Reference measurement channel RMC parameters of LTE downlink waveforms

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Abstract. Long-Term Evolution (LTE) is a standard for high speed wireless communication for mobile devices and data terminals. It increases the capacity and speed using a different radio interface together with core network improvements. LTE employs SC-FDMA for uplink UL transmission and OFDM for downlink DL data transmission, in this paper LTE DL implemented with MATLAB programing and Simulink, Reference measurement channel RMC on DL waveform illustrated in different Transmission scheme of single, 4 antenna and cyclic delay diversity scheme CDD, duplexing mode, resources blocks and modulation approaches leadings to a various number of total information per frame, QPSK, 16 QAM and 64 QAM modulation approaches used in the proposed system are tested under AWGN Rayleigh fading channels.

1. Introduction

Fixed telephone networks, cable TV networks, cellular telephone networks and data networks have been constructed by operators in order to provide multiple services to the customer. All of these functions can be provided by Next Generation Network (NGN) that used a flat all-IP core which interconnects multiple access technologies and provides a steady and trustworthy user-experience regardless of the access method. The NGN provides a wide variety of applications and services and Quality of Service (QoS) support[1][2]. The NGN network will offer routing management and mobility and ensure that the core perceives the mobile networks merely as another IP network. LTE is the first technology designed explicitly for the NGN and is set to become the de-facto NGN mobile access network standard. It takes advantage of the NGN's capabilities to provide an always-on mobile data experience comparable to wired networks [3][4].

Long Term Evolution (LTE) of the Universal Mobile Telecommunication System (UMTS) also known as the Evolved Packet System (EPS) is a transient move in the field of mobile communications[5][6]. Such a revolution is necessitated by the unceasing increase in demand for high speed connections on networks, low latency and delay, low error rates and resilience because modern users and network applications have become increasingly dependent on these requirements for efficient functionality and performance. High spectral efficiency, high peak data rates, short round trip time, and frequency flexibility provided by LTE. It relies on the following technologies; Orthogonal Frequency Division Multiplexing (OFDM) and Multiple-Input and Multiple- Output (MIMO) [7], robust channel coding, scheduling and link adaptation [2]. LTE is interoperable with widely used technologies such as GPRS,
WCDMA and HSPA, and this enables mobile operators deploying LTE to provide seamless service and multimode devices for customers [3]. Some companies have already launched commercial LTE networks, e.g., Verizon Wireless in the United States and Vodafone in Europe [4]. The LTE technology has evolved over multiple releases, which have led to improved data throughput, lower latencies, and increasingly flexible configurations. Also Enhancements to Carrier Aggregation, MIMO, and relay nodes, introduction of new frequency bands, and coordinated multipoint transmission and reception [1][8].

The design goals for LTE are to provide downlink peak rates of 100Mbps and uplink of 50Mbps, to exhibit spectral efficiency and flexibility by supporting scalable bandwidth which enhances the provision of more data and voice services over a given bandwidth. In addition, it should provide low latency, specifically, for the control plane: 50 – 100msec to establish the U-plane and for the User Plane: less than 10msec from the user equipment (UE) to server. In terms of mobility, LTE is designed to be optimized for low speeds of about 15km/hr, provide high performance at speeds up to 120km/hr and to maintain the link at speeds up to 350km/hr. With respect to the coverage area it is expected that full performance will be achieved up to 5km[1][9].

LTE leverages on a number of technologies namely Multi Input Multiple Output (MIMO) antennas, Orthogonal Frequency Division Multiplexing (OFDM) and Orthogonal Frequency Division Multiplexing Access (OFDMA) at the downlink, Single Carrier Frequency Division Multiple Access (SCFDMA) at the uplink, support for Quadrature Phase Shift Keying (QPSK), 16 Quadrature Amplitude Modulation (16QAM), and 64QAM.[9][10]

In this paper LTE DL implemented with MATLAB programming and Simulink, Reference measurement channel RMC on DL waveform illustrated in different Transmission scheme, duplexing mode, resources blocks and modulation approaches leadings to a various number of total information per frame, QPSK, 16 QAM and 64 QAM modulation approaches used in the proposed system are tested under AWGN Rayleigh fading channels.

2. LTE downlink transmission

The LTE standard does not only need wider bandwidth but also a more advanced modulation technique to matching the high data rates of LTE transmission. Orthogonal Frequency Division Multiplexing (OFDM) is considered the optimum modulation technique to fulfill the downlink transmission requirement; the high Peak-to-Average Power Ratio (PAPR) property of OFDM makes it less favorable for the uplink transmission. Instead, the Single-Carrier FDMA technique is used for LTE uplink transmission.[5][11]

OFDMA allocates individual users in the time and the frequency domain and its signal generation in the transmitter is based on the Inverse Fast Fourier Transform (IFFT) [6]. OFDMA converts the wide-band frequency selective channel into a set of many fading sub-channels, which enables optimum receivers to be implemented with reasonable complexity during MIMO transmission.

LTE downlink (from tower to device) transmission is based on OFDMA. A time-frequency resource grid can represent the LTE downlink physical resources. Resource elements are grouped into Resource Blocks (RBs) and each RB consists of 12 subcarriers with a spacing of 15 kHz in the frequency domain and 7 consecutive OFDM symbols in the time domain. The number of available RBs in the frequency domain varies depending on the channel bandwidth [12], and channel bandwidths may vary between 1.4 MHz and 20 MHz. The LTE PHY specification is designed to accommodate bandwidths from 1.25 MHz to 20 MHz.

The transmitter and receiver structure of PDSCH is shown in Fig 1. The transmitter in the physical layer starts with the grouped resource data, which are in the form of transport blocks. PDSCH is used to transmit the Downlink Shared Channel (DL-SCH). The DL-SCH is the transport channel used for transmitting downlink data (a transport block). One or two coded transport blocks (codewords) can be transmitted simultaneously on the PDSCH depending on the precoding scheme used. According to [1] the processing steps of transmitting downlink data in PDSCH are given below.
1- Transport block CRC attachment: A cyclic redundancy check (CRC) is used for error detection in transport blocks. The entire transport block is used to calculate the CRC parity bits and these parity bits are then appended to the end of the transport block.

2- Code block segmentation and CRC attachment: In LTE, a minimum and maximum code block size are specified so the block sizes are compatible with the block sizes supported by the turbo the interleaver. Minimum code block size is 40 bits and the maximum code block size is 6144 bits. The input block is segmented when the input block is greater than the maximum code block size.

3- Channel coding: The channel coding scheme for PDSCH adopts Turbo coding, which is a robust channel coding [2]. The coding rate of turbo encoder is 1/3 [9]. The code blocks undergo turbo coding which is a form of forward error correction that improves the channel capacity by adding redundant information. The turbo encoder scheme uses a Parallel Concatenated Convolutional Code (PCCC) with two recursive convolutional coders and a contention free Quadratic Permutation Polynomial (QPP) interleaver.

4- Rate Matching: The main task of the rate matching block is to create an output bit stream to be transmitted with the desired code rate. As the number of bits available for transmission depends on the available resources the rate matching algorithm is capable of producing. The three bit streams from the turbo encoder are interleaved followed by bit collection to create a circular buffer. Bits are selected and pruned from the buffer to create an output bit stream with the desired code rate. The Hybrid Automatic Repeat Request (HARQ) error correction scheme is incorporated into the rate-matching algorithm of LTE.

5- Code Block Concatenation: In this stage, the rate matched code blocks are concatenated back together. This task is done by sequentially concatenating the rate-matched blocks together to create the output of the channel coding.

6- Scrambling: The code words are bit-wise multiplied with an orthogonal sequence and a UE-specific scrambling sequence to create the following sequence of symbols for each code word.

7- Modulation: The scrambled codewords undergo modulation using one of the PDSCH modulation schemes QPSK, 16 QAM, 64 QAM, resulting in a block of modulation symbols [9].
Layer Mapping: The modulation symbols are mapped to one, two, or four layers depending on the number of transmit antennas used. There are mainly two kinds of layer mapping, one for transmit diversity and the other for spatial multiplexing. If transmit diversity is used, the input symbols are mapped to layers based on the number of layers. In the case of spatial multiplexing, the number of layers used is always less or equal to the number of antenna ports used for transmission of the physical channel.

Precoding: Symbols on each layer will be pre-coded for transmission on the antenna ports according to different modes of transmission, which are spatial multiplexing, transmit diversity, and single antenna port transmission.

Mapping to Resource Elements: For each of the antenna ports used for transmission of the PDSCH, the block of complex valued symbols, are mapped in sequence to resource elements not occupied by the other physical downlink channels except PDSCH, or synchronization and reference signals. The number of resource elements mapped to is controlled by the number of resource blocks allocated to the PDSCH. The symbols are mapped by increasing the subcarrier index and mapping all available REs within allocated resource blocks for each OFDM symbol.

OFDM Modulation: Data stream is modulated to many orthogonal sub-carriers in parallel. A carrier will reduce each code element rate of the sub-carrier, increase the code element symbols cycle, and improve the system of anti-interference ability. OFDM modulation is mainly for the Inverse Fast Fourier Transform (FFT) [9].

3. Physical Channels
The LTE air interface comprises of physical channels and physical signals. The physical signals are created in Layer 1 and they are used for system synchronization, cell identification, and radio channel estimation. The physical channels are used to carry data form a higher layer including control, scheduling, and user payload [1].

A. LTE Downlink Physical Signals
Primary Synchronization Signal: this signal used for cell search and identification by the user equipment (UE). It carries a part of the cell ID. Secondary Synchronization Signal: performs the same function as the primary but carries the remainder of the cell ID. Reference Signal: Used for downlink channel estimation.

B. LTE Downlink Channels
Physical Downlink Shared Channel (PDSCH): this channel is transported data and multimedia (payload) hence it is designed for very high data rates. QPSK, 16QAM and 64 QAM are suitable modulation techniques that can be employed in this channel. Physical Downlink Control Channel (PDCCH): this channel carries control information that is UE-specific e.g. scheduling, ACK/NACK. Understandably, robustness is therefore of main interest than the maximum data rate. QPSK is the only available modulation format. Common Control Physical Channel (CCPCH): this channel conveys cell-wide control information. The CCPCH is transmitted as close to the centre frequency as possible. Physical broadcast channel (PBCH): carries cell-specific/system information. Physical multicast channel (PMCH): a downlink physical channel that carries the multicast/broadcast information. Physical control format indicator channel (PCFICH): defines number of PDCCH OFDMA symbols per sub-frame [1][3][13][14].
Figure 2. The Physical downlink channels

4. BER equations of modulation type used in the model

4.1. BER equation of M-QAM in AWGN channel [15, 16, 17].

\[
P_s = 4 \frac{\sqrt{M} - 1}{\sqrt{M}} Q\left(\frac{3}{M - 1} \frac{kE_b}{N_o}\right) - 4 \left(\frac{\sqrt{M} - 1}{\sqrt{M}}\right)^2 Q^2\left(\frac{3}{M - 1} \frac{kE_b}{N_o}\right)
\]

\[
P_b = \frac{2}{\sqrt{M} \log_2 \sqrt{M}} \sum_{k=1}^{\log_2 \sqrt{M}} \sum_{l=0}^{(1-2^{-k})\sqrt{M} - 1} \left\{ (-1)^{\frac{i2^{-k-1}}{M}} \left(2^{k-1} \right) - \frac{6\log_2 M E_b}{2(M - 1) N_o}\right\}
\]

Where

- \(P_s\): Symbol error rate (SER)
- \(P_b\): Bit error rate (BER)
- \(M\): Size of modulation constellation
- \(K\): Number of bits per symbol \(\rightarrow k = \log_2 M\)
- \(\frac{E_b}{E_0}\): Energy per bit -to- noise power -spectral -density ratio

BER equation of M-QAM in Rayleigh fading channel [15]
\[ P_s = \frac{4}{\pi} \left( 1 - \frac{1}{\sqrt{M}} \right)^2 \int_0^{\pi/2} \prod_{l=1}^{L} M_{y_l} \left( \frac{3}{2(M-1)} \right) d\theta - \frac{4}{\pi} \left( 1 - \frac{1}{\sqrt{M}} \right)^2 \int_0^{\pi/4} \prod_{l=1}^{L} M_{y_l} \left( -\frac{3}{2(M-1)} \right) d\theta \]

From \[15][16\]
\[ P_b = \frac{2}{\pi \sqrt{M} \log_2 \sqrt{M}} \times \sum_{k=1}^{\log_2 \sqrt{M}} \sum_{l=0}^{(M-1)/\sqrt{M}} (-1)^{\frac{i 2^{k-1}}{\sqrt{M}}} \left( \begin{array}{c} 2^{k-1} \\ 2^k - 1 \end{array} \right) \frac{\pi}{2} \prod_{l=1}^{L} M_{y_l} \left( -\frac{(2i+1)^2 3}{2(M-1)} \right) \frac{1}{\sin^2 \theta} d\theta \]

4.2. M-PSK under AWGN can be given in equation below \[15\]:
\[ P_s = \frac{1}{\pi} \left( \frac{(M-1)\pi/M}{\sin^2 \theta} \right) \exp \left( -\frac{k E_b \sin^2 \left( \frac{\pi}{M} \right)}{N_0 \sin^2 \theta} \right) d\theta \]

The following expression is very close, but not strictly equal, to the exact BER \[15][16\]:
\[ P_b = \frac{1}{k} \sum_{i=1}^{M/2} (w_i') P_i \]

where \( w_i' = w_i + w_{M-i} \), \( w_{M/2} = w_{M/2} \), \( w_i \) is the Hamming weight of bits assigned to symbol \( i \), and
\[ P_i = \frac{\pi}{2\pi} \left( 1-(2i-1)/M \right) \exp \left( -\frac{k E_b \sin^2 \left( \frac{(2i-1)\pi}{M} \right)}{N_0 \sin^2 \theta} \right) d\theta \]
\[ - \frac{1}{2\pi} \left( 1-(2i-1)/M \right) \exp \left( -\frac{k E_b \sin^2 \left( \frac{(2i+1)\pi}{M} \right)}{N_0 \sin^2 \theta} \right) d\theta \]

PSK in Rayleigh channel

M-PSK under Rayleigh channel \[15\]:
\[ P_s = \frac{1}{\pi} \left( \frac{(M-1)\pi/M}{\sin^2 \theta} \right) \prod_{l=1}^{L} M_{y_l} \left( \sin^2 \left( \frac{\pi}{M} \right) \right) d\theta \]
From [2] and [1]:

\[
P_b = \frac{1}{k} \left( \sum_{i=1}^{M/2} (w'_i) \overline{P}_l \right)
\]

Where \( w'_i = w_i + w_{M-i} \) \( w'_{M/2} = w_{M/2} \), \( w_i \) is the Hamming weight of bits assigned to symbol \( i \), and

\[
P_l = \frac{1}{2\pi} \int_0^\pi \prod_{l=1}^L M_{Y_l} \left( -\frac{\sin^2 \left( \frac{(2l - 1)\pi}{M} \right)}{\sin^2 \theta} \right) d\theta
\]

\[
-\frac{1}{2\pi} \int_0^\pi \prod_{l=1}^L M_{Y_l} \left( -\frac{\sin^2 \left( \frac{(2l - 1)\pi}{M} \right)}{\sin^2 \theta} \right) d\theta
\]

5. Results

The processing steps of transmitting downlink data in PDSCH is implemented in MATLAB Simulink with different modulation schemes, duplexing mode and allocated resource blocks as shown in results below:

1. Transmission scheme port0(single antenna), QPSK modulation, Number of downlink resource blocks 6, Number of allocated resource blocks 6, transmission layers 1, FDD and TDD duplex mod, total information bits per frame per codeword 3416. From figure 3, the power spectrum (dB) reached 25 dB between main and side loop in FDD mode while in TDD mode reached 35dB and with 15 dB drop in the middle of the spectrum for both mods.

2. Transmission scheme port0(single antenna), QPSK modulation, Number of downlink resource blocks 50, Number of allocated resource blocks 50, transmission layers 1, FDD and TDD duplex mod, total information bits per frame per codeword 39528. As comparing figure 3 and 4, code word increased

![Figure 3. Transmitted power spectrum with a single antenna, QPSK and ARB 6](image-url)
with the increasing of ARB, from figure 4 power spectrum (dB) reached to 35 dB between main and side loop in FDD mode while in TDD mode reached to 30dB and with 5 dB drop in the middle of the spectrum for both mods.

![Power Spectrum](image)

**Figure 4.** transmitted power spectrum with single antenna, QPSK and ARB 50

3. Transmission scheme Txdiversity (number of antenna 4), QPSK modulation, Number of downlink resource blocks 6, Number of allocated resource blocks 6, transmission layers 4, FDD and TDD duplex mod, total information bits per frame per codeword 3416. figure 5 shows the power spectrum of transmitted signal with 4 antenna diversity and both FDD, TDD duplexing mode.

![Power Spectrum](image)

**Figure 5.** transmitted power spectrum with 4 antenna, QPSK and ARB 6

4. Transmission scheme Txdiversity (4 antenna), QPSK modulation, Number of downlink resource blocks 50, Number of allocated resource blocks 50, transmission layers 2, FDD and TDD duplex mod, total information bits per frame per codeword 39528. Figure 6 shows power spectrum of the transmitted signal with 4 antenna diversity and both FDD, TDD duplexing mode.
5. Transmission scheme port0, 16 QAM modulation, Number of downlink resource blocks 15, Number of allocated resource blocks 1, transmission layers 1, FDD and TDD duplex mod, total information bits per frame per codeword 2016. As shown in figure 7.

6. Transmission scheme port0, 16 QAM modulation, Number of downlink resource blocks 50, Number of allocated resource blocks 50, transmission layers 1, FDD and TDD duplex mod, total information bits per frame per codeword 125856.

Figure 6. transmitted power spectrum with 4 antenna, QPSK and ARB 50

Figure 7. transmitted power spectrum with 16 QAM and ARB 1

Figure 8. transmitted power spectrum with 16QAM and ARB 50
7. Transmission scheme TxDiversity, 16 QAM modulation, Number of downlink resource blocks 50, Number of allocated resource blocks 50, transmission layers 2, FDD and TDD duplex mod, total information bits per frame per codeword 116640. As shown in figure 9.

![Figure 9. transmitted power spectrum with 4 antenna, 16 QAM and ARB 50](image)

8. Transmission scheme CDD (large delay cyclic delay diversity scheme), 64 QAM modulation, Number of downlink resource blocks 50, Number of allocated resource blocks 50, transmission layers 2, FDD mod, total information bits per frame per codeword 365424 bits. As shown in figure 10 & table 1.

| Modulation | Transmission scheme | resource blocks | Duplexing mod | Codeword length (bits) |
|------------|---------------------|-----------------|---------------|-----------------------|
| QPSK       | Single antenna      | 6               | FDD, TDD      | 3416                  |
| QPSK       | Single antenna      | 50              | FDD, TDD      | 39528                 |
| QPSK       | 4 antenna           | 6               | FDD, TDD      | 3416                  |
| QPSK       | 4 antenna           | 50              | FDD, TDD      | 39528                 |
| 16 QAM     | Single antenna      | 1               | FDD, TDD      | 2016                  |
| 16 QAM     | 4 antenna           | 50              | FDD, TDD      | 125856                |
| 16 QAM     | 4 antenna           | 50              | FDD, TDD      | 116640                |
| 64 QAM     | Cyclic delay diversity CDD | 50       | FDD            | 365424                |
9. As shown in figure 11 modulation scheme that used in the model tested under AWGN and Rayleigh channels in term of BER, from the result in the figure QPSK shows batter BER over QAM about 8 dB of $E_b/N_o$ in $10^{-8}$ BER at AWGN channel and 6 dB of $E_b/N_o$ in $1*10^{-5}$ at Rayleigh fading channel.

6. Conclusions

LTE DL implemented with MATLAB programing and Simulink, Reference measurement channel RMC on DL waveform illustrated in different Transmission scheme of single, 4 antenna and cyclic delay diversity scheme CDD, duplexing mode of FDD and TDD, resources blocks of 6 and 50, modulation approaches leadings to a various number of total information per frame, QPSK, 16 QAM and 64 QAM modulation approaches used in the proposed system are tested under AWGN Rayleigh fading channels where QPSK shows batter BER over QAM about 8 dB of $E_b/N_o$ in $10^{-8}$ BER at AWGN channel and 6 dB of $E_b/N_o$ in $1*10^{-5}$ at Rayleigh fading channel while in term of codeword length QAM shows batter performance of codeword length reached to 365424 bits.

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