A New Approach for the Modeling of LTE/LTE-A Downlink/Uplink Systems based on LTE System Toolbox

Sherry Varghese George[1], Luxy Mathews[2], Sakuntala S. Pillai[3]
Department of Electronics and Communication Engineering
Mar Baselios College of Engineering and Technology
Trivandrum, India
(E-mail: [1]sherryvarghesegeorge@gmail.com, [2]luxyampanat@yahoo.co.in, [3]sakuntala.pillai@gmail.com)

Abstract—LTE/LTE-A is the standard for next generation wireless communications which provides high data rates of 1 Gbps. LTE-A is an extension to LTE providing more bandwidth leading to higher data rates. LTE-A is backward compatible with LTE making it a very reliable system. Traditional system models in LTE used the 3GPP spatial channel model in both the uplink and downlink where the parameters have to be changed at the backend which is a complex process. The use of channel estimation algorithms for downlink and uplink channel estimation makes the process even more complicated. In this paper, a new approach for the modeling of LTE/LTE-A systems in both the downlink and uplink is done where the physical signals and physical channels are generated and mapped onto the specified indices. The LTE system tool box makes the procedures for simulation and verification of LTE wireless communications much easier compared to the models used traditionally.

Keywords—*MIMO; OFDM; OFDMA; SCFDMA; 3GPP; LTE; LTE-A; Physical Frame Structure; Physical signals; Physical Channels; LTE System Toolbox*

I. INTRODUCTION

The communication scenario in the world is growing at a large pace and the industry is gearing up for a thousand times growth in the current data rate. So, the standards of wireless communication are making a change to meet the demands of the rapidly growing customer base. The 3GPP (Third Generation Partnership Project) is an organisation of telecommunication associations for the development and improvement of GSM standard and was later extended for the development of newer standards of wireless communication.

Multiple Input Multiple Output (MIMO) is a default feature in LTE systems to boost the overall data rates. It offers subsequently higher data rates without any additional bandwidth and transmit power. The number of transmitter or receiver antennas will decide the number of data streams supported. Traditional cellular systems provide best performance under line-of-sight conditions but MIMO tries to provide best performance under scattering environments. LTE systems make the promise of delivering large data rate to users which is substantially larger than what the current 3G systems are offering. This is a challenging proposition as wireless networks are subject to interference and multipath. So, MIMO techniques have emerged as a solution to provide high data rates by exploiting multipath characteristics of wireless channel. This is accomplished by using several antennas at the transmitter and receiver leveraging spatial dimensions. When the signals are properly combined at the receiver, data rate of each MIMO user will be improved. The different configurations possible for MIMO are 2X2, 4X4, 8X8. Higher configuration of MIMO antennas will lead to higher data rates.

OFDM (Orthogonal Frequency Division Multiplexing) is a multi-carrier modulation technique where the total bandwidth is split into a large number of smaller and narrow bandwidth units known as subcarriers which are orthogonal to each other. Orthogonality means that the maximum of one subcarrier is at the minimum of the next subcarrier thereby eliminating inter symbol interference (ISI). Frequency representation of one OFDM subcarrier is a sinc function. OFDM converts high speed data channel into a number of low speed channels so that processing becomes easier. OFDMA (Orthogonal Frequency Division Multiple Access) is an access scheme that uses OFDM principle to organize the distribution of scarce radio resources among several users enabling multi-user communication. A set of carriers known as pilot carriers are used to track the residual phase error if present after correction of the frequency. The carriers of OFDM are having different frequencies and Discrete Fourier Transform (DFT) is applied to generate orthogonal subcarriers. The reason for choosing OFDMA in the downlink is the bandwidth flexibility it offers, since changing the number of subcarriers can increase or decrease the used frequency bandwidth.

SCFDMA (Single Carrier Frequency Domain Multiple Access) is used in the uplink transmission scheme of LTE. It is a very desirable technique for the uplink to have an efficient usage of power amplifier in the transceiver antenna. This provides a high battery life to the devices used by the customers. SCFDMA provides low peak to average power ratio (PAPR) which is an advantage over the OFDMA technique used in the downlink.

MIMO-OFDM is the dominant air interface for 4G and 5G broadband systems. It combines MIMO technology which multiplies capacity by transmitting different signals over multiple antennas and OFDM which divides a radio channel into a large number of closely spaced subchannels to provide more reliable communication at higher speeds. MIMO provides a high data rate along with OFDM eliminating the interference makes the MIMO-OFDM medium a highly reliable one.

The LTE (Long Term Evolution) became a standard for wireless communications under the 3GPP after the GSM and CDMA. These standards are structured as release versions by 3GPP board and the first LTE was released in 2008. First generation (1G), second generation (2G) and third generation (3G) of mobile communication works on GSM standard and 4G and higher generations work on LTE standard [1].

LTE follows a flat architecture which is completely different from the architecture of GSM which is having a two dimensional architecture. It is an all IP architecture where all the devices are having an IP address and it is called as Evolved Packet Core. LTE provides a bandwidth of 20 MHz which is capable of a downlink peak rate of 300 Mbps and an uplink peak rate of 75 Mbps. LTE follows an all IP based network architecture called as Evolved Packet Core (EPC).

In LTE systems, the base station is called as eNB (evolved node B) which directly communicates with the mobile station or UE (user equipment). Evolved node B is the hardware in the mobile phone network that communicates directly with the mobile. It is similar to Base Transceiver Station (BTS) in GSM which is controlled by the Radio Network Controller (RNC). There are three processes which occurs at the eNB: first is the transmission mode selection, second is precoding, and the third is resource allocation and scheduling.

II. PHYSICAL FRAME STRUCTURE OF LTE-A DOWNLINK

The physical frame structure of LTE-A in the downlink is constituted by a number of physical signals and channels which should be generated and plotted onto the specified indices. Each of the physical signals and channels has a specific set of functions which is explained below:

A. Physical signals

There are two physical signals in LTE which are Primary Synchronisation Signal (PSS) and Secondary Synchronisation Signal (SSS). These are used by the user equipment (UE) to obtain the identity of the cell and frame timing. These physical signals and their indices are generated by the LTE system toolbox using the functions ltePSS( ), lteSSS( ) and ltePSSIndices( ), lteSSSIndices( ) respectively. Then the physical signals are plotted onto the indices [2].

B. Physical channels

There are five physical channels in LTE which carry the different control data and user data. These channels and their indices are generated by the functions and the channel symbols are mapped to the indices. The different physical channels are:

1) Physical Broadcast Channel (PBCH): MIB is the first information to be broadcasted by eNB irrespective of the users present in the cell. This is a 24 bit value which describes the system bandwidth and is transmitted through PBCH channel. If MIB cannot be configured, the UE considers the cell as barred and no communication will be possible. The functions used are ltePBCH( ) and ltePBCHIndices( ) for symbol and index generation.

2) Physical HARQ Indicator Channel (PHICH): LTE uses HARQ scheme for error correction in the received control and user data. The eNB will send a HARQ indicator to UE to indicate a positive or negative acknowledgement for the data. This HARQ indicator value is sent through PHICH channel. The data sent through this channel is either a 1 or 0 depending on whether the data is correctly received or not. The functions used are ltePHICH( ) and ltePHICHIndices( ) for symbol and index generation.

3) Physical Control Format Indicator Channel (PCFICH): PCFICH is the control channel in LTE which is to be decoded by the UE to decode the other control channels and data channels. This channel transmits the information regarding the number of OFDM symbols used by the control data. It is represented in terms of Control Format Indicator (CFI) which can take values 1, 2 and 3. If CFI value is 1, there is only one OFDM symbol that carries the control data in each sub-frame. The functions used are ltePCFICH( ) and ltePCFICHIndices( ) for symbol and index generation.

4) Physical Downlink Control Channel (PDCCH): The downlink scheduling and control information (DCI) is carried by the PDCCH to each of the UE in the cell. It gives the information about resource block carrying the data and the demodulation scheme that should be used to decode the data. The user data can be decoded only if the DCI is decoded. The functions used are ltePDCCH( ) and ltePDCCHIndices( ) for symbol and index generation.

5) Physical Downlink Shared Channel (PDSCH): PDSCH is the channel which transmits all the user data. The majority of the OFDM symbols in the time domain carry the user data in each sub-frame. In Fig. 1, the OFDM symbol indices 2, 3, 4, 11, 12, 13 are allotted for user data and all the 72 subcarriers in those OFDM symbols carry the data to the UE. The functions used are ltePDSCH( ) and ltePDSCHIndices( ) for symbol and index generation.

The plot of transmit resource grid shows the physical signals and channels that are transmitted in different frames in the time and frequency domain. Fig. 1 shows the transmit resource grid in the downlink for a single sub-frame (1 ms). The X-axis shows the OFDM symbol index in the time domain and the Y-axis shows the number of subcarriers in the frequency domain. PSS and SSS are transmitted in the 6^{th} OFDM symbol of every 0^{th} sub-frame and 5^{th} sub-frame. PBCH is transmitted in 0^{th} sub-frame of every radio frame. PCFICH is transmitted in the 0^{th} OFDM symbol of every radio frame and the number of OFDM symbols used by it depends on the CFI value which ranges from 1 to 3. Here, CFI value is taken as 1, so only one OFDM symbol carries PCFICH.

PHICH and PDCCH are transmitted in the 0^{th} OFDM symbol of every radio frame. PDSCH is transmitted in OFDM symbol indices 2, 3, 4, 11, 12, 13 in every sub-frame [3].

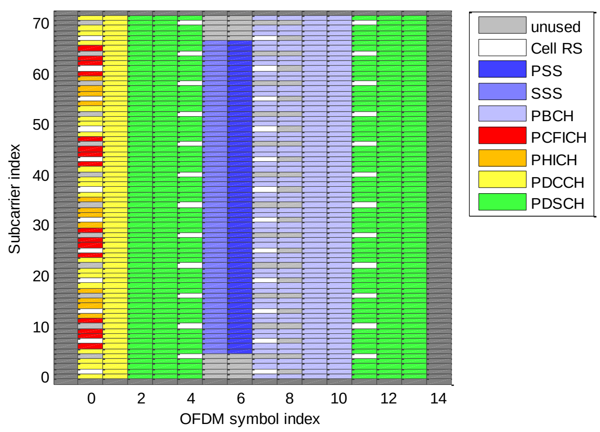

Fig. 1 Downlink transmit resource grid for a sub-frame

Fig. 1 clearly shows the type of data carried by each of the OFDM symbol. The number of resource blocks can take values of 6, 15, 25, 50 and 100. As the number of resource blocks increases, the number of subcarriers increases. For 100 resource blocks, there will be 1200 subcarriers in the frequency domain which corresponds to a system bandwidth of 100 MHz. So, for a duration of 14 OFDM symbols (1 ms), there will be 16800 resource elements.

III. PHYSICAL FRAME STRUCTURE OF LTE-A UPLINK

Similar to the downlink LTE-A, there are a number of physical signals and channels which constitute an uplink system for transmission of data. Each of the physical signals and channels has to be generated and plotted onto the specified indices. Each of the physical signals and channels has a specific set of functions which is explained below:

A. Physical signals

There are two physical signals required for LTE-A uplink transmission. The symbols and their indices are generated by the LTE system toolbox. These symbols are then plotted onto the indices. The different physical signals in the uplink are:

1) PUSCH Demodulation Reference Signal: This is the reference signal used in the uplink transmission scheme for demodulation of the uplink data received through PUSCH (Physical Uplink Shared Channel) by the eNB. It is generated by using the function ltePUSCHDRS( ) and the respective indices are generated by ltePUSCHDRSIndices( ). The generated and demodulated reference symbols are then mapped onto these indices.

2) PUCCH Demodulation Reference Signal: This is the reference signal used in the uplink transmission scheme for demodulation of the uplink data received through PUCCH (Physical Uplink Control Channel) by the eNB. It is generated by using the function ltePUCCH2DRS( ) and the respective indices are generated by ltePUCCH2DRSIndices( ). The generated demodulated reference symbols are then mapped onto these indices. The format of PUCCH2 allows the modeled uplink channel to give the channel status reports or the parameters of channel estimation to the eNB.

B. Physical channels

There are three physical channels in LTE which carry the different control data and user data in the uplink. These channels and their indices are generated by the functions and the channel symbols are mapped to the indices [4]. The different physical channels are:

1) Physical Uplink Shared Channel (PUSCH): This is the uplink channel used for the transportation of data required by the eNB. It carries the data relevant for scheduling requests and channel quality parameters. The function ltePUSCH( ) will generate the symbols and ltePUSCHIndices( ) will allot the indices. Then these symbols are mapped to these indices constituting the PUSCH channel.

2) Physical Uplink Control Channel Format 2 (PUCCH Format 2): This is an uplink transmission channel used for the transportation of channel status reports as well as HARQ acknowledgements to the eNB which facilitates the immediate retransmission of data again to the user equipment. The function ltePUCCH2( ) will generate the symbols and ltePUCCH2Indices( ) will allot the indices. Then these symbols are mapped to these indices constituting the PUCCH format 2 channel.

3) Physical Random Access Channel (PRACH): This is also an uplink transmission channel based on OFDM signal to initiate synchronization with the eNB. These symbols are not orthogonal to the symbols generated in PUSCH and PUCCH, so they will suffer from interference while the subcarriers of PRACH are orthogonal to each other thereby avoiding the interference.

Fig. 2 shows the resource grid for the uplink transmission model for 10 ms or 140 SCFDMA symbols. The resource grid for the downlink is similar to that of uplink but the change is the use of SCFMDA in the uplink which has a low peak to average power ratio and saves battery life of user equipments. The X-axis shows the SCFDMA symbol indices which indicate the number of SCFDMA symbols. The Y-axis shows the number of subcarriers used. The number of resource elements containing user data or control data is substantially less compared to the downlink since only limited number of parameters are fed back to the eNB like parameters of channel state information and scheduling requests. The number of uplink resource blocks is 6 which correspond to 1.4 MHz of bandwidth in the uplink. The uplink resource grid can be called as a needle-like plot because of its representation.

IV. SIMULATION SCENARIO

Scheduling is the process of allocating resource blocks to users. One resource block has duration of 7 OFDM symbols (0.5 ms) in the time domain and 12 subcarriers in the frequency domain. Two such resource blocks constitute a PRBP (Physical Resource Block Pair) which has duration of 14 OFDM symbols (1 ms) in the time domain. A number of such PRBP's constitute a PRBG (Physical Resource Block Group) and usually resources are allocated as PRBG's so as to reduce the system overheads.

The first and foremost step in an LTE system is to create physical signals and physical channels for the transmission of

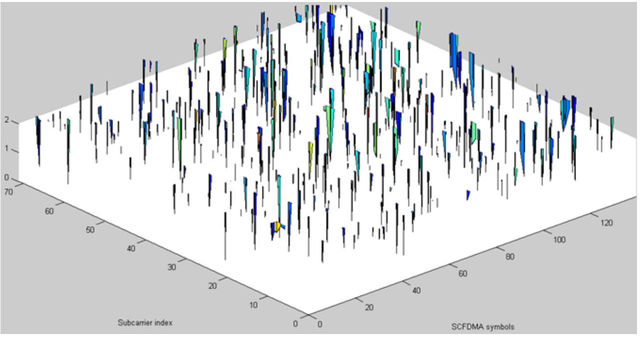

Fig. 2 Uplink transmit resource grid for a sub-frame

control data and user data. Specified slots in the time and frequency domain are allocated by default in this toolbox.

The simulation platform under consideration is MATLAB R2014a which consists of an inbuilt LTE system toolbox. It provides standard functions and tools for the design, verification and simulation of LTE and LTE-A systems. The physical layer frame structure of LTE in the downlink and uplink is modeled by using this toolbox. There are a number of physical signals and physical channels to be generated which is plotted onto the indices. In LTE, ten sub-frames constitute a radio frame (10 ms) [5].

Table I shows the downlink simulation and configuration parameters. All these parameters are prefixed with ‘enb.’ for modeling of LTE downlink system. Table II shows the uplink simulation and configuration parameters. All these parameters are prefixed with ‘ue.’ for modeling of LTE uplink system.

TABLE I: DOWNLINK SIMULATION CONFIGURATION AND PARAMETERS

Simulation Parameters	**Value**
CyclicPrefix	Normal
PHICHDuration	Normal
Ng	Sixth
NDLRB	6
System bandwidth	1.4 MHz
DuplexMode	FDD
NCellID	1
NSubframe	0
CFI	1

TABLE II: UPLINK SIMULATION CONFIGURATION AND PARAMETERS

Simulation Parameters	**Value**
CyclicPrefixUL	Normal
PUCCH	Format2
Hopping	Off
NULRB	6
System bandwidth	1.4 MHz
RNTI	77
NCellID	0
NSubframe	0
CQI	Obtained from downlink

V. CONCLUSION

The physical frame structure of LTE in the downlink is highly complex but flexible which makes it very much useful for modeling an LTE downlink and uplink system according to the service providers’ requirements. As the number of resource blocks increases, the downlink and uplink resource grid varies correspondingly. The physical frame structure of LTE is a combination of time domain OFDM symbols and frequency domain subcarrier indices where OFDMA and SCFDMA is used in the downlink and uplink respectively. Traditionally, the system models were made using the 3GPP spatial channel model for LTE and a number of parameters have to be varied at the backend. Along with that, the use of channel estimation algorithms for estimating the downlink and uplink channels makes it even more complicated. Altogether, the procedures are hectic. But now, with the introduction of LTE system toolbox, the parameters can be varied at the front end which makes the system modeling of LTE wireless communication systems much easier than before.

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