, or the high-rise skyscrapers in otherwise typical urban environment. Increased delay and angular dispersion can also be caused by mountains surrounding the city. Base station is typically located above the average rooftop level, but within its coverage range there can also be several high-rise buildings exceeding the base station height. From modeling point of view this differs from typical urban macro-cell by an additional far scatterer cluster. The path loss equation for this scenario is in Equation (5.6)

$$PL = (44.9 - 6.55\log_{10}(h_{BS}))\log_{10}(d) + 34.46 + 5.83\log_{10}(h_{BS}) + 23\log_{10}\left(\frac{f_c}{5}\right) \tag{5.6}$$

where,

d is the distance between transmitter and the receiver

h_{BS} is the height of the base station

h_{UE} is the height of the mobile station

f_c is the carrier frequency

For this scenario, the SNR vs Symbol Error Rate curve for this scenario is shown in Figure 5.8. In this scenario it is clear that in the higher signal to noise ratio, Co-operative environment having two relays performs much better than the rest of the three environments.

From all of the above simulation results it is clear that in both the co-operative environment, WINNER II model shows better performance than the non co-operative environments and without relay environment. Especially, the co-operative environment which deploys two relays, shows the best performance so far. Comparing to the non co-operative environment, in the both co-operative environments, the UE received the signal from the BS through more than one paths. In co-operative environment with single relay, UE gets the signal from BS through Access link and Direct Link (Figure 5.1) and in co-operative environments with two relays, UE gets the signal from BS through two Access links (Access link 1 and Access link 2) and a Direct Link (Figure 5.2). In the co-operative environments, the different signal powers of different links are added up in the receiving UE. Which in fact reduces the bit error rate in receiver. So it

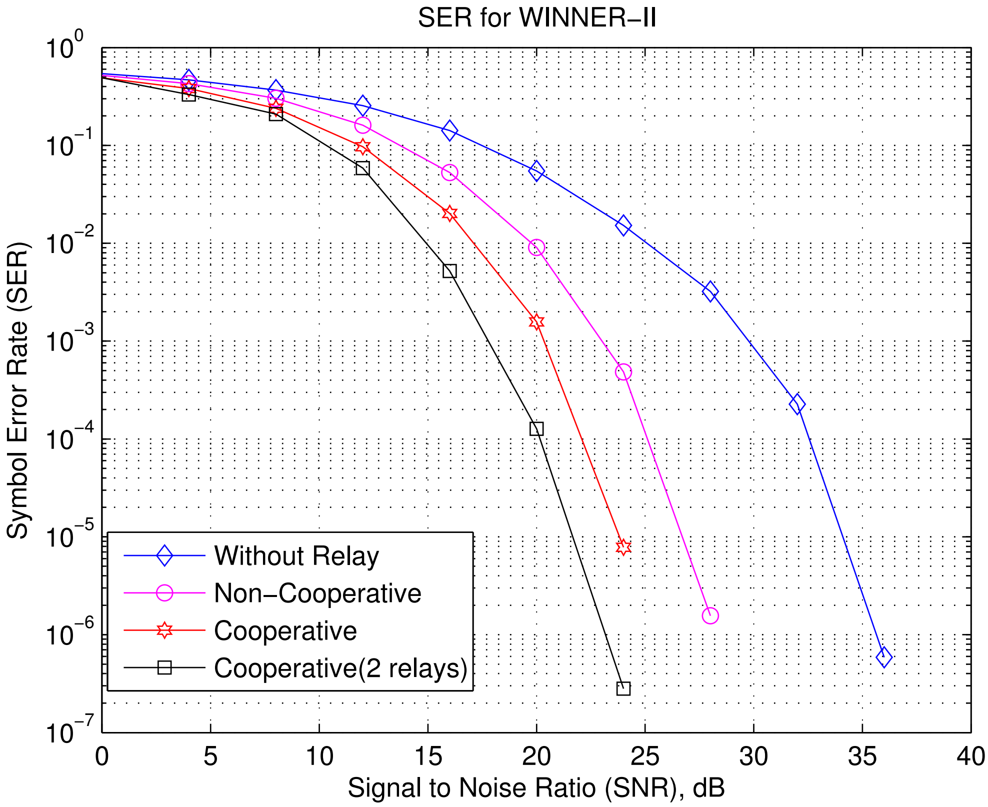

Figure 5.8: SNR vs SER (bad urban macro cell)

can be stated that, by deploying more relays into the scenario, the better performance can be expected. Apart from this, as this model is a link layer model, so the interference situations are not considered here. In case of interference, a second BS transmits a non-desired signal which creates interference, which in fact, does not change the parameters of the WINNER II channel model [26]. What changes, however, is the degree of realism that is needed for the interference channel. So we are not considering the interference situation here. As a result, the simulation depicts that, both the co-operative environment perform better than the without relay environment and non co-operative environment.

The next chapter presents the conclusions that can be drawn from this research study based on the results that have been obtained and carefully analyzed in this chapter.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

LTE Release 8 is one of the primary broadband technologies based on OFDM, which is currently being commercialized. LTE Release 8, which is mainly deployed in a macro/micro cell layout, provides improved system capacity and coverage, high peak data rates, low latency, reduced operating costs, multi-antenna support, flexible bandwidth operation and seamless integration with existing systems. LTE-Advanced significantly enhances the existing LTE Release 8 and supports much higher peak rates, higher throughput and coverage, and lower latencies, resulting in a better user experience. In this work, we took a channel model for LTE (release-8) and extended it to support LTE-Advanced by adding the relay support and the LTE release-10 parameters.

The main idea of this study was to explore the feasibility of deploying a relay into a current LTE model to extend its support for the LTE-Advanced in the near future. We have considered WINNER II channel model as the LTE channel model for our research interest. This channel model is used to create several scenarios where relay is involved as a medium of transmitting signal to the UE. First we consider the scenario with one BS and one UE. Then we introduce relay and consider the scenarios with one BS, one RN and one UE to reduce the complexities. Finally we introduce another relay to the scenario. We also built a simulator to support relay nodes from the WINNER II model, to simulate the results and to evaluate the performance of the network by performing the SNR vs SER test. In relay environments, we simulate both the non co-operative and co-operative environment. So, a total of four different environments for all the selected scenarios are considered. And we simulated all the selected scenarios with all four environments.

The simulation results showed that, the co-operative environment, which added up two signals of different links, performs better than the non co-operative environment (where signals are not added up) and without relay environment. And when another additional relay is deployed the performance in the co-operative environment gets better. We observed that, the performance of co-operative environment with two relays is better in all the WINNER scenarios those are used in this work. The analysis shows that, the addition of different path powers in co-operative environment actually results in a lower symbol error rate in the SNR vs SER curve.

6.2 Recommendation for the Future Research

In this study, deploying the relay node into a LTE model has been an interesting practice. However, we have identified the following areas for further research:

1. We constructed the basic model for simulating a LTE-Advanced scenario by deploying one BS, one UE and two RNs. Further development can be carried out to introduce multiple Base Stations and Relays with multi User scenarios for multiple cells.

2. For simplicity of the simulation, we considered only the Amplify and Forward relay. In future research, Selective Decode and Forward Relay and Demodulation and Forward Relay can also be involved.

3. Within the 14 scenarios of WINNER-II channel model, only six of them were considered and evaluated in this thesis work. Effect of deploying relay nodes in the rest of the scenarios can be of further interests.

4. In order to reduce the complexities, scheduling and interference controlling are not focused in this thesis work. Therefore, a more detailed study of relay nodes considering the scheduling and the impact of the interferences can be included in the future further research.

5. Femtocells are a promising method to increase system capacity of a cellular network. Relays can be a interesting solution to extend the coverage area of the macro cells by reaching more femtocells. Future research may therefore involve investigating the performance of LTE-Advanced with the adoption of relay nodes and femtocells.

APPENDICES

Appendix A

Propagation Scenarios

The generic WINNER-II channel model follows a geometry-based stochastic channel modeling approach, which allows creating of an arbitrary double directional radio channel model. The channel models are antenna independent, i.e., different antenna configurations and different element patterns can be inserted. The channel parameters are determined stochastically, based on statistical distributions extracted from channel measurement. The distributions are defined for, e.g., delay spread, delay values, angle spread, shadow fading, and cross-polarization ratio. For each channel snapshot the channel parameters are calculated from the distributions. Channel realizations are generated by summing contributions of rays with specific channel parameters like delay, power, angle-of-arrival and angle-of-departure. Different scenarios are modeled by using the same approach, but different parameters. The propagation scenarios [25] modeled in WINNER are briefly discussed below:

A.1 A1 – Indoor office

In the scenario A1 base stations (Access Points) are assumed to be in corridor, thus LOS case is corridor-to-corridor and NLOS case is corridor-to-room. In the NLOS case the basic path-loss is calculated into the rooms adjacent to the corridor where the AP is situated. For rooms farther away from the corridor wall-losses must be applied for the walls parallel to the corridors. Finally, we have to model the Floor Loss (FL) for propagation from floor to floor. It is assumed that all the floors are identical. The Floor Loss is constant for the same distance between floors, but increases with the floor separation and has to be added to the path-loss calculated for the same floor.

A.2 A2 – Indoor to outdoor

In indoor-to-outdoor scenario the MS antenna height is assumed to be at 1 – 2 m, and BS antenna height at 2 – 2.5 m + floor height. The corresponding outdoor and indoor environments are B1 an A1, respectively. It is assumed that the floors 1 to 3 are used in simulations, floor 1 meaning the ground floor.

A.3 B1 – Urban micro-cell

Both antennas are assumed to be outdoors in an area where streets are laid out in a Manhattan-like grid. The streets in the coverage area are classified as "the main street", where there is the LOS from all locations to the BS, with the possible exception in cases where the LOS is temporarily blocked by traffic (e.g. trucks and buses) on the street. Streets that intersect the main street are referred to as perpendicular streets, and those that run parallel to it are referred to as parallel streets. This scenario is defined for both the LOS and the NLOS cases. Cell shapes are defined by the surrounding buildings, and energy reaches NLOS streets as a result of the propagation around corners, through buildings, and between them.

A.4 B2 – Bad Urban Micro-cell

Bad urban micro-cell scenarios are identical in layout to Urban Micro-cell scenarios, as described above. However, propagation characteristics are such that multipath energy from distant objects can be received at some locations. This energy can be clustered or distinct, has significant power (up to within a few dB of the earliest received energy), and exhibits long excess delays. Such situations typically occur when there are clear radio paths across open areas, such as large squares, parks or bodies of water.

A.5 B3 – Indoor hot spot Scenario

B3 represents the propagation conditions pertinent to operation in a typical indoor hot spot, with wide, but non-ubiquitous coverage and low mobility (0-5 km/h). Traffic of high density would be expected in such scenarios, as for example, in conference halls, factories, train stations and airports, where the indoor environment is characterized by larger open spaces, where ranges between a BS and a MS or between two MS can be significant. Typical dimensions of such areas could range from 20 m × 20 m up to more than 100m in length and width and up to 20 m in height. Both LOS and NLOS propagation conditions could exist.

A.6 B4 – Outdoor to indoor

In outdoor-to-indoor urban micro cell scenario the MS antenna height is assumed to be at 1 – 2 m (plus the floor height), and the BS antenna height below rooftop, at 5 - 15 m depending on the height of surrounding buildings (typically over four floors high). Outdoor environment is metropolitan area B1, typical urban micro cell where the user density is typically high, and thus the requirements for system throughput and spectral efficiency are high. The corresponding indoor environment is A1, typical indoor small office. It is assumed that the floors 1 to 3 are used in simulations, floor 1 meaning the ground floor.

A.7 B5 – Stationary Feeder

Fixed feeder links scenario is defined as propagation scenario B5. In this scenario, both terminals are fixed. Based on this, the scenario is divided in four categories or sub-scenarios in; these are B5a (LOS stationary feeder: rooftop to rooftop), B5b (LOS stationary feeder: street level to street level), B5c (LOS stationary feeder: below rooftop to street level) and B5d (NLOS stationary feeder: rooftop to street level). Height of street level terminal antenna is assumed to be 3-5 meters.

A.7.1 B5a

The signal in B5a can be assumed to consist of a strong LOS signal and single bounce reflection. Also far away reflections can occur. The connection is almost like in free space, so that the path-loss does not depend noticeably on the antenna heights. For this scenario fixed angle spread, delay spread and XPR values are applied. However, the model is applicable for omni-directional antennas for up to 300 meters in distance. By using directive antennas the range can be extended approximately to 8 km.

A.7.2 B5b

In B5b it is assumed that both the transmitter and receiver have many scatterers in their close vicinity similar. In addition there can also be long echoes from the ends of the street. There is a LOS ray between the transmitter and receiver and when this path is strong, the contribution from all the scatters is small. However, beyond the break point distance the scatterers start to play an important role.

A.7.3 B5c and B5d Scenarios

B5c and B5d can be considered as LOS of B1 and NLOS of C2 respectively. Only support for Doppler spectrum of stationary cases has to be introduced. B5c is probably the most important feeder link scenario, because it will be used in urban micro-cell relay scenario. B5c is almost identical to the B1 micro-cellular LOS scenario. The only difference in environment is the assumed antenna height of the mobile/relay. Same channel model will cover both of the cases, except the difference in Doppler spectrum (mobility). Feeder link ends are stationary and the Doppler frequency results from motion of the environment. In scenario B5c some clusters represent vehicles with speed of ~50 km/h and the rest of the clusters represent stationary objects like walls and building corners.

A.7.4 B5f

B5f scenario consists of the cases with relay antennas some meters over the roof-top or some meters below the roof-top. Critical information is, if the link is LOS or NLOS, it is possible to create LOS links with the antennas below roof-tops. As well it is possible to implement NLOS links with antennas above the average roof-top level. Our approach is that the desired BS to FRS links can be planned to be LOS or OLOS, or at least “good” links. It is assumed that the interfering links from undesired BS to FRS can be LOS or NLOS. (Although in practice this can be also affected by careful planning.) It should be pointed out that the link FRS to MS is covered by the model B1. Interference to undesired feeder link may occur. In B5f it is assumed that the relay station is shadowed due to some obstacle.

A.8 C1 – Suburban macro-cell

In suburban macro-cells base stations are located well above the rooftops to allow wide area coverage, and mobile stations are outdoors at street level. Buildings are typically low residential detached houses with one or two floors, or blocks of flats with a few floors. Occasional open areas such as parks or playgrounds between the houses make the environment rather open. Streets do not form urban-like regular strict grid structure. Vegetation is modest.

A.9 C2 – Urban macro-cell

In typical urban macro-cell mobile station is located outdoors at street level and fixed base station clearly above surrounding building heights. As for propagation conditions, non- or obstructed line-of-sight is a common case, since street level is often reached by a single diffraction over the rooftop. The building blocks can form either a regular Manhattan type of grid, or have more irregular locations. Typical building heights in urban environments are over four floors. Buildings height and density in typical urban macro-cell are mostly homogeneous.

A.10 C3 – Bad urban macro-cell

Bad urban environment describes cities with buildings with distinctly inhomogeneous heights or densities, and results to a clearly dispersive propagation environment in delay and angular domain. The inhomogeneities in city structure can be e.g. due to large water areas separating the built-up areas, or the high-rise skyscrapers in otherwise typical urban environment. Increased delay and angular dispersion can also be caused by mountains surrounding the city. Base station is typically located above the average rooftop level, but within its coverage range there can also be several high-rise buildings exceeding the base station height.

From modeling point of view this differs from typical urban macro-cell by an additional far scatterer cluster.

A.11 C4 – Urban macro outdoor to indoor

The Outdoor-to-Indoor scenario is specified here as follows: The outdoor environment is the same as in urban macro cellular case, C2, and the indoor environment is the same as in indoor case, A1. The base station antenna is clearly above the mean building height. This means that there will be quite long LOS paths to the walls penetrated by the signals, mainly in the higher floors of the buildings. On the other hand there is often quite a severe shadowing, especially in the lower floors.

A.12 D1 – Rural macro-cell Propagation scenario

D1 represents radio propagation in large areas (radii up to 10 km) with low building density. The height of the AP antenna is typically in the range from 20 to 70 m, which is much higher than the average building height. Consequently, LOS conditions can be expected to exist in most of the coverage area. In case the UE is located inside a building or vehicle, an additional penetration loss is experienced which can possibly be modeled as a (frequency-dependent) constant value. The AP antenna location is fixed in this propagation scenario, and the UE antenna velocity is in the range from 0 to 200 km/h.

A.13 D2 – Moving networks Propagation scenario

D2 (“Rural Moving Network”) represents radio propagation in environments where both the AP and the UE are moving, possibly at very high speed, in a rural area. A typical example of this scenario occurs in carriages of high-speed trains where wireless coverage is provided by so-called moving relay stations (MRSs) which can be mounted, for example, to the roof. The link between the fixed network and the moving network (train) is typically a LOS type. In addition there is a link from the MRS to the UE. It is assumed that the indoor part of the MRS is mounted in the ceiling in the middle of the carriage.

Appendix B

MATLAB Codes

This section contains the MATLAB codes that has been introduced and applied in addition to the original WINNER II channel model MATLAB source code. The source code of WINNER II channel model is free and open sourced and can be downloaded from *http://www.ist-winner.org/phase_2_model.html*

B.1 Main Simulator Code

```
clear all;
clc;

%% Defining the antenna arrays

Arrays=arrayparset;

%% Defining the scenerio with BS, MS, Relays

BsAAIdxCell = {[1]; [2]} ;
MsAAIdx = [2 3];
L=3; %Number of links
S=12; %Identification number of the Scenario

layoutpar=layoutparset (MsAAIdx, BsAAIdxCell, L, Arrays);
layoutpar.ScenarioVector = S*ones(1,L);
layoutpar.Stations(1).Pos = [0;0;32]; %Position of BS1
layoutpar.Stations(2).Pos = [250;250;32]; %Position of BS2
layoutpar.Stations(3).Pos = [250;250;32]; %Position of MS1
layoutpar.Stations(4).Pos = [0;500;1.5]; %Position of MS2

%% Defining the pairing of BS, MS, Relays

layoutpar.Pairing = [1 2 1;3 4 4];

%% Defining the initial conditions for the iteration

SER_tot_nc = zeros(11,1);
SER_tot_c = zeros(11,1);
```

```
SER_tot_wor = zeros(11,1);

for n=1:5000

        wimpar = wimparset; %Generation the Winner
           parameters
        [H, delays, out]=wim(wimpar,layoutpar) % Generation
            of all the radio links according to the layout

        %Processing the bits for Calculation

        SP.FFTsize = 512; % The size of the FFT and IFFT
        SP.CPsize = 20; % CP length
        SP.SNR = [0:4:40]; % Simulated SNR range is from 0
           dB to 40 dB with an increament of 4 dB.
        SP.numRun = 10^4; % The number of simulation
           iterations is 10^4

        a=isnan(out.path_powers);
        out.path_powers(a)=0;
        SP.equalizerType ='MMSE';

        %Calculation of path powers for Non-cooperative

        h_1=out.path_powers(1,:); %Relay Link
        SP.channel_1 = h_1;
        SP.channel_1 = h_1/sqrt(sum(h_1.^2));

        h_2= out.path_powers(2,:); %Access Link
        SP.channel_2 = h_2;
        SP.channel_2 = h_2/sqrt(sum(h_2.^2));

        %Calculation of BER

        SER_ofdm_nc = ofdm_wr_nc(SP);
        SER_tot_nc = SER_tot_nc + SER_ofdm_nc;

        %Calculation of path powers for Cooperative

        h_1=out.path_powers(1,:);  %Relay Link
        SP.channel_1 = h_1;
        SP.channel_1 = h_1/sqrt(sum(h_1.^2));

        h_2= out.path_powers(2,:); %Access Link
        SP.channel_2 = h_2;
        SP.channel_2 = h_2/sqrt(sum(h_2.^2));
        h_3= out.path_powers(3,:); %Direct Link
        SP.channel_3 = h_3;
        SP.channel_3 = h_3/sqrt(sum(h_3.^2));

        h_4= out.path_powers(2,:)+out.path_powers(3,:);
```

```
        SP.channel_4 = h_4;
        SP.channel_4 = h_4/sqrt(sum(h_4.^2));

        %Calculation of BER

        SER_ofdm_c = ofdm_wr_c(SP);
        SER_tot_c = SER_tot_c + SER_ofdm_c;

        %Calculation of path powers Without relay

        h=out.path_powers(3,:);  %Direct Link
        SP.channel = h;
        SP.channel = h/sqrt(sum(h.^2));

        %Calculation of BER

        SER_ofdm_wor = ofdm(SP);
        SER_tot_wor = SER_tot_wor + SER_ofdm_wor;

end

%% Taking Average of the data

SER_wor = SER_tot_wor/n; % SER for without relay environment
SER_nc = SER_tot_nc/n; % SER for non co-operative environment
SER_c = SER_tot_c/n; % SER for co-operative environment (with one relay)

%% Defining the MS and BS positions for the co-operative environments with 2 relays

BsAAIdxCell = {[1];[2];[2]};
MsAAIdx = [2 2 3];
L=5;
layoutpar=layoutparset (MsAAIdx, BsAAIdxCell, L, Arrays);
layoutpar.ScenarioVector = S*ones(1,L);
layoutpar.Stations(1).Pos = [0;250;32]; % BS1
layoutpar.Stations(2).Pos = [500;500;25]; % BS2
layoutpar.Stations(3).Pos = [500;0;25]; % BS3
layoutpar.Stations(4).Pos = [500;500;25]; % MS1
layoutpar.Stations(5).Pos = [500;0;25]; % MS2
layoutpar.Stations(6).Pos = [1000;250;1.5]; % MS3
layoutpar.Pairing = [1 1 2 1 3 ; 6 4 6 5 6];

%Defining the initial conditions for the iteration

SER_tot_c_two = zeros(11,1);

for n=1:5000
```

```
        %Generation the Winner parameters
        wimpar = wimparset;
        [H2, delays2, out2]=wim(wimpar,layoutpar)
        %Processing the bits for Calculation
        SP.FFTsize = 512;
        SP.CPsize = 20;
        SP.SNR = [0:4:40];
        SP.numRun = 10^4;

        a=isnan(out2.path_powers);
        out2.path_powers(a)=0;
        SP.equalizerType ='MMSE';

        %Calculation of path powers for Cooperative
           environment with two relays

        h_1=out2.path_powers(1,:); % direct link
        SP.channel_1 = h_1;
        SP.channel_1 = h_1/sqrt(sum(h_1.^2));

        h_2= out2.path_powers(2,:); % relay link 1
        SP.channel_2 = h_2;
        SP.channel_2 = h_2/sqrt(sum(h_2.^2));

        h_3= out2.path_powers(3,:); % access link 1
        SP.channel_3 = h_3;
        SP.channel_3 = h_3/sqrt(sum(h_3.^2));

        h_4= out2.path_powers(4,:); % relay link 2
        SP.channel_4 = h_4;
        SP.channel_4 = h_4/sqrt(sum(h_4.^2));
        h_5= out2.path_powers(5,:); % access link 2
        SP.channel_5 = h_5;
        SP.channel_5 = h_5/sqrt(sum(h_5.^2));
        h_6= out2.path_powers(1,:)+ out2.path_powers(3,:)+
           out2.path_powers(5,:); % combined link in
           reciever
        SP.channel_6 = h_6;
        SP.channel_6 = h_6/sqrt(sum(h_6.^2));

        %Calculation of SER

        SER_ofdm_c_two = ofdm_wr_c_two(SP);
        SER_tot_c_two = SER_tot_c_two + SER_ofdm_c_two;
end

%% Taking Average of the data

SER_c_two = SER_tot_c_two/n; % SER for co-operative
   environment with 2 relays

```

```
%saving data

save results/ofdm_data;

% Creating figures

figure
semilogy(SP.SNR,SER_wor,'bh-');
hold on
semilogy(SP.SNR,SER_nc,'mo-');
semilogy(SP.SNR,SER_c,'rd-');
semilogy(SP.SNR,SER_c_two,'kx-');
grid on
legend('Without Relay Environment', 'Non-Cooperative Environment', 'Cooperative Environment', 'Cooperative Environment (2 relay)');

xlabel('Signal to Noise Ratio (SNR), dB');
ylabel('Symbol Error Rate (SER)');
title('SER for WINNER-II');
```

B.2 OFDM Simulator code for Without Relay Environment

```
function SER = ofdm(SP)

numSymbols = SP.FFTsize; % The size of the data block is equal to the FFT size

H_channel = fft(SP.channel,SP.FFTsize); %Frequency domain version of the Direct Link channel response

for n = 1:length(SP.SNR),
        tic;
        errCount = 0; % Initialize the error count

        for k = 1:SP.numRun,
                tmp = round(rand(2,numSymbols)); % Generate random data block.
                tmp = tmp*2 - 1;

                inputSymbols = (tmp(1,:) + i*tmp(2,:))/sqrt(2);
                TxSamples = sqrt(SP.FFTsize)*ifft(inputSymbols); %Generation of transmission signal
                ofdmSymbol = [TxSamples(numSymbols-SP.CPsize+1:numSymbols) TxSamples]; %OFDM Symbol generation        RxSamples = filter(SP.channel, 1, ofdmSymbol); % Recieved signal through Direct Link
                tmp = randn(2, numSymbols+SP.CPsize);
```

```
            complexNoise = (tmp(1,:) + i*tmp(2,:))/sqrt(2); %Generation of Noise
            noisePower = 10^(-SP.SNR(n)/10);
            RxSamples = RxSamples + sqrt(noisePower)*complexNoise; % Noise added to the signal

            EstSymbols = RxSamples(SP.CPsize+1:numSymbols+SP.CPsize);
            Y = fft(EstSymbols, SP.FFTsize);

            %Selecting the equalization Type

            if SP.equalizerType == 'ZERO'
                    Y = Y./H_channel;
            elseif SP.equalizerType == 'MMSE'
                    C = conj(H_channel)./(conj(H_channel).*H_channel + 10^(-SP.SNR(n)/10));
            Y = Y.*C;
            end

            EstSymbols = Y;
            EstSymbols = sign(real(EstSymbols)) + i*sign(imag(EstSymbols)); % Hard decision detection.
            EstSymbols = EstSymbols/sqrt(2);

            I = find((inputSymbols-EstSymbols) == 0);    %Comparing transmitted and recieved signals
            errCount = errCount + (numSymbols-length(I)); %Finding the errors in the recieved signal
    end

    SER(n,:) = errCount / (numSymbols*SP.numRun); % Calculation of symbol error rate
    [SP.SNR(n) SER(n,:)]
    toc
end
```

B.3 OFDM Simulator code for Non Co-operative Environment

```
function SER = ofdm_wr_nc(SP)

numSymbols = SP.FFTsize; % The size of the data block is equal to the FFT size

```

```
H_channel_1 = fft(SP.channel_1,SP.FFTsize); %Frequency domain channel response of the Relay Link
H_channel_2 = fft(SP.channel_2,SP.FFTsize); %Frequency domain channel response of the Access link

for n = 1:length(SP.SNR),
        tic;
        errCount = 0;

        for k = 1:SP.numRun,

                %Data transmission through Relay link STARTS

                tmp = round(rand(2,numSymbols)); % Generate random data block
                tmp = tmp*2 - 1;
                inputSymbols = (tmp(1,:) + i*tmp(2,:))/sqrt(2);
                TxSamples = sqrt(SP.FFTsize)*ifft(inputSymbols); %Generation of transmission signal
                ofdmSymbol = [TxSamples(numSymbols-SP.CPsize+1:numSymbols)TxSamples]; %OFDM symbol generation
                RxSamples = filter(SP.channel_1, 1, ofdmSymbol); % Recieved Signal through Relay link
                tmp = randn(2, numSymbols+SP.CPsize);
                complexNoise = (tmp(1,:) + i*tmp(2,:))/sqrt(2); %Generation of Noise
                noisePower = 10^(-SP.SNR(n)/10);
                RxSamples = RxSamples + sqrt(noisePower)*complexNoise;  %Noise added to the signal
                EstSymbols = RxSamples(SP.CPsize+1:numSymbols+SP.CPsize);
                Y = fft(EstSymbols, SP.FFTsize);

                %Selecting the Equalization Method

                if SP.equalizerType == 'ZERO'
                        Y = Y./H_channel_1;
                elseif SP.equalizerType == 'MMSE'
                        C = conj(H_channel_1)./(conj(H_channel_1).*H_channel_1 + 10^(-SP.SNR(n)/10));
                Y = Y.*C;
                end

                EstSymbols = Y;
```

```
                EstSymbols = sign(real(EstSymbols)) + i*sign(imag(EstSymbols)); % Hard decision detection
                EstSymbols = EstSymbols/sqrt(2); %Signal recieved in the reciever of the Relay

                %Data transmission through Relay link ENDS

                %Data transmission through Access link STARTS

                inputSymbols=EstSymbols; % Signal recieved in the Relay is considered as transmitted signal
                TxSamples = sqrt(SP.FFTsize)*ifft(inputSymbols); %Transmission Signal
                ofdmSymbol = [TxSamples(numSymbols-SP.CPsize+1:numSymbols)TxSamples]; %OFDM Symbol generation         RxSamples = filter(SP.channel_2, 1, ofdmSymbol); % Recived symbols through Access Link
                tmp = randn(2, numSymbols+SP.CPsize);
                complexNoise = (tmp(1,:) + i*tmp(2,:))/sqrt(2); %Noise Generation
                noisePower = 10^(-SP.SNR(n)/10);
                RxSamples = RxSamples + sqrt(noisePower)*complexNoise;  %Noise added

                EstSymbols = RxSamples(SP.CPsize+1:numSymbols+SP.CPsize);
                Y = fft(EstSymbols, SP.FFTsize);

                %Selecting the equalization method

                if SP.equalizerType == 'ZERO'
                        Y = Y./H_channel_2;
                elseif SP.equalizerType == 'MMSE'
                        C = conj(H_channel_2)./(conj(H_channel_2).*H_channel_2 + 10^(-SP.SNR(n)/10));
                Y = Y.*C;
                end

                EstSymbols = Y;
                EstSymbols = sign(real(EstSymbols)) + i*sign(imag(EstSymbols)); % Hard decision detection
                EstSymbols = EstSymbols/sqrt(2);

                %Data transmission through Access link ENDS

```

```
                I = find((inputSymbols-EstSymbols) == 0); %Comparing the transmitted and recieved signals
                errCount = errCount + (numSymbols-length(I)); %Finding the errors in recieved signal
        end

        SER(n,:) = errCount / (numSymbols*SP.numRun);
        [SP.SNR(n) SER(n,:)]
        toc
end
```

B.4 OFDM Simulator code for Co-operative Environment

```
function SER = ofdm_wr_c(SP)

numSymbols = SP.FFTsize;

H_channel_1 = fft(SP.channel_1,SP.FFTsize); %Frequency domain channel response of the Relay Link
H_channel_2 = fft(SP.channel_2,SP.FFTsize); %Frequency domain channel response of the Access Link
H_channel_3 = fft(SP.channel_3,SP.FFTsize); %Frequency domain channel response of the Direct Link
H_channel_4 = fft(SP.channel_4,SP.FFTsize); %Combination of Access link and Direct link

for n = 1:length(SP.SNR),
        tic;
        errCount = 0;

        for k = 1:SP.numRun,

                %Data transmission through Relay link and Direct link STARTS

                tmp = round(rand(2,numSymbols));
                tmp = tmp*2 - 1;
                inputSymbols = (tmp(1,:) + i*tmp(2,:))/sqrt(2);
                TxSamples = sqrt(SP.FFTsize)*ifft(inputSymbols); %Generation of Transmission signal
                ofdmSymbol = [TxSamples(numSymbols-SP.CPsize+1:numSymbols)TxSamples]; %OFDM Signal generation          RxSamples = filter(SP.channel_1, 1, ofdmSymbol); %Recieved Signal through Relay Link
                RxSamples_DL = filter(SP.channel_3, 1, ofdmSymbol); %Recieved Signal through
```

```
Direct Link
        tmp = randn(2, numSymbols+SP.CPsize);
        complexNoise = (tmp(1,:) + i*tmp(2,:))/sqrt(2); %Generation of noise
        noisePower = 10^(-SP.SNR(n)/10);
        RxSamples = RxSamples + sqrt(noisePower)*complexNoise; %Noise added
        EstSymbols = RxSamples(SP.CPsize+1:numSymbols+SP.CPsize);
        Y = fft(EstSymbols, SP.FFTsize);

        %Selection of channel equalization

        if SP.equalizerType == 'ZERO'
                Y = Y./H_channel_1;
        elseif SP.equalizerType == 'MMSE'
                C = conj(H_channel_1)./(conj(H_channel_1).*H_channel_1...
                + 10^(-SP.SNR(n)/10));
        Y = Y.*C;
        end

        EstSymbols = Y;
        EstSymbols = sign(real(EstSymbols)) + i*sign(imag(EstSymbols));
        EstSymbols = EstSymbols/sqrt(2);

        %Data transmission through Relay link and Direct link ENDS
        %Data transmission through Access link and Direct link STARTS

        inputSymbols=EstSymbols; %Data recieved by the Relay
        TxSamples = sqrt(SP.FFTsize)*ifft(inputSymbols); %Generation of transmitted signal
        ofdmSymbol = [TxSamples(numSymbols-SP.CPsize+1:numSymbols)TxSamples]; %OFDM symbol generation        RxSamples = filter(SP.channel_2, 1, ofdmSymbol); %Recieved signal through Access Link

        RxSamples=RxSamples + RxSamples_DL; %Signals through Access Link and Direct Links are added

        tmp = randn(2, numSymbols+SP.CPsize);
        complexNoise = (tmp(1,:) + i*tmp(2,:))/sqrt(2); %Noise generation
        noisePower = 10^(-SP.SNR(n)/10);
```

```
                RxSamples = RxSamples + sqrt(noisePower)*complexNoise; %Noise Added
                EstSymbols = RxSamples(SP.CPsize+1:numSymbols+SP.CPsize);
                Y = fft(EstSymbols, SP.FFTsize);

                %Selection of channel equalization
                if SP.equalizerType == 'ZERO'
                        Y = Y./H_channel_4;
                elseif SP.equalizerType == 'MMSE'
                        C = conj(H_channel_4)./(conj(H_channel_4).*H_channel_4...
                              + 10^(-SP.SNR(n)/10));
                Y = Y.*C;
                end

                EstSymbols = Y;
                EstSymbols = sign(real(EstSymbols)) + i*sign(imag(EstSymbols));
                EstSymbols = EstSymbols/sqrt(2);

                %Data transmission through Access link and Direct link ENDS

                I = find((inputSymbols-EstSymbols) == 0);
                errCount = errCount + (numSymbols-length(I));
        end

        SER(n,:) = errCount / (numSymbols*SP.numRun);
        [SP.SNR(n) SER(n,:)]
        toc
end
```

B.5 OFDM Simulator code for Co-operative Environment (with 2 relays)

```
function SER = ofdm_wr_c_two(SP)

numSymbols = SP.FFTsize;

H_channel_1 = fft(SP.channel_1,SP.FFTsize); %Frequency domain channel response of the Direct Link
H_channel_2 = fft(SP.channel_2,SP.FFTsize); %Frequency domain channel response of the Relay Link 1
H_channel_3 = fft(SP.channel_3,SP.FFTsize); %Frequency domain channel response of the Access Link 1
H_channel_4 = fft(SP.channel_4,SP.FFTsize); %Frequency domain channel response of the Relay Link 2
H_channel_5 = fft(SP.channel_5,SP.FFTsize); %Frequency domain channel response of the Access Link 2
```

```
H_channel_6 = fft(SP.channel_6,SP.FFTsize); %Combination of Access links and Direct link

for n = 1:length(SP.SNR),
        tic;
        errCount = 0;
        for k = 1:SP.numRun,

                %% Data transmission through Relay link and Direct link STARTS

                tmp = round(rand(2,numSymbols));
                tmp = tmp*2 - 1;
                inputSymbols = (tmp(1,:) + i*tmp(2,:))/sqrt(2);
                TxSamples = sqrt(SP.FFTsize)*ifft(inputSymbols);%Generation of Transmission signal
                ofdmSymbol = [TxSamples(numSymbols-SP.CPsize+1:numSymbols) TxSamples];%OFDM Symbol generation

                RxSamples_DL = filter(SP.channel_1, 1, ofdmSymbol); % Recieved Signal through Direct Link
                RxSamples_RL1 = filter(SP.channel_2, 1, ofdmSymbol); % Recieved Signal through Relay Link 1
                RxSamples_RL2 = filter(SP.channel_4, 1, ofdmSymbol); % Recieved Signal through Relay Link 2
                %% Relay Link 1

                tmp = randn(2, numSymbols+SP.CPsize);
                complexNoise = (tmp(1,:) + i*tmp(2,:))/sqrt(2); %Generation of noise
                noisePower = 10^(-SP.SNR(n)/10);
                RxSamples_RL1 = RxSamples_RL1 + sqrt(noisePower)*complexNoise; %Noise added
                EstSymbols_1 = RxSamples_RL1(SP.CPsize+1:numSymbols+SP.CPsize);
                Y = fft(EstSymbols_1, SP.FFTsize);

                %Selection of channel equalization

                if SP.equalizerType == 'ZERO'
                        Y = Y./H_channel_2;
                elseif SP.equalizerType == 'MMSE'
                        C = conj(H_channel_2)./(conj(H_channel_2).*H_channel_2+ 10^(-SP.SNR(n)/10));
```

```
            Y = Y.*C;
    end

    EstSymbols_1 = Y;
    EstSymbols_1 = sign(real(EstSymbols_1)) + i*sign(imag(EstSymbols_1));
    EstSymbols_RL1 = EstSymbols_1/sqrt(2);  % Symbols at Relay node 1

    %% Relay link 2

    complexNoise = (tmp(1,:) + i*tmp(2,:))/sqrt(2); %Generation of noise
    noisePower = 10^(-SP.SNR(n)/10);
    RxSamples_RL2 = RxSamples_RL2 + sqrt(noisePower)*complexNoise; %Noise added
    EstSymbols_2 = RxSamples_RL2(SP.CPsize+1:numSymbols+SP.CPsize);
    Y = fft(EstSymbols_2, SP.FFTsize);

    %Selection of channel equalization

    if SP.equalizerType == 'ZERO'
            Y = Y./H_channel_4;
    elseif SP.equalizerType == 'MMSE'
            C = conj(H_channel_4)./(conj(H_channel_4).*H_channel_4+ 10^(-SP.SNR(n)/10));
            Y= Y.*C;
    end

    EstSymbols_2 = Y;
    EstSymbols_2 = sign(real(EstSymbols_2)) + i*sign(imag(EstSymbols_2));
    EstSymbols_RL2 = EstSymbols_2/sqrt(2);% Symbols at Relay node 2

    % Data transmission through Relay link and Direct link ENDS

    %% Data transmission through Access link and Direct link STARTS

    TxSamples = sqrt(SP.FFTsize)*ifft(inputSymbols); %Generation of transmitted signal

    %% Access link 1

    inputSymbols=EstSymbols_RL1; % Data recieved by the Relay 1
```

```
ofdmSymbol = [TxSamples(numSymbols-SP.CPsize+1:numSymbols) TxSamples]; %OFDM Symbol generation
RxSamples_AL1 = filter(SP.channel_3, 1, ofdmSymbol); % Recieved signal through Access Link 1

%% Access link 2

inputSymbols=EstSymbols_RL2; % Data recieved by the Relay 2
ofdmSymbol = [TxSamples(numSymbols-SP.CPsize+1:numSymbols) TxSamples];
RxSamples_AL2 = filter(SP.channel_5, 1, ofdmSymbol); % Recieved signal through Access Link

%% Combibed data of three links

RxSamples=RxSamples_AL1 + RxSamples_AL1 + RxSamples_DL; % Signals of all links are added
tmp = randn(2, numSymbols+SP.CPsize);
complexNoise = (tmp(1,:) + i*tmp(2,:))/sqrt(2); %Noise generation
noisePower = 10^(-SP.SNR(n)/10);
RxSamples = RxSamples + sqrt(noisePower)*complexNoise; %Noise Added
EstSymbols = RxSamples(SP.CPsize+1:numSymbols+SP.CPsize);
Y = fft(EstSymbols, SP.FFTsize);

%Selection of channel equalization

if SP.equalizerType == 'ZERO'
        Y = Y./H_channel_6;
elseif SP.equalizerType == 'MMSE'
        C = conj(H_channel_6)./(conj(H_channel_6).*H_channel_6+ 10^(-SP.SNR(n)/10));
        Y = Y.*C;
end

EstSymbols = Y;
EstSymbols = sign(real(EstSymbols)) + i*sign(imag(EstSymbols));% Hard decision detection
EstSymbols = EstSymbols/sqrt(2);

%Data transmission through Access link and Direct link ENDS
```

```
                    I = find((inputSymbols-EstSymbols) == 0);
                    errCount = errCount + (numSymbols-length(I)
                       );
            end
            SER(n,:) = errCount / (numSymbols*SP.numRun);
            [SP.SNR(n) SER(n,:)]
            toc
end
```

Appendix C

Sample Raw Results

This section shows the sample raw results from the analysis performed after generating all the radio links in WINNER II channel model. For each scenarios the simulation has been repeated for 5000 times. This sample result is one of the iterated values of *Indoor to Outdoor* scenario. This result includes the following parameters:

- Delays: It is a $K \times N$ matrix of the path delays, measured in seconds. Here K is the number of links and N is the number of paths in each links. In the analysis we used 3 links (Relay link, Access link, Direct link). And the number of paths in each link is 16. So the values of delay will be a 3×16 matrix. First row of the matrix represents the delays of Relay Link, the row column represents the delay of Access Link and the third row represents the delays for Direct Link. The sample values are listed in Table C.1.

- Angle of Departure (AoD): It is a $K \times N \times M$ array of sub path angles of departure in degrees over -180^o to 180^o. Here K is the number of links and N is the number of paths in each links and M is the number of sub paths in each path. In this analysis, the number of links are 3, number of paths in each link is 12 and number of sub paths in each path is 20. So the size of the array is $3 \times 12 \times 20$. As a sample, the results for first 3 sub paths are shown in Table C.2.

- Angle of Arrival (AOA): It is a $K \times N \times M$ array of sub path angles of arrival in degrees over -180^o to 180^o. Here K is the number of links and N is the number of paths in each links and M is the number of sub paths in each path. In this analysis, the number of links are 3, number of paths in each link is 12 and number of sub paths in each path is 20. So the size of the array is $3 \times 12 \times 20$. As a sample, the results for first 3 sub paths are shown in Table C.3.

- Path Losses - It is $K \times 1$ matrix of Path losses for the scenario. Here K is the number of links. So for each three links, three separate path loss can be found. It is a coefficient by which the transmitted power is multiplied. The results for path losses are shown in Table C.4.

	Path 1	Path 2	Path 3	Path 4	Path 5	Path 6	Path 7	Path 8	Path 9	Path 10	Path 11	Path 12	Path 13	Path 14	Path 15	Path 16
Relay Link	0	5.00E-009	1.00E-008	1.00E-008	3.00E-008	3.50E-008	4.00E-008	3.50E-008	6.50E-008	8.00E-008	8.50E-008	1.10E-007	1.35E-007	2.05E-007	2.50E-007	3.45E-007
Access Link	0	5.00E-009	1.00E-008	1.50E-008	2.00E-008	2.50E-008	2.00E-008	4.00E-008	1.00E-007	1.10E-007	1.10E-007	1.20E-007	1.55E-007	2.30E-007	3.40E-007	3.85E-007
Direct Link	0	5.00E-009	1.00E-008	1.50E-008	1.50E-008	1.50E-008	2.00E-008	2.50E-008	3.00E-008	4.00E-008	4.50E-008	5.00E-008	7.00E-008	9.00E-008	1.25E-007	2.60E-007

Table C.1: Sample results of delays (seconds)

- Path Powers: It is a $K \times N$ matrix of Path powers. Here K is the number of links and N is the number of paths in each links. In this analysis it is a 3×12 matrix. This power is the clustered path powers of each paths of each links. It is a coefficient by which the transmitted power is multiplied. The values are shown in Table C.5.

- Station Distance - The distances between the stations can be measured in meters, which is a $1 \times K$ matrix. Here K is the number of links. So this is a 1×3 matrix. The first row shows the distance between the BS and RN, the second row shows the distance between RN and UE and the third tow shows the distance between BS and UE (the direct link). The values are shown in Table C.6.

- Shadow Fading - A $K \times 1$ matrix of shadow fading losses in linear scale can be measured. Here K is the number of links. So it is a 3×1 matrix shadow fading. The first column is the shadow fading for the Relay Link, the second column is for the Access link and the third one is the shadow fading value of the Direct link. It is a coefficient by which the mean path-loss is multiplied. The values are shown in Table C.7.

Sub Path 1	Relay Link	Access Link	Direct Link
Path 1	155.5198	-32.0735	-64.4819
Path 2	-25.5281	-88.7925	-52.8173
Path 3	39.0593	-77.7462	-53.4003
Path 4	132.9115	-80.5229	98.1758
Path 5	-65.6887	-124.4270	3.0345
Path 6	175.2415	-88.4549	63.1519
Path 7	126.3269	-2.1645	-115.8648
Path 8	137.8870	50.9868	102.2566
Path 9	153.3871	-108.8793	88.6755
Path 10	160.0605	63.6300	-55.1993
Path 11	-46.2898	61.5262	-75.3504
Path 12	167.5754	81.1866	-150.0917

Sub Path 2	Relay Link	Access Link	Direct Link
Path 1	154.8046	-32.7887	-65.1971
Path 2	-26.2433	-89.5077	-53.5325
Path 3	38.3441	-78.4614	-54.1155
Path 4	132.1963	-81.2381	97.4606
Path 5	-66.4039	-125.1422	2.3193
Path 6	174.5263	-89.1701	62.4367
Path 7	125.6117	-2.8797	-116.5800
Path 8	137.1718	50.2716	101.5414
Path 9	152.6719	-109.5945	87.9603
Path 10	159.3453	62.9148	-55.9145
Path 11	-47.0050	60.8110	-76.0656
Path 12	166.8602	80.4714	-150.8069

Sub Path 3	Relay Link	Access Link	Direct Link
Path 1	156.2926	-31.3007	-63.7091
Path 2	-24.7553	-88.0197	-52.0445
Path 3	39.8321	-76.9734	-52.6275
Path 4	133.6843	-79.7501	98.9486
Path 5	-64.9159	-123.6542	3.8073
Path 6	176.0143	-87.6821	63.9247
Path 7	127.0997	-1.3917	-115.0920
Path 8	138.6598	51.7596	103.0294
Path 9	154.1599	-108.1065	89.4483
Path 10	160.8333	64.4028	-54.4265
Path 11	-45.5170	62.2990	-74.5776
Path 12	168.3482	81.9594	-149.3189

Table C.2: Sample results of AoD for 3 sub paths out of 20 sub paths (degrees)

	Path 1	Path 2	Path 3	Path 4	Path 5	Path 6	Path 7	Path 8	Path 9	Path 10	Path 11	Path 12
Sub Path 1												
Relay Link	154.0318	-27.0161	37.5713	131.4235	-67.1767	173.7535	124.8389	136.3990	151.8991	158.5725	-47.7778	166.0874
Access Link	-33.5615	-90.2805	-79.2342	-82.0109	-125.9150	-89.9429	-3.6525	49.4988	-110.3673	62.1420	60.0382	79.6986
Direct Link	-65.9699	-54.3053	-54.8883	96.6878	1.5465	61.6639	117.3528	100.7686	87.1875	-56.6873	-76.8384	-151.5797
Sub Path 2												
Relay Link	157.1558	-23.8921	40.6953	134.5475	-64.0527	176.8775	127.9629	139.5230	155.0231	161.6965	-44.6538	169.2114
Access Link	-30.4375	-87.1565	-76.1102	-78.8869	-122.7910	-86.8189	-0.5285	52.6228	-107.2433	65.2660	63.1622	82.8226
Direct Link	-62.8459	-51.1813	-51.7643	99.8118	4.6705	64.7879	-114.2288	103.8926	90.3115	-53.5633	-73.7144	-148.4557
Sub Path 3												
Relay Link	-165.2154	-157.7738	-132.2456	-115.0655	-112.1531	-154.5299	-161.8811	-165.8241	-159.4122	176.5951	-157.5231	-154.8356
Access Link	131.7425	119.3210	153.7449	99.9824	71.9217	167.8595	103.6823	61.9431	86.5104	-149.9131	-154.3839	-125.9137
Direct Link	154.8315	-178.1632	-168.6908	-155.6320	-179.9549	168.3690	144.2830	-147.1466	145.9307	163.8953	152.3001	-125.8420

Table C.3: Sample results of AoA for 3 sub paths out of 20 sub paths (degrees)

	Path loss values
Relay Link	6.593E-17
Access Link	1.843E-16
Direct Link	2.631E-23

Table C.4: Sample results of Path losses

	Relay Link	Access Link	Direct Link
Path 1	1.68E-001	1.50E-001	5.53E-002
Path 2	1.01E-001	9.00E-002	9.20E-002
Path 3	6.71E-002	6.00E-002	5.52E-002
Path 4	5.35E-002	0.0777054743301286	3.68E-002
Path 5	1.01E-001	0.0466232845980772	5.35E-002
Path 6	6.05E-002	0.0310821897320514	1.53E-001
Path 7	0.0403550314513158	0.0739938994049202	7.83E-002
Path 8	0.0822968698259876	0.0427448097634717	0.0469836955178709
Path 9	0.0594440609890573	0.154512044068161	0.0313224636785806
Path 10	0.0333155892385721	0.0439658123894066	0.0342082099921472
Path 11	0.00509268764429964	0.0761280692441026	0.0626305634269477
Path 12	0.0577403280907501	0.0408224081033884	0.0565945732462993
Path 13	0.116386008218092	0.0537301544662139	0.0594611818410695
Path 14	0.0413700759142168	0.039863965863767	0.143967436612552
Path 15	0.0129323257862249	0.00736364477389663	0.0342549117458774
Path 16	0.000686772828027539	0.0113797091488658	0.00597666751480313

Table C.5: Sample results of Path powers

	BS to RN	RN to UE	BS to UE
Distance	500	500	1000

Table C.6: Sample results of Station distance (meter)

	Shadow fading values
Relay Link	0.9517
Access Link	0.0553
Direct Link	1.0249

Table C.7: Sample results of the shadow fading

References

[1] C. Mehlfhrer, M. Wrulich, J. C. Ikuno, D. Bosanska and M. Rupp, *Simulating the Long Term Evolution Physical Layer*; in Proc. of the 17th European Signal Processing.

[2] Mamoru Sawahashi†, Yoshihisa Kishiyama, Hidekazu Taoka, Motohiro Tanno, and Takehiro Nakamura; *Broadband Radio Access: LTE and LTE-Advanced*; International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS 2009), December 7-9, 2009,

[3] Tommaso Beniero, Simone Redana, Jyri Hämäläinen, Bernhard Raaf; *Effect of Relaying on Coverage in 3GPP LTE-Advanced*; IEEE 69th Vehicular Technology Conference, VTC Spring 2009, Barcelona.

[4] K. N Shantha Kumar, Madhu Kata, Paruchuri Chaitanya, Dinesh Mukkollu; *LTE-Advanced: Future of Mobile Broadband*; White Paper, Tata Consultancy Services Limited, 2009.

[5] Vít Štencel, Andreas Muller, Philipp Frank; *LTE Advanced – A Further Evolutionary Step for Next Generation Mobile Networks*; 20th International Conference Radioelektronika, 2010.

[6] Matti Kiiski, *LTE-Advanced: The Mainstream in Mobile Broadband Evolution*; European Wireless Conference, 2010.

[7] Amitava Ghosh, Rapeepat Ratasuk, Bishwarup Mondal, Nitin Mangalvedhe, Tim Tomas, *LTE Advanced - Next Generation Broadband Technology*, IEEE Wireless Communications, June 2010.

[8] Thomas Wirth, V. Venkatkumar, Thomas Haustein, Egon Schulz, Rüdiger Halfmann; *LTE-Advanced Relaying for Outdoor Range Extension*; IEEE 70th Vehicular Technology Conference Fall (VTC 2009-Fall), 2009, Anchorage, AK.

[9] Mogensen, P.E. Koivisto, T. Pedersen, K.I. Kovacs, I.Z. Raaf, B. Pajukoski, K. Rinne, M.J.; *LTE-Advanced: The Path towards Gigabit/s in Wireless Mobile Communications*; 1st International Conference on Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology, 2009.

[10] Teleca White Papers, *LTE-Advanced — The future of mobile broadband.*

[11] Anthony Lo, and Ignas Niemegeers; *Multi-hop Relay Architectures for 3GPP LTE-Advanced*; Proceedings of the 2009 IEEE 9th Malaysia International

Conference on Communications, pp 15 -17, December 2009, Kuala Lumpur, Malaysia.

[12] Sanghyeon Lee, Kyongkuk Cho, Kwanghun Kim, Dongweon Yoon, Takkyu Kim; *Performance analysis of LTE-Advanced system in the down link spatial channel model*; IEEE International Conference on Network Infrastructure and Digital Content, 2009. IC-NIDC 2009.

[13] Yang Yang, Honglin Hu and Jing Xu, Guoqiang Mao; *Relay Technologies for WiMAX and LTE-Advanced Mobile Systems*; IEEE Communications Magazine, October 2009.

[14] Erik Dahlman, Stefan Parkvall; *3G Evolution HSPA and LTE for Mobile Broadband*, 2nd Edition, Academic Press, Oct 2008.

[15] Farooq Khan, *LTE for 4G Mobile Broadband - Air Interface Technologies and Performance*; Cambridge University Press, 2009.

[16] Hyung G. Myung, David J. Goodman; *Single Carrier FDMA: A New Air Interface for Long Term Evolution*; John Wiley & Sons, Ltd, 2008.

[17] *HSPA to LTE-Advanced*; Rysavy Research / 3G Americas, September 2009.

[18] S. Parkvall et al.; *Evolving 3G Mobile Systems: Broadband and Broadcast Services in WCDMA*, IEEE Communications Magazine, February 2006.

[19] 3GPP, RP-040461*; Proposed Study Item on Evolved UTRA and UTRAN*; www.3gpp.org.

[20] D. Astely et al.; *A Future-Radio-Access Framework*; Journal on Selected Areas in Communications, Special Issue on 4G Wireless Systems.

[21] E. Mino Diaz, et al.; *The WINNER project: Research for new Radio Interfaces for better Mobile Services*; IEICE Transactions, Japan, Vol. E87-A, No. 10, October 2004.

[22] H. Ekström et al.; *Technical Solutions for the 3G Long-term Evolution*; IEEE Communications Magazine, March 2006.

[23] 3GPP, TR 36.913 V8.0.0; *Requirements for Further Advancements for E-UTRA (LTE-Advanced)*; http://www.3gpp.org/ftp/Specs/html-info/36913.htm

[24] Giuseppe Caire, Shlomo Shamai; *On the Achievable Throughput of a Multiantenna Gaussian Broadcast Channel*; IEEE Trans. Inf. Theory, 2003, 21 (5), pp. 1691-1706.

[25] Pekka Kyösti, Juha Meinilä, Lassi Hentilä, Xiongwen Zhao, Tommi Jämsä, Christian Schneider, Milan Narandzić, Marko Milojević, Aihua Hong, Juha Ylitalo, Veli-Matti Holappa, Mikko Alatossava, Robert Bultitude, Yvo de Jong, Terhi Rautiainen; *Part I: Channel Models*, IST-4-027756, WINNER II D1.1.2 V1.1, WINNER II Channel Models, 2007.

[26] Daniel S. Baum, Hassan El-Sallabi, Tommi Jämsä, Juha Meinilä, Pekka

Kyösti, Xiongwen Zhao, Daniela Laselva, Jukka-Pekka Nuutinen, Lassi Hentilä, Pertti Vainikainen, Jarmo Kivinen, Lasse Vuokko, Per Zetterberg, Mats Bengtsson, Kai Yu, Niklas Jaldén, Terhi Rautiainen, Kimmo Kalliola, Marko Milojevic, Christian Schneider, Jan Hansen; *Final Report on Link Level and System Level Channel Models*; IST-2003-507581, WINNER D5.4 v. 1.4, Nov. 18th, 2005.

[27] *Guidelines for evaluation of radio transmission technologies for IMT-2000*, Rec. ITU-R M.1225.

[28] *An Introduction to LTE*. 3GPP LTE Encyclopedia.

[29] *Long Term Evolution (LTE): A Technical Overview*. Motorola.

[30] 3rd Generation Partnership Project, 3GPP TS 25.101 – Technical Specification Group Radio Access Network; *User Equipment (UE) Radio Transmission and Reception (FDD) (Release 7)*, Sep. 2007, Section B.2.2.

[31] 3rd Generation Partnership Project; Technical specification group radio access network; 3GPP TR 25.996, *Spatial channel model for MIMO simulations (release 6)*, V6.1.0.

[32] Andrea Goldsmith; *Wireless Communications*; Stanford University, California, September 2005.

[33] T. S. Rappaport; *Wireless Communications: Principles and Practice*; Upper Saddle River, New Jersey: Prentice Hall PTR, 1996.

[34] Michael Souryal, *Physical Layer Models for PAP02: Wireless Communications for the Smart Grid - Task 6*; Emerging and Mobile Network Technologies Group Information Technology Laboratory National Institute of Standards and Technology, February 17, 2010.

[35] Pekka Kyösti, Juha Meinilä, Lassi Hentilä, Tommi Jämsä, Milan Narandzić, Essi Suikkanen, Esa Kunnari; *WINNER+ Final Channel Models*; WINNER II D5.3, WINNER II Channel Models, 2010.