International Journal of Emerging Technologies in Engineering Research (IJETER)
Volume 4, Issue 7, July (2016) www.ijeter.everscience.org

A Review on Adaptive Modulation and Turbo Coding in LTE

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Abstract – The LTE standard uses three different modulation schemes to adapt to various channel conditions in order to improve achievable data rates. These modulation schemes are the QPSK, 16-QAM and 64-QAM. This paper presents an overview of a LTE digital communication system Simulink model, designed in order to study the effects of the QPSK, 16-QAM and 64-QAM modulation schemes on the BER performance with an AWGN channel model. Different subsystems within the transmitter and receiver blocks are implemented in Simulink. It is noted that the LTE system uses Turbo channel coding and bit level scrambling to offer reliable and secure services to the users. Depending on the assumed channel condition (clear, medium clear or noisy), the 64-QAM, 16-QAM or QPSK modulation scheme, on the transmitter side; as well as the corresponding demodulation scheme, on the receiver side; are automatically selected. Based on the recovered data bits, the obtained bit error rates are analysed, compared and discussed.

Index Terms – Long term evolution (LTE), turbo codes, QPSK, QAM.

1. INTRODUCTION

The cellular communication system requires the design of more robust and efficient radio access technology to provide spectrally efficient and flexible data rate to access new multimedia applications, voice and data services etc. Long Term Evolution (LTE) is a 3GPP (Third Generation Partnership Project) cellular network technology, which adapts AMC schemes such as QPSK (Quadrature Phase Shift Keying) or 4-QAM (Quadrature Amplitude Modulation), 16-QAM and 64- QAM to p r o v i d e spectrally efficient and flexible data rates for mobile broadband services by adjusting the transmission parameters based on the link quality to reach the capacity limits of the channel. This AMC is also allows a wireless system to choose the highest order modulation schemes depending on the channel conditions to achieve higher system throughputs of the particular user based on the received signal quality by minimizing the BER, noise and interference. The coding scheme is also modified along the time to match the instantaneous channel conditions of each user. Thus in a LTE network AMC technique track the channel variations, changes the modulation and coding scheme to provide higher system throughput by transmitting information with higher data rates [1, 2].

This paper presents a mathematical study and associated algorithms of the LTE enabling technologies, such as Turbo channel coding and bit-level scrambling. This design study uniquely contributes to the understanding of the LTE digital communication PHY models and the improvement of the BER performance of the system by means of Turbo channel coding. This study particularly evaluates the impact of both the channel conditions based adaptive modulation and the Turbo channel coding on the BER performance of the system. As opposed to other related works, this design explores the isolated effect of LTE changes in the modulation schemes on the BER of the system.

2. RELATED WORK

Long Term Evolution (LTE) is the new upgrade path for carrier with both GSM/UMTS networks and CDMA2000 networks. The LTE is targeting to become the first global mobile phone standard regardless of the different LTE frequencies and bands use in other countries barrier. Adaptive Modulation and Coding (AMC) is used to increase the network capacity or downlink data rates. Various modulation types has been discussed such as Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation (QAM). Spatial multiplexing techniques for 4×4 MIMO antenna configuration is been studied. With channel station information feedback from the mobile receiver to the base station transmitter, adaptive modulation and coding can be applied to adapt to the mobile wireless channels condition to increase spectral efficiencies without increasing bit error rate in noisy channels. In High-Speed Downlink Packet Access (HSDPA) in Universal Mobile Telecommunications System (UMTS), AMC can be used to choose modulation types and forward error correction (FEC) coding rate.

In [1] paper presents an overview of a LTE digital communication system Simulink model, designed in order to study the effects of the QPSK, 16-QAM and 64-QAM modulation schemes on the BER performance with an AWGN channel model. Different subsystems within the transmitter and receiver blocks are implemented in Simulink. It is noted that the LTE system uses Turbo channel coding and bit level scrambling to offer reliable and secure services to the users. Depending on the assumed channel condition (clear, medium clear or noisy), the 64-QAM, 16-QAM or QPSK modulation scheme, on the transmitter side; as well as the corresponding demodulation scheme, on the receiver side; are automatically selected. In [2] various modulation types are discussed such as Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation (QAM). Spatial multiplexing techniques for 4×4 MIMO antenna configuration is studied. With channel station information feedback from the mobile receiver to the base station transmitter, adaptive modulation and coding can be applied to adapt to the mobile wireless channels condition to increase spectral efficiencies without increasing bit error rate in noisy channels. In High-Speed Downlink Packet Access (HSDPA) in Universal Mobile Telecommunications System (UMTS), AMC can be used to choose modulation types and forward error correction (FEC) coding rate. In paper [4] channel coding and link adaptation in LTE was considered, which important issues are in modern digital communication systems. With channel coding, errors caused by distortion during transmission are detected and/or corrected. In LTE both convolutional and Turbo codes are used. The structure of convolutional codes in LTE is presented here. Turbo codes and internal contention free interleaver, which is an important part of the Turbo encoder are also topics of this work. The concept of the circular buffer, which is used in the rate matching module and HARQ was discussed, too. Another key feature used in LTE is the link adaptation. Link adaptation makes the efficient use of the channel capacity possible, matching the transmission parameters, modulation scheme and coding rate to the channel conditions.

3. SYSTEM MODEL

The model of the LTE transmission system is depicted in Fig. 1. An information bit vector $b = (b_1, \ldots, b_m, \ldots, b_{lb})$, including 24 Cyclic Redundancy Check (CRC) bits, is encoded by a systematic rate-1/3 Turbo encoder, consisting of two Parallel Concatenated Convolutional Codes (PCCCs) with octal generator polynomials $G_{CC} = (1, 15/13)_8$ and constraint length £ + 1 = 4. The encoded bits are then separated into three streams: The first contains the systematic bits b, while the second and third contain the parity bits of the two constituent encoders $c^I = (c_1^I, \ldots, c_m^I, \ldots, c_{lb}^I)$ and $c^{II} = (c_1^{II}, \ldots, c_m^{II}, \ldots, c_{lb}^{II})$, respectively. Then, all streams are individually interleaved by so-called sub-interleavers π_b, π_1 and π_2 and written to a ring buffer. At first, all systematic bits $\tilde{\mathbf{b}}$ are written to the ring buffer. Then, the parity bits of both streams $\tilde{\mathbf{c}}^I$ and $\tilde{\mathbf{c}}^{II}$ are interlaced and also written to the ring buffer according to the structure shown in Fig. 1. Finally, a block $\mathbf{y} = (y_1, \ldots, y_n, \ldots, y_{ly})$ of l_y encoded bits is selected for transmission resulting in an effective code rate $r_{RM} = l_b/l_y$ after rate matching. The bits selected for transmission are finally assigned to complex modulation symbols **S** according to the specified modulation schemes QPSK, 16QAM, or 64QAM.

On the receiving side, the demodulated complex symbols Z are fed into a soft demapper which delivers reliability information in terms of Log-Likelihood Ratios (LLRs) $L^{[chan]}_{DM}(b)$, $L^{[chan]}_{DM}(c^I)$. $L^{[chan]}_{DM}(c^{II})$ on the interleaved, systematic information bits and the parity bits of the two constituent encoders. The deinterleaved LLRs are then passed on to the Turbo decoder which uses the Bahl-Cocke-Jelinek-Raviv (BCJR) algorithm for soft channel decoding. After a fixed number of decoding iterations, b is estimated from the resulting a posteriori LLRs.

If the CRC detects an erroneous frame, the receiver will request for a transmission of additional (incremental) redundancy about the same frame by sending a Negative ACKnowledge (NACK) to the transmitter. Otherwise, an ACKnowledge (ACK) is fed back resulting in the transmission of consecutive (new) frames. The feedback channel is indicated by the dashed line in Fig. 1. The LTE HARQ scheme allows for up to K = 4 transmissions of different combinations of systematic and parity bits, the so-called Redundancy Versions (RVs). Obviously, each RV transmission implicitly decreases the effective code rate which results in a decreased throughput and increased latency. According to [1], the initial reading position θρ in the ring buffer of a distinct RV ρ (1 ≤ ρ ≤ K) is given by

$$\theta_p = \Psi \left(2 \, (p-1) \, [\, 3(l_b + 4) / 8\Psi \,] + 2 \right), \ \Psi = [\, l_b + 4 / 32 \,] \quad (1)$$

where [.] rounds up its argument to nearest integer value.

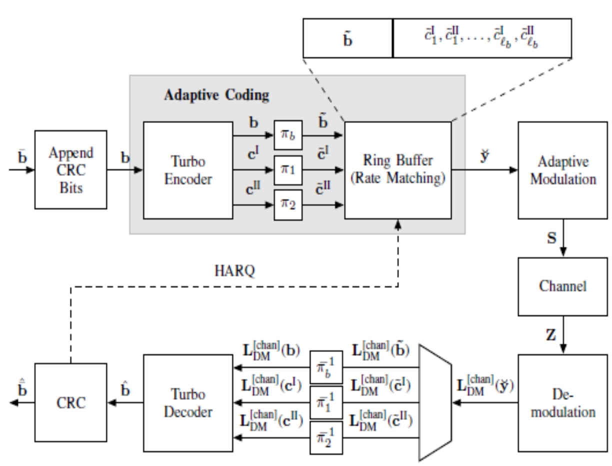

Fig. 1 Model of LTE physical layer

4. ADAPTIVE MODULATION AND CODING IN LTE

4.1. MODULATION AND CODING SCHEMES

In cellular communication systems, the quality of a signal received by a UE depends on the distance between the desired and interfering base stations, multipath or shadow fading, noise etc,. In order to improve system capacity, peak data rate and coverage reliability of the cellular systems, the signal transmitted E_b to and by a particular user is modified to signal quality variation to provide maximum system throughput and flexible data rate for services. This can be achieved by adapting AMC schemes. The AMC scheme adjust the modulation and coding scheme to the channel state conditions (CSCs) to accomplish the highest spectral efficiency at all times by overcome the fading and other interference. LTE network supports QPSK or 4-QAM, 16-QAM and 64-QAM modulation schemes in order to provide different data rates for different kind of mobile broadband services by reacting dynamically to the channel fluctuation. The users closer to the eNB (enhanced Base Station) exploits the 64-QAM scheme to provide higher data rates for services, but the modulation order and/or code rate will decrease as the distance from eNB increases. The AMC schemes are generally represented by M- QAM, where M represents the modulation order or number of conditions or constellation points are available to provide high transmission data rates by transmitting more bits per symbol with high spectral efficiency[7].In general the constellation points for M-QAM can be generated as [8, 9]

$$\propto_{MQAM} = \{\pm(2m-1) \pm (2m-1)j\},$$

where $\mathbf{m} \in \left\{1, 2, \ldots, \frac{\sqrt{M}}{2}\right\}$

$\mathbf{m} \in \{1\}$

For QPSK modulation scheme

and hence constellation

symbols $\{-1-j, -1+j, 1+j, 1-j\}$ are used to transmits the information.

For 64-QAM scheme $\mathbf{m} \in \{1, 2, 3, 4\}$, thus the constellation

$$\begin{Bmatrix} \pm7\pm7j & \pm7\pm5j & \pm7\pm3j & \pm7\pm1j \\ \pm5\pm7j & \pm5\pm5j & \pm5\pm3j & \pm5\pm1j \\ \pm3\pm7j & \pm3\pm5j & \pm3\pm3j & \pm3\pm1j \\ \pm1\pm7j & \pm1\pm5j & \pm1\pm3j & \pm1\pm1j \end{Bmatrix}$$

symbols are used to transmits the information.

In M-QAM modulator, the data stream is divided into I and Q bit streams, each encoded onto a separate axis using identical Gray coding mapping blocks. The distance between two adjacent signal points is given by [10]

$$\mathbf{d} = \sqrt{\frac{3E_b \log_2(M)}{2(M-1)}}$$

Where is the energy per bit.

The constellation diagrams show the different position for the states within different forms of M- QAM. The data rates of AMC techniques depends on its constellation points and is calculated by using the equation,

k= $\log_2$ (M) bits/sec/Hz.

0Where, M is modulation order or possible signal (symbol) and hence M-QAM constellation can encode **$\log_2$ (M)** bits per symbol i.e., each symbol consists of **k** bits. Thus by increasing modulation order M-QAM it is possible to transmit more bits per symbol to achieve higher system throughput with the same system bandwidth [11, 12].

The QPSK uses four constellation points and hence the data rate of each symbol or constellation point is **k=$\log_2$(M)=$\log_2$(4)=2** bits/sec/Hz. Hence in LTE network the higher order modulation scheme able to carries more data bits per symbol to provide higher data rates for services and are less flexible to noise and interference.

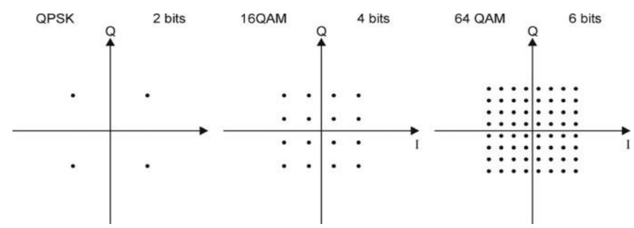

Figure 2: Constellation diagrams of AMC Schemes

In general, bandwidth required to pass M-QAM signal is approximately given by

$$\mathbf{B} = \frac{1}{T_s}$$

But, $R_b = \frac{\log_2(M)}{T_s}$ =bit rate

Then, the bandwidth efficiency may be expressed as

$$\rho = \frac{R_b}{B} = \log_2(M)$$

bits/sec/Hz

Hence, as **M** increases the bandwidth efficiency of **M-QAM** increases.

Modulation Schemes	Symbol time (sec)	Bandwidth (Hz)	Bits Per Symbol/ Data Rate
QPSK	T	1/T	2
16-QAM	T	1/T	4
64-QAM	T	1/T	6

Table1. Data rate of AMC Schemes

4.2 BER Analysis for M-QAM

In a digital transmission, BER is the percentage of bits that have errors relative to the total number of bits that have been transmitted, received or processed over a given time period [14]. Hence Bit error rate (BER) is a parameter which gives an excellent indication of the system performance and is given by,

$$\text{BER} = \frac{\text{number of error bits}}{\textit{total number of bits sent}}$$

In cellular network AMC techniques allows to maintain the BER below a predefined target value by modifying the signal transmitted to a particular user according to the instantaneous received signal quality to provide higher data rates. Then the relationship between bit error and symbol error is given as,

$$P_b \approx \frac{P_s}{k}$$

Hence the higher order modulation scheme renders higher system throughput in a LTE network by reducing the BER [15]. The symbol error rate for 4-QAM (QPSK) is given as [8],

$$P_{s,}4QAM = \text{erfc}\left(\sqrt{\frac{E_s}{2N_0}}\right)$$

The symbol error rate for 16-QAM modulation is given as [8],

$$P_{s,}16QAM = \frac{3}{2}\text{erfc}\left(\sqrt{\frac{E_s}{10N_0}}\right)$$

In general symbol error rate for M-QAM constellation point (where M= 2^k and **k** is even) is given by [8],

$$P_s MQAM = 2\left(1-\frac{1}{\sqrt{M}}\right)\text{erfc}\left(\sqrt{\frac{3E_s}{2(M-1)N_0}}\right) - \left(1-\frac{2}{\sqrt{M}}+\frac{1}{M}\right)\text{erfc}^2\left(\sqrt{\frac{3E_s}{2(M-1)N_0}}\right)$$

5. SUMMARY OF DIFFERENT MODULATION TECHNIQUE

In paper [1] a comparison between the results obtained by simulating the LTE system without any channel coding subsystem and with the 1/3 Turbo channel coding has been established. The outcomes of the simulations have been analysed and it has been observed that the 1/3-Turbo channel coded LTE model performs much better in terms of BER than the non-coded model. It has also been observed that in both non-coded and 1/3 Turbo-coded scenarios, the denser the constellation modulation scheme (QPSK to 16-QAM to 64-QAM); the poorer its BER performance, meaning the poorer the reliability of the whole communication system

QPSK Modulation SNR (dB)	0	2	4	5	5.5	
Simulated BER	0.415	0.21	0.11	0.03	0.0001	
16-QAM Modulation SNR (dB)	0	2	4	5	6	7
Simulated BER	0.65	0.541	0.419	0.3522	0.031	0.01
64-QAM Modulation SNR (dB)	0	2	4	6	7	7.5
Simulated BER	0.86	0.817	0.7259	0.6309	0.398	0.251

Table 2. Turbo-coded QPSK, 16-QAM and 64-QAM BER performance results from [1]

6. CONCLUSION

In this paper we have presented a comparative study of turbo coding with different modulation schemes for LTE system. The main focus of this paper is on QoS improvement by efficiently utilizing available spectrum in LTE. The main objective is to obtain higher system throughput for LTE compared to standard LTE solution. It is been observed that by using proper modulation scheme in LTE the BER performance and reliability of communication channel can be improved.

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