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Mobility Aspects of Physical Layer in Future Generation Wireless Networks

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1. Introduction

The demand from social market for high speed broadband communications over wireless media is pushing the requirements of both the mobile and fixed networks. The past decade has witnessed tremendous advancement in the blooming development of mobile communications including mobile-to-mobile and mobile-to-fixed networks. Wireless fixed and cellular networks of future generation will need to support new protocols, standards and architecture leading to all IP-based networks. Different systems like digital video broadcasting (DVB) via satellites have great success commercially as they provide ubiquitous coverage and serve large number of users with high signal quality. Satellite communications have proven to be attractive means to provide communication services such as broadband communications (3G services), surveillance, remote monitoring, intelligent transportation systems, navigation, traffic warnings and location-based information etc. to fixed and mobile users. However, to meet the growing demands of mass market integration of satellites and terrestrial networks seems to be inevitable for future generation wireless networks.

Due to technology advances and growing traffic demands, communication systems must evolve to completely new systems or within themselves in order to provide broadband services in a safe and efficient way. While enhancements continue to be made to leverage the maximum performance from currently deployed systems, there is a bound to the level to which further improvements will be effective. If the only purpose were to deliver superior performance, then this in itself would be relatively easy to accomplish. The added complexity is that such superior performance must be delivered through systems which are cheaper from installation and maintenance prospect. Users have experienced an incredible reduction in telecommunications charges and they now anticipate receiving higher quality communication services at low cost. Therefore, in deciding the subsequent standardization step, there must be a dual approach: in search of substantial performance enhancement but at reduced cost. Long Term Evolution (LTE) is that next step and will be the basis on which future mobile telecommunications systems will be built. LTE is the first cellular communication system optimized from the outset to support packet-switched data services, within which packetized voice communications are just one part.

In case of highly mobile scenarios, the effects of signal blockages and Doppler shifts introduce more burdens on the receiver demodulator. The signals blockage is prominent in the case of land mobile communications as compared to satellite communications. In deciding the technologies to comprise in LTE, one of the key concerns is the trade-off between cost of implementation and practical advantage. Fundamental to this assessment, therefore, has been an enhanced understanding different scenarios of the radio propagation environment in which LTE will be deployed and used.

The organization of the chapter is as follows. In section 2, different mobility aspects related to the physical layer of future generation mobile communication networks are discussed. Section 3 discusses the propagation scenarios in which LTE will be deployed. Section 4 describes space-time processing techniques to enhance the system performance. In section 5 LTE system's performance is evaluated at different mobile speeds. Finally, section 6 concludes the chapter.

2. Physical layer aspects

The high data rate multimedia broadcast/multicast services at cheap rates with appropriate quality-of-service (QoS), fast handoff techniques and wide area seamless mobility pave the way for future generation wireless communications. Wireless network operators require different schemes for including new services to take benefits from new access technologies. Fundamental to these strategies is to incorporate mobility that can bring unique advantages to mobile users. In response to these requirements, the wireless industry is foreseen to shift toward LTE and world wide interoperability of microwave access (WiMAX) technologies to be able to support cost effectively the capacity required by mobile operators to meet mass market demands of data services (Motorola, 2010). LTE must be able to provide superior performance compared to the existing wireless network infrastructures which suffer from cell-edge performance, spectral efficiency and desired QoS to end users. In order to provide high data rates with high QoS in already crowded spectrum, LTE is susceptible to different impairments: noise and interference. Therefore to mitigate these propagation impairments, efficient and robust techniques need to be adapted to take full benefits of the technology. A thoughtful design of physical layer aspects to mitigate these propagation impairments and improve the system performance is thus crucial for successful operation and support of the desired QoS.

2.1 Objectives of physical layer

The objectives of LTE physical layer are the significant increase in peak data rates up to 100 Mb/s in downlink and 50 Mb/s in uplink within 20 MHz spectrum leading to spectrum efficiency of 5 Mb/s, increased cell-edge performance maintains site locations as in Wide Band Code Division Multiple Access (WCDMA), reduced user and control plane latency to less than 10 ms and less than 100 ms, respectively (Kliazovich1, et al.). LTE will be able to provide interactive real-time services such as high quality video/audio conferencing and multiplayer gaming with mobility support for up to 350 km/h or even up to 500 km/h and reduced operation cost. It also provides a scalable bandwidth 1.25/2.5/5/10/20 MHz in order to allow flexible technology to coexist with other standards, 2 to 4 times improved spectrum efficiency the one in Release 6 HSPA to permit operators to accommodate increased number of customers within their existing and future spectrum allocation with a reduced cost of delivery per bit, low power consumption and acceptable system and terminal complexity. The system should be optimized for low mobile speed but also support high mobile speed as well. In this section we will discuss some of the features included in LTE physical layer to mitigate propagation impairments.

Scalable OFDMA: Multiple access schemes are used in multi-user communications to provide on-demand data rates to users by sharing the available resources in available finite bandwidth. The orthogonal frequency division multiple access (OFDMA) is used as multiple access scheme in the downlink and single carrier frequency division multiple access (SC-FDMA) is used in the uplink. OFDMA is OFDM based multiple access technique used for LTE to facilitate the exploitation of multi-user diversity, frequency diversity and flexible users scheduling to enhance the system capacity in challenging multi-user communications with wide range of applications, data rates and QoS requirements. The flexible structure of OFDMA allows efficient implementation of space-time processing techniques, e.g., multiple-input multiple-output (MIMO) with reasonable complexity. The scalable bandwidth with different FFT sizes and dynamic subcarrier allocation allows the efficient use of spectrum in different regional regulations for mobile applications.

Frame Structure and Transmission Modes: LTE supports two types of frame structures: type1 frame structure which is designed for frequency division duplex (FDD) and is valid for both half duplex and full duplex FDD modes. Type 1 radio frame has a duration 10 ms and consists of 20 slots each of 0.5 ms. A sub-frame comprises two slots, thus one radio frame has 10 sub-frames. In FDD mode, half of the sub-frames are available for downlink and the other half are available for uplink transmission in each 10 ms interval, where downlink and uplink transmission are separated in the frequency domain (3GPP, 2008). Type 2 frame structure is applicable for time division duplex mode (TDD). The radio frame is composed of two identical half-frames having duration of 5 ms. Each half-frame is further divided into 5 sub-frames having duration of 1 ms. Two slots of length 0.5 ms constitute a sub-frame which is not special sub-frame. The special type of sub-frame is composed of three fields Downlink Pilot Timeslot (DwPTS), GP (Guard Period) and Uplink Pilot Timeslot (UpPTS). Seven uplink-downlink configurations are supported with both types (10 ms and 5 ms) of downlink-to-uplink switch-point periodicity. In 5 ms downlink-to-uplink switch-point periodicity, special type of sub-frames are used in both half-frames but it is not the case in 10 ms downlink-to-uplink switch-point periodicity, special frame is used instead of are used only in first half-frame. For downlink transmission sub-frames 0, 5 and DwPTS are always reserved. UpPTS and the sub-frame next to the special sub-frame are always reserved for uplink communication (3GPP, 2009).

Mobility Support: One of the features of LTE is appropriate physical layer design to facilitate users at high vehicular speeds to support delay sensitive applications (e.g., VOIP) with appropriate QoS. The physical layer features such as power control, hybrid automatic repeat request (HARQ), sub-channelization and pilot structure are used to mitigate the fluctuations in the received signal caused by channel fast fading. In addition, link adaptation technique is used to adjust system parameters according to channel dynamics, i.e, to select appropriate parameters under available propagation conditions. This permits to optimize the spectral and power sources of the system under poor propagation conditions.

Advanced Antenna Techniques: Multiple antenna systems based on space-time processing algorithms have brought great benefits to wireless communications by exploiting the spatial domain to use the resources in efficient way. Advanced antenna techniques such as diversity techniques, spatial multiplexing and beamforming are employed to create independent multiple parallel channels which result in overall system improvement in terms of link reliability, high capacity, extended coverage and reduced transmitted power. LTE uses advanced antennas techniques in both single-user and multi-user MIMO cases.

Link Adaptation and Channel Coding: Link adaptation is used to adjust the system parameters in time varying propagation conditions to facilitate users at different data rates. Thus link adaptation scheme is very closely related to channel coding schemes used for forward error correction (Sesia, et al. 2009). LTE schedules down link data transmission and selects modulation and coding schemes based on the feedback information in terms of signal-to-interference plus noise ratio (SINR) provided by channel quality indicator (CQI) in uplink direction. The LTE specifications define the signalling between user terminal and eNodeB for link adaptation and switching between different modulation schemes and coding rates that depend on several factors including cell throughput and required QoS.

Scheduling and Quality-of-Service: The purpose of scheduling is to manage the resources in uplink and downlink channels while maintaining the desired QoS according to user expectations. In LTE eNodeB performs this operation. The principle of scheduling algorithm is to allocate the resources and transmission powers in order to optimize certain set of parameters such as throughput, user spectral efficiency, average delay and outage probability. The LTE MAC layer can support large number of users with desired QoS.

3. Radio propagation models

From the beginning of wireless communications there is a high demand for realistic mobile fading channels. The reason for this importance is that efficient channel models are essential for the analysis, design, and deployment of communication systems for reliable transfer of information between two parties. Realistic channel models are also significant for testing, parameter optimization and performance evolution of communication systems. The performance and complexity of signal processing algorithms, transceiver designs and smart antennas etc., employed in future mobile communication systems, are highly dependent on design methods used to model mobile fading channels. Therefore, correct knowledge of mobile fading channels is a central prerequisite for the design of wireless communication systems (Rappaport, 1996; Ibnkahla, 2005; Ojanpera, et al., 2001).

The difficulties in modeling the wireless channel are due to complex propagation processes. A transmitted signal arrives at the receiver through different propagation mechanisms as shown in Figure 1. The propagation mechanisms involve the following basic mechanisms: i) free space or line of sight (LOS) propagation ii) specular reflection due to interaction of electromagnetic waves with plane and smooth surfaces which have large dimensions as compared to the wavelength of interacting electromagnetic waves iii) Diffraction caused by bending of electromagnetic waves around corners of buildings iv) Diffusion or scattering due to contacts with objects having irregular surfaces or shapes with sizes of the order of wavelength v) Transmission through objects which cause partial absorption of energy (Oestges, et al., 2007; Rappaport, 1996). It is significant here to note that the level of information about the environment a channel model must provide is highly dependent on the category of communication system under assessment. To predict the performance of narrowband receivers, classical channel models which provide information about signal power level distributions and Doppler shifts of the received signals, may be sufficient. The advanced technologies (e.g., UMTS and LTE) build on the typical understanding of Doppler spread and fading also incorporate new concepts such as time delay spread, direction of departures (DOD), direction of arrivals (DOA) and adaptive antenna geometry (Ibnkahla, 2005). The presence of multipaths (multiple scattered paths) with different delays, attenuations, DOD and DOA gives rise to highly complex multipath propagation channel. Figure 2 illustrates power delay profile (PDP) of a multipath channel with three distinct paths.

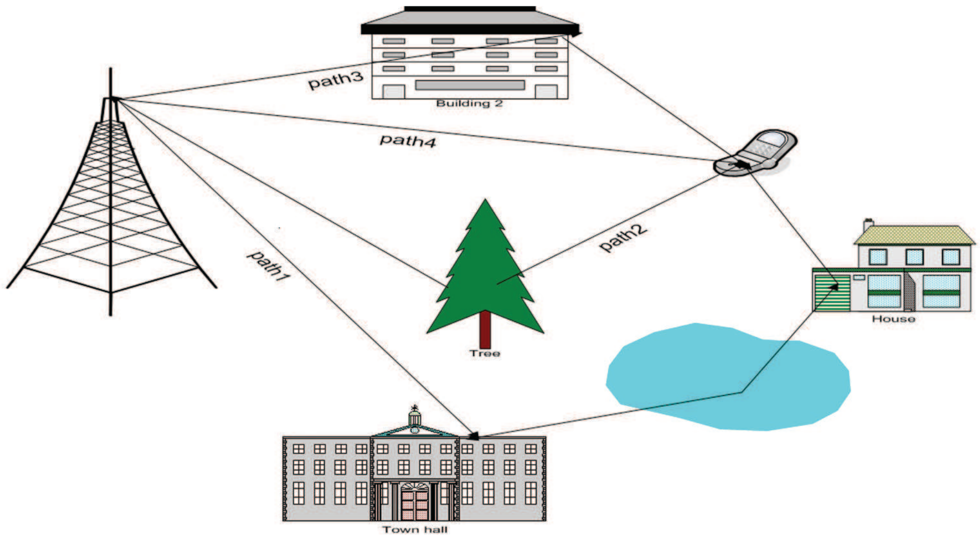

Fig. 1. Signal propagation through different paths showing multipath propagation phenomena

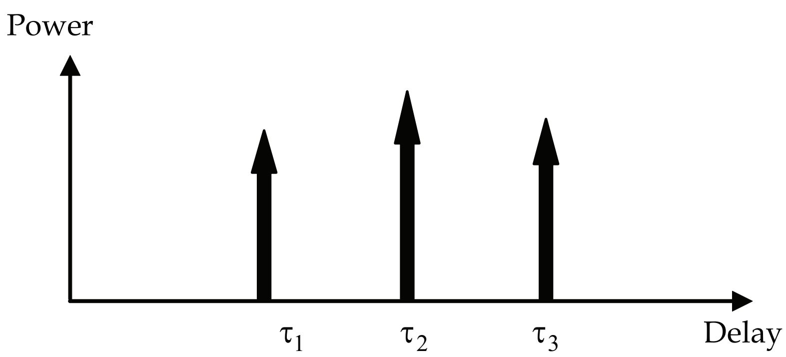

Fig. 2. Power delay profile of a multipath channel

3.1 Propagation aspects and parameters

The behaviour of a multipath channel needs to be characterized in order to model the channel. The concepts of Doppler spread, coherence time, delay spread and coherence bandwidth are used to describe various aspects of the multipath channel.

3.1.1 Delay spread

To measure the performance capabilities of a wireless channel, the time dispersion or multipath delay spread related to small scale fading of the channel needs to be calculated in a convenient way. One simple measure of delay spread is the overall extent of path delays called the excess delay spread. This is an appropriate way because different channels with the same excess delay can exhibit different power profiles which have more or less impact on the performance of the system under consideration. A more efficient method to determine channel delay spread is the root mean square (rms) delay spread (τ_{rms}) which is a statistical measure and gives the spread of delayed components about the mean value of the channel power delay profile. Mathematically, rms delay spread can be described as second central moment of the channel power delay profile (Rappaport, 1996) which is written as:

$$\tau_{rms} = \frac{\sqrt{\sum_{n=0}^{N-1} P_n(\tau_n - \tau_m)^2}}{\sum_{n=0}^{N-1} P_n} \quad (1)$$

where, $\tau_m = \frac{\sum_{n=0}^{N-1} P_n \tau_n}{\sum_{n=0}^{N-1} P_n}$ is the mean excess delay.

3.1.2 Coherence bandwidth

When the channel behaviour is studied in frequency domain then coherence bandwidth Δf_c is of concern. The frequency band, in which the amplitudes of all frequency components of the transmitted signal are correlated, i.e., with equal gains and linear phases, is known as coherence bandwidth of that channel (Ibnkahla, 2005). The channel behaviour remains invariant over this bandwidth. The coherence bandwidth varies in inverse proportion to the delay spread. A multipath channel can be categorized as frequency flat fading or frequency selective fading in the following way.

Frequency flat fading: A channel is referred to as frequency flat if the coherence bandwidth Δf_c >>B, where B is the signal bandwidth. In this case frequency components of the signal will experience the same amount of fading.

Frequency selective fading: A channel is referred to as frequency selective if the coherence bandwidth $\Delta f_c \leq B$. In this case different frequency components will undergo different amount of fading. The channel acts as a filter since the channel coherence bandwidth is less than the signal bandwidth; hence frequency selective fading takes place (Fleury, 1996).

3.1.3 Doppler spread

The Doppler spread arises due to the motion of mobile terminal. Due to the motion of mobile terminal through standing wave the amplitude, phase and filtering applied to the transmitted signal vary with time according to the mobile speed (Cavers, 2002). For an unmodulated carrier, the output is time varying and has non-zero spectral width which is Doppler spread. For a single path between the mobile terminal and the base station, there will be zero Doppler spread with a simple shift of the carrier frequency (i.e., Doppler frequency shift) at the base station. The Doppler frequency depends on the angle of movement of the mobile terminal relative to the base station.

3.1.4 Coherence time

The time over which the characteristics of a channel do not change significantly is termed as coherence time. The reciprocal of the Doppler shift is described as the coherence time of the channel. Mathematically we can describe coherence time as:

$$T_c = \frac{1}{2\pi\nu_{rms}} \quad (2)$$

where ν_{rms} is root mean square vale of Doppler spread.

The coherence time is related to the power control schemes, error correction and interleaving schemes and to the design of channel estimation techniques at the receiver.

4. Standard channel models

Standard channel models can be developed by setting up frame work for generic channel models and finding set of parameters that need to be determined for the description of the channel. Another method is to set up measurement campaigns and extracting numerical values of parameters and their statistical distributions (Meinilä, et al., 2004).
When designing LTE, different requirements are considered: user equipment (UE) and base station (BS) performance requirements which are crucial part of LTE standards, Radio Resource Management (RRM) requirements to ensure that the available resources are used in an efficient way to provide end users the desired quality of service, the RF performance requirements to facilitate the existence of LTE with other systems (e.g., 2G/3G) systems (Holma, et al., 2009). The standard channel models play a vital role in the assessment of these requirements. In the following section, some standard channel models are discussed which are used in the design and evaluation of the UMTS-LTE system.

4.1 SISO, SIMO and MISO channel models

COST projects, Advanced TDMA (ATDMA) Mobile Access, UMTS Code Division Testbed (CODIT) conducted extensive measurement campaigns to create datasets for SISO, SIMO and MISO channel modeling and these efforts form the basis for ITU channel models which are used in the development and implementation of the third generation mobile communication systems (Sesia, et al., 2009). COST stands for the "European Co-operation in the Field of Scientific and Technical Research". Several Cost efforts were dedicated to the field of wireless communications, especially radio propagation modeling, COST 207 for the development of Second Generation of Mobile Communications (GSM), COST 231 for GSM extension and Third Generation systems, COST 259 "Flexible personalized wireless communications (1996-2000)" and COST 273 "Towards mobile broadband multimedia networks (2001-2005)". These projects developed channel models based on extensive measurement campaigns including directional characteristics of radio propagation (Cost 259 and Cost 273) in macro, micro and picocells and are appropriate for simulations with smart antennas and MIMO systems. These channel models form the basis of ITU standards for channel models of Beyond 3G systems. Detailed study of COST projects can be found in (Molisch, et al., 2006; Corria, 2001).
The research projects ATDMA and CODIT were dedicated to wideband channel modelling specifically channel modelling for 3rd generation systems and the corresponding radio environments. The wideband channel models have been developed within CODIT using physical-statistical channel modelling approach while stored channel measurements are used in ATDMA which are complex impulse responses for different radio environments. The details of these projects can be found in (Ojanpera, et al., 2001).

4.2 ITU multipath channel models

The ITU standard multipath channel models proposed by ITU (ITU-R, 1997) used for the development of 3G 'IMT-2000' group of radio access systems are basically similar in structure to the 3GPP multipath channel models. The aim of these channel models is to develop standards that help system designers and network planners for system designs and performance verification. Instead of defining propagation models for all possible environments, ITU proposed a set of test environments in (ITU-R, 1997) that adequately span the all possible operating environments and user mobility. In this chapter we use ITU standard channel models for pedestrian and vehicular environments.

4.2.1 ITU Pedestrian-A, B

In both Pedestrian-A and Pedestrian-B channel models the mobile speed is considered to be 3 km/h. For Pedestrian models the base stations with low antennas height are situated outdoors while the pedestrian users are located inside buildings or in open areas. Fading can follow Rayleigh or Rician distribution depending upon the location of the user. The number of taps in case of Pedestrian-A model is 3 while Pedestrian-B has 6 taps. The average powers and relative delays for the taps of multipath channels based on ITU recommendations are given in Table 1 (ITU-R, 1997).

4.2.2 ITU Vehicular-A (V-30, V-120 and V-350)

The vehicular environment is categorized by large macro cells with higher capacity, limited spectrum and large transmit power. The received signal is composed of multipath reflections without LOS component. The received signal power level decreases with distance for which path loss exponent varies between 3 and 5 in the case of urban and suburban areas. In rural areas path loss may be lower than previous while in mountainous areas, neglecting the path blockage, a path loss attenuation exponent closer to 2 may be appropriate.

For vehicular environments, the ITU vehicular-A channel models consider the mobile speeds of 30 km/h, 120 km/h and 350 km/h. The propagation scenarios for LTE with speeds from 120 km/h to 350 km/h are also defined in (Ericsson, et al., 2007) to model high speed scenarios (e.g., high speed train scenario at speed 350km/h). The maximum carrier frequency over all frequency bands is f=2690 MHz and the Doppler shift at speed v=350 km/h is 900 Hz. The average powers and relative delays for the taps of multipath channels based on ITU recommendations are given in Table 2 (ITU-R, 1997).

Tap No	Pedestrian-A		Pedestrian-B		Doppler Spectrum
	Relative Delay (ns)	Average Power(dB)	Relative Delay (ns)	Average Power(dB)	
1	0	0	0	0	Classical
2	110	-9.7	200	-0.9	Classical
3	190	-19.2	800	-4.9	Classical
4	410	-22.8	1200	-8	Classical
5	NA	NA	2300	-7.8	Classical
6	NA	NA	3700	-23.9	Classical

Table 1. Average Powers and Relative Delays of ITU multipath Pedestrian-A and Pedestrian-B cases

	Tap No					
Average Power(dB)	0	-1.0	-9.0	-10.0	-15.0	-20.0
Relative Delay(ns)	0	310	710	1090	1730	2510

Table 2. Average Powers and Relative Delays for ITU Vehicular-A Test Environment.

5. Multiple antenna techniques

Broadly, multiple antenna techniques utilize multiple antennas at the transmitter or/and receiver in combination with adaptive signal processing to provide smart antenna array processing, diversity combining or spatial multiplexing in a wireless system (Dahlman, et al., 2007; Salwa, et al., 2007). Previously, in conventional single antenna systems the exploited dimensions are only time and frequency whereas multiple antenna systems exploit an additional spatial dimension. The utilization of spatial dimension with multiple antenna techniques fulfils the requirements of LTE; improved coverage (possibility for larger cells), improved system capacity (more user/cell), QoS and targeted date rates are attained by using multiple antenna techniques as described in (3 GPP, 2008). Multiple antenna techniques are an integrated part of LTE specifications because some requirements such as user peak data rates cannot be achieved without the utilization of multiple antenna techniques.

The radio link is influenced by the multipath fading phenomena due to constructive and destructive interferences at the receiver. By applying multiple antennas at the transmitter or at the receiver, multiple radio paths are established between each transmitting and receiving antenna. In this way dissimilar paths will experience uncorrelated fading. To have uncorrelated fading paths, the relative location of antennas in the multiple antenna configurations should be distant from each other. Alternatively, for correlated fading (instantaneous fading) antenna arrays should be closely separated. Whether uncorrelated fading or correlated fading is required depends on what is to be attained with the multiple antenna configurations (diversity, beamforming, or spatial multiplexing) (Dahlman, et al., 2007). Generally, multiple antenna techniques can be divided into three categories (schemes) depending on their benefits: spatial diversity, beamforming and spatial multiplexing which will be discussed further in the following sections.

5.1 Spatial diversity

Conventionally, multiple antennas are exercised to achieve increased diversity to encounter the effects of instantaneous fading on the signal propagating through the multipath channel. The basic principle behind spatial diversity is that each transmitter and receiver antenna pair establishes a single path from the transmitter to the receiver to provide multiple copies of the transmitted signal to obtain an improved BER performance (Zheng, et al., 2003). In order to achieve large gains with multiple antennas there should be low fading correlation between the transmitting and the receiving antennas. Low value of correlation can be achieved when inter-antenna spacing is kept large. Hence it is difficult to place multiple antennas on a mobile device due size restrictions depending upon the operating carrier frequency. An alternative solution is to use antenna arrays with cross polarizations, i.e., antenna arrays with orthogonal polarizations. The number of uncorrelated branches (paths) available at the transmitter or at the receiver refers to the diversity order and the increase in diversity order exponentially decreases with the probability of losing the signal. To achieve spatial diversity for the enhancement of converge or link robustness multiple antennas can be used either at the transmitter side or at the receiver side. We will discuss both transmit diversity where multiple antennas are used at the transmitter (MISO-multiple-input signal-output), and receive diversity using multiple receive antenna (SIMO signal-input multiple-output). On the other hand, MIMO channel provides diversity as well as additional degree of freedom for communication.

5.2 Transmit diversity

The transmit diversity scheme relies on the use of $N_t \geq 2$ antennas at the transmitter side in combination with pre-coding in order to achieve spatial diversity when transmitting a single data stream (Furht, et al., 2009; Jankiraman, 2004). Usually transmit diversity necessitates the absolute channel information at the transmitter but it becomes feasible to implement transmit diversity without the knowledge of the channel with space-time block coding (Jankiraman, 2004). The simplest transmit diversity technique is Alamouti space-time coding (STC) scheme (Alamouti, 1998). Transmit diversity configuration is illustrated in Figure 3.

The use of transmit diversity is common in the downlink of cellular systems because it is easier and cheaper to install multiple antennas at base station than to put multiple antennas on every handheld device. In transmit diversity to combat instantaneous fading and to achieve considerable gain in instantaneous SNR, the receiver is being provided with multiple copies of the transmitted signal. Hence transmit diversity is applied to achieve extended converge and better link quality when the users experience hostile channel conditions.

In LTE, transmit diversity is defined only for 2 and 4 transmit antennas and these antennas usually need to be uncorrelated to take full advantage of the diversity gain.

LTE physical layer supports both open loop and closed loop diversity schemes. In open loop scheme channel state information (CSI) is not required at the transmitter, consequently multiple antennas cannot provide beamforming and only diversity gain can be achieved. On the other hand, closed loop scheme does not entail channel state information (CSI) at the transmitter and it provides both spatial diversity and beamforming as well.

By employing cyclic delay diversity and space frequency block coding, open loop transmit diversity can be accomplished in LTE. In addition, LTE also implements close loop transmit diversity schemes such as beamforming.

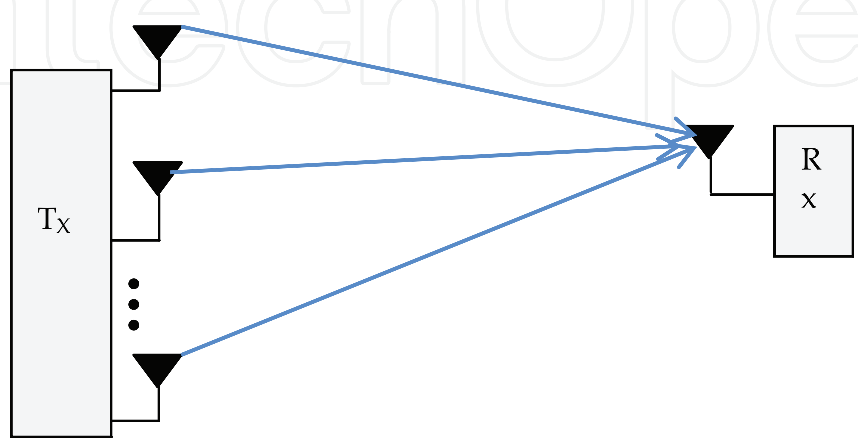

Fig. 3. Transmit diversity configuration

5.3 Space-Frequency Block Coding (SFBC)

In LTE, transmit diversity is implemented by using Space-Frequency Block Coding (SFBC). SFBC is a frequency domain adaptation of the renowned Space-Time Block Coding (STBC) where encoding is done in antenna/frequency domains rather than in antenna/time domains. STBC is also recognized as Alamouti coding (Rahman, et al.). Thus, SFBC is merely appropriate to OFDM and other frequency domain based transmission schemes.
The advantage of SFBC over STBC is that in SFBC coding is done across the subcarriers within the interval of OFDM symbol while STBC applies coding across the number of OFDM symbols equivalent to number of transmit antennas (Rahman, et al.). The implementation of STBC is not clear-cut in LTE as it operates on the pairs of adjacent symbols in time domain while in LTE the number of available OFDM symbols in a sub-frame is often odd. The operation of SFBC is carried out on pair of complex valued modulation symbols. Hence, each pair of modulation symbols are mapped directly to OFDM subcarriers of first antenna while mapping of each pair of symbols to corresponding subcarriers of second antenna are reversely ordered, complex conjugated and signed reversed as shown in Figure 4.
For appropriate reception, mobile unit should be notified about SFBC transmission and linear operation has to be applied to the received signal. The dissimilarity between CDD and SFBC lies in how pairs of symbols are mapped to the second antenna. Contrarily to CDD, SFBC grants diversity on modulation symbol level while CDD must rely on channel coding in combination with frequency domain interleaving to provide diversity in the case of OFDM.

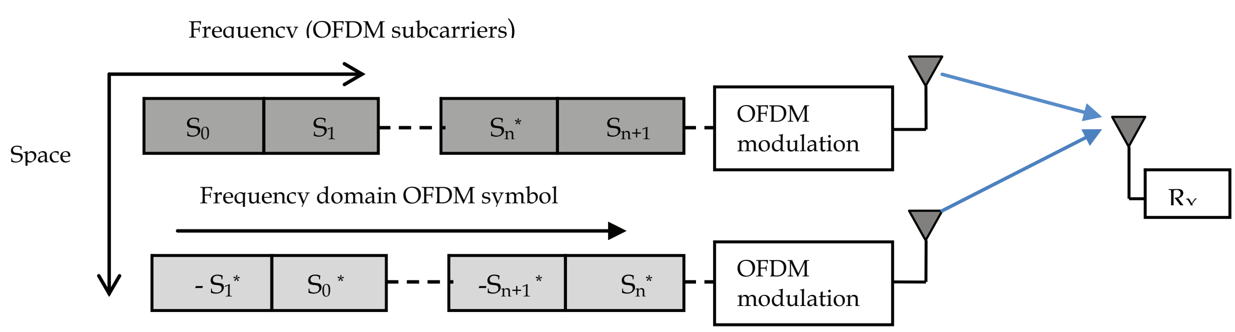

Fig. 4. Space-Frequency Block Coding SFBC assuming two antennas

The symbols transmitted from two transmitted antennas on every pair of neighboring subcarriers are characterized in (Sesia, et al., 2009) as:

$$X = \begin{bmatrix} x^{(0)}(1) & x^{1}(1) \\ x^{(0)}(2) & x^{1}(2) \end{bmatrix} \tag{3}$$

where $X^{(P)}(K)$ denotes the symbols transmitted from antenna port 'p' on the k^{th} subcarrier. The received symbol can be expressed as:

$$y = Hs + n \tag{4}$$

$$\begin{bmatrix} y_0 \\ y_1^* \end{bmatrix} = \begin{bmatrix} h_{00} & -h_{01} \\ h_{11}^* & h_{10}^* \end{bmatrix} \begin{bmatrix} S_0 \\ S_1^* \end{bmatrix} + \begin{bmatrix} n_0 \\ n_1^* \end{bmatrix} \tag{5}$$

where h_{ij} is the channel response for symbol *i* transmitted from antenna *j*, and *n* is the additive white Gaussian noise.

6. Performance comparison of channel estimation schemes

We simulate LTE down link using the SISO system with the parameters given in the specifications (3GPP, 2009). The system bandwidth selected is 15 MHz with the numbers of subcarriers 1536 out of which 900 subcarriers are used and the remaining are zero padded. The sub frame duration is 0.5 ms which leads to a frame length of 1 sec. This corresponds to a sampling frequency of 23.04 MHz or sampling interval of 43.4 ns. A cyclic prefix of length 127 (selected from specification which is extended CP) is inserted among data subcarriers to render the effects of multipath channel which completely removes inter-symbol-interference (ISI) and inter-carrier-interference (ICI). In simulating the SISO system, only one port of an antenna is considered and this antenna port is treated as a physical antenna. We consider one OFDM symbol of size 900 subcarriers and the reference symbols which are (total numbers of reference symbols are 150) distributed among data subcarriers according to specifications (3GPP, 2009) transmitted from the antenna during one time slot. The constellation mappings employed in our work are QPSK, 16 QAM and 64 QAM.

The channel models used in the simulation are ITU channel models (ITU-R, 1997). At the receiver end we used regularized LS and LMMSE estimation methods for the channel estimation. All channel taps are considered independent with equal energy distribution. In addition, frequency domain linear equalization is carried out on the received data symbols. The performance of the system is evaluated by calculating the bit error rates using ITU channel models with different modulation schemes.

The designed simulator is flexible to use. A scalable bandwidth is used, i.e., there is option for using bandwidths of 5 MHz, 10 MHz, 15 MHz and 20 MHz. In addition, cyclic prefixes of different lengths specified in (3GPP, 2009) can be easily selected in the simulation of the system. We used single port of antenna which is taken as physical antenna however changes can be easily made to include two ports antenna.

The performance of LTE transceiver is shown in terms of curves representing BER against SNR values and is compared with AWGN for different channel models. Figures 5 and 6 show BER versus SNR for LMMSE and LS channel estimations, respectively, for different ITU channel models using QPSK modulation. From these figures, it can be seen that LMMSE channel estimation gives better performance than LS channel estimation. Figures 7 and 8 show BER plots for ITU channel models using 16QAM modulation format. It is seen that by increasing the modulation order, the system performance degrades as compared to QPSK modulation. This is due to the fact that higher modulations schemes are more sensitive to channel estimation errors and delay spreads. For 16QAM, LMMSE still have superior performance as compared to LS estimation but its performance also diminishes in environments with high mobile speeds (Doppler spread) and large delay spreads. The LS estimation gives poor performance for higher modulation schemes. Some interpolation techniques can be employed to mitigate ISI effects which can enhance system performance.

Figure 9 illustrates the performance of transceiver for ITU vehicular-A channel model using multiple antennas. The SISO system is also shown for comparision purposes.

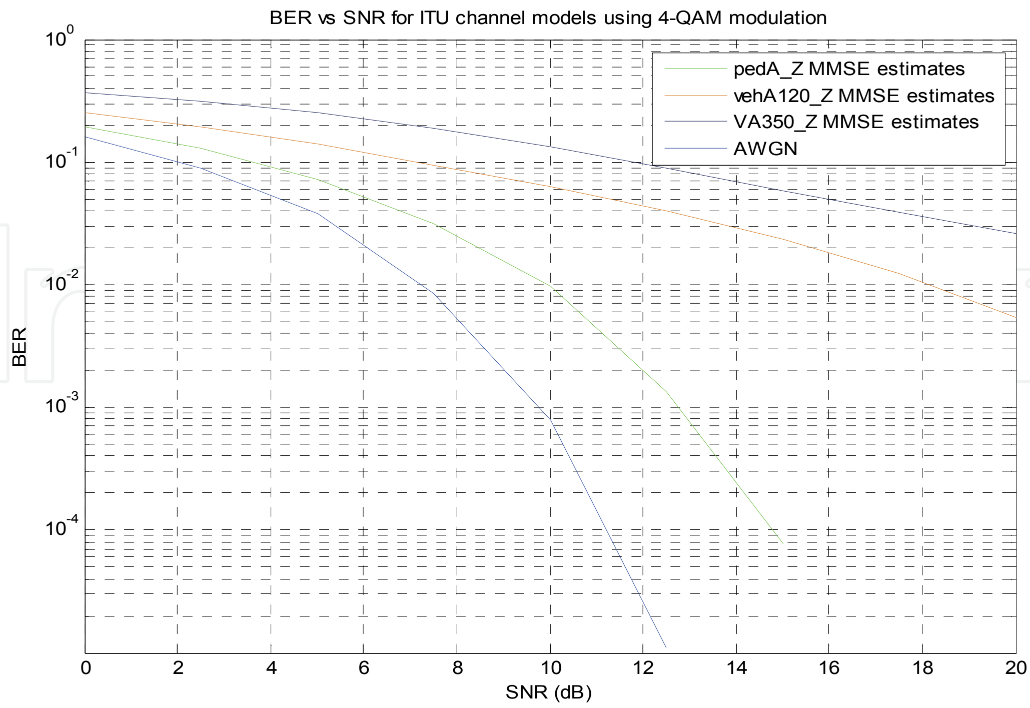

Fig. 5. BER performance of LTE transceiver for different channels using QPSK modulation and LMMSE channel estimation

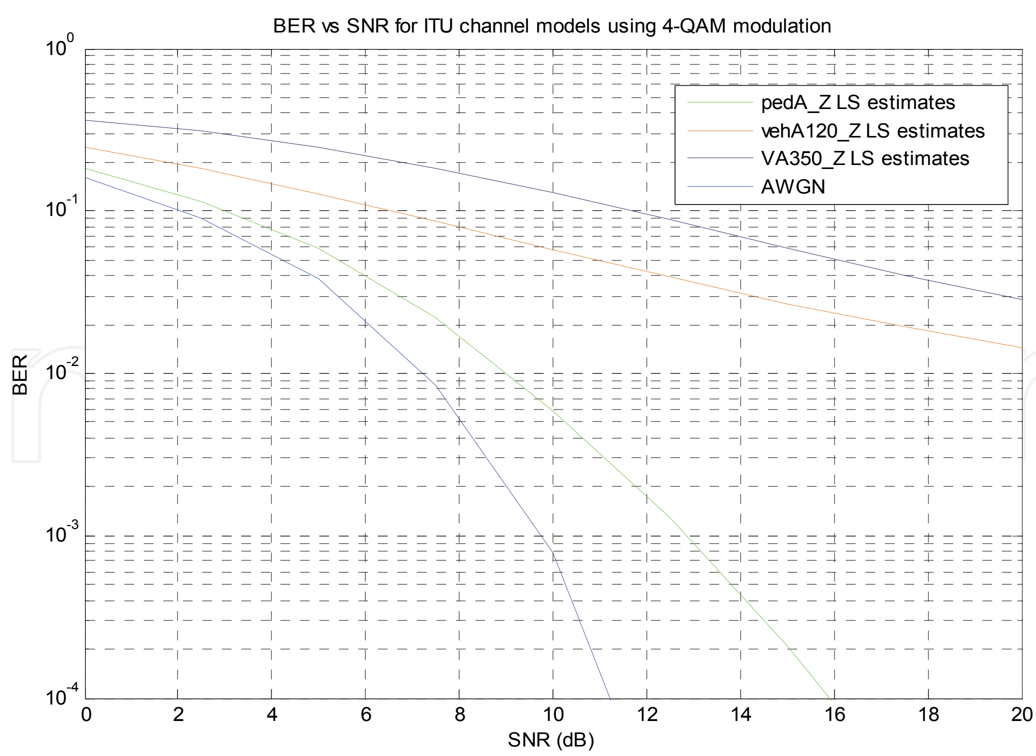

Fig. 6. BER performance of LTE transceiver for different channel models using QPSK modulation and LS channel estimation

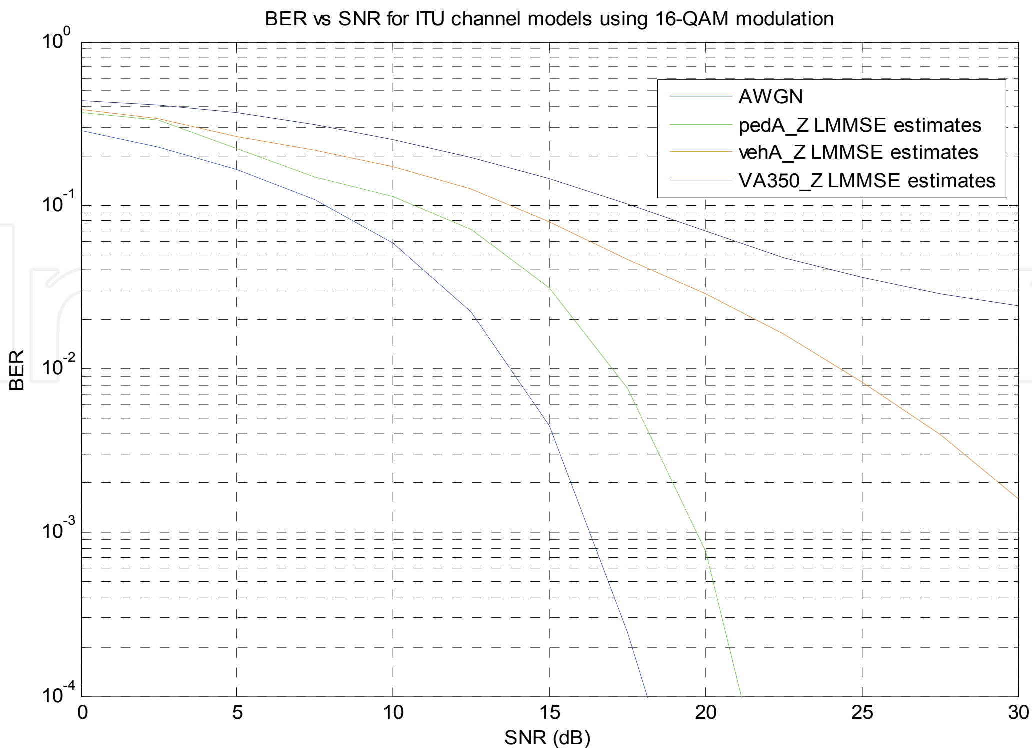

Fig. 7. BER performance of LTE transceiver for different channel models using 16 QAM modulation and LMMSE channel estimation

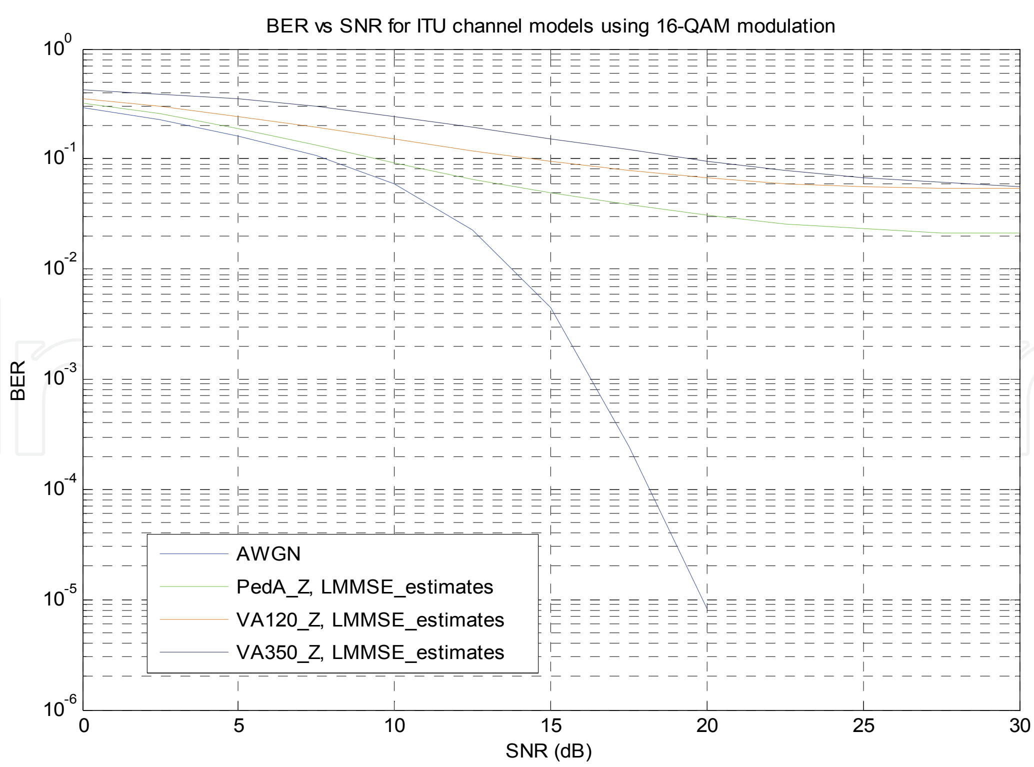

Fig. 8. BER performance of LTE transceiver with multiple antennas for different ITU channel models using 16 QAM modulation and LS channel estimation

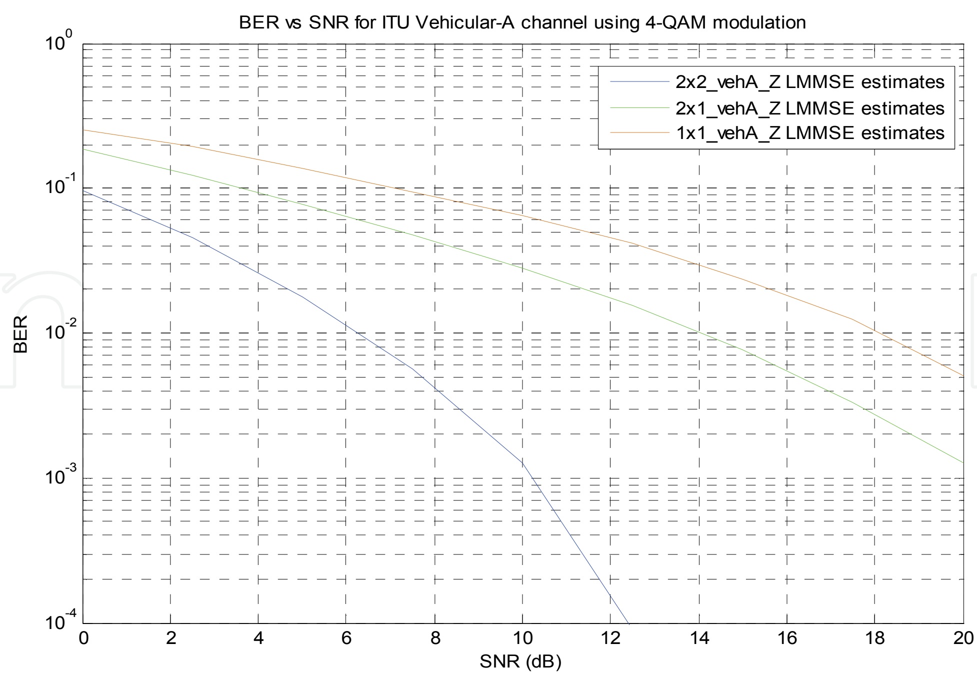

Fig. 9. BER performance of LTE transceiver with multiple antennas for ITU Vehicular-A channel model using 4-QAM modulation and LMMSE channel estimation

7. Conclusions

This chapter illustrates the physical layer aspects of future generation mobile communication systems. Proper knowledge of propagation impairments and channel models is necessary for the design and performance assessment of advanced transceiver techniques employed to establish reliable communication links in future generation mobile communication systems.

The results have been presented by means of simulations. The performance is evaluated in terms of BER and SER and the obtained results are compared with theoretical values. The LS estimator is simple and suitable for high SNR values; however its performance degrades with higher constellation mappings for high mobile speeds. On the other hand, LMMSE estimator is computationally complex and requires a priori knowledge of noise variance but its performance is superior to LS estimates for higher modulation schemes and large delay spreads. The performance of future generation mobile communication systems will be highly dependent on different factors including operating frequency, elevation angles, geographic location, climate etc.

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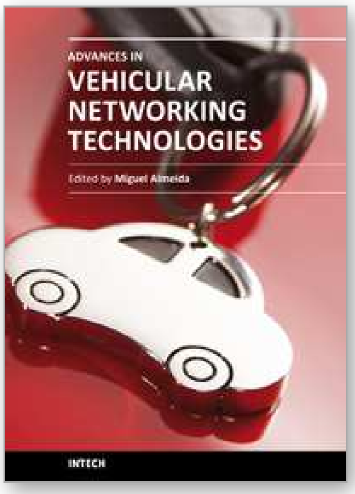

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This book provides an insight on both the challenges and the technological solutions of several approaches, which allow connecting vehicles between each other and with the network. It underlines the trends on networking capabilities and their issues, further focusing on the MAC and Physical layer challenges. Ranging from the advances on radio access technologies to intelligent mechanisms deployed to enhance cooperative communications, cognitive radio and multiple antenna systems have been given particular highlight.