Int. J. Communications, Network and System Sciences, 2015, 8, 229-235
Published Online June 2015 in SciRes. http://www.scirp.org/journal/ijcns
http://dx.doi.org/10.4236/ijcns.2015.86023

Design of OFDM Transceiver for LTE System—A Survey

Nivish Vishnumohan, Krishnaveni Vellingiri, Kesavamurthy Thangavelu

Department of ECE, PSG College of Technology, Coimbatore, India
Email: nivish.v@gmail.com, vk@ece.psgtech.ac.in, tkm@ece.psgtech.ac.in

Received 9 April 2015; accepted 19 June 2015; published 24 June 2015

Abstract

LTE (Long Term Evolution) is the latest technology in wireless communication. It is being used because of its peak data rate and spectral efficiency. LTE uses OFDMA (Orthogonal Frequency Division Multiple Access) technology for radio transmission and reception in downlink. OFDM is a multicarrier modulation and multiplexing technique to improve data rate, spectral efficiency and minimize the problem of fading and ISI (Inter Symbol Interference). Many transceivers design have been designed for OFDM system to minimize error and maximize throughput of the information being transmitted and received at the system. The purpose of this article is to present a survey of the published literature which deals with various OFDM transceiver design, focusing on the merits and demerits of the corresponding OFDM transceiver design.

Keywords

LTE (Long Term Evolution), OFDM (Orthogonal Frequency Division Multiplexing), FEC (Forward Error Correction), HARQ (Hybrid Automatic Repeat Request)

1. Introduction

The mobile data has increased dramatically over the recent years. 2G and 3G networks have become congested leading to requirement of increased capacity. LTE network satisfies the need of increased capacity. LTE is the vital part of critical communication in the future [1]. LTE delivers a peak data rate of 300 Mbps in the downlink and 75 Mbps in the uplink [2]. The technique used in radio transmission and reception in LTE downlink is OFDM.

The OFDM transmitter sends the information by dividing it into many parallel substreams. OFDM is an efficient way to deal with multipath. In relatively slow time-varying channels, it is possible to enhance capacity significantly by adapting the data rate per subcarrier according to the signal-to-noise ratio (SNR) of that particular

How to cite this paper: Vishnumohan, N., Vellingiri, K. and Thangavelu, K. (2015) Design of OFDM Transceiver for LTE System—A Survey. *Int. J. Communications, Network and System Sciences*, **8**, 229-235.
http://dx.doi.org/10.4236/ijcns.2015.86023

subcarrier and it is a bandwidth efficient scheme saving approximately 50 percent of the total bandwidth required [3].

The main focus of the article is on the OFDM transceiver design based on the analysis of coding technique and error management technique. There are two types of coding techniques: Space Time Coding (STC) and Bit Interleaved Coded Modulation (BICM). The available error management techniques are: ARQ Schemes and hybrid ARQ schemes. The ARQ Schemes are Stop and wait ARQ, Go-Back-N ARQ and Selective Repeat ARQ. Hybrid ARQ Schemes are divided into Type I Hybrid ARQ and Type II Hybrid ARQ.

The currently used error control technique for LTE system is HARQ which is the combination of FEC (Forward Error Correction) and ARQ Scheme. FEC scheme is used to correct the errors and avoid the number of retransmissions. ARQ is used to correct the errors in case of information is not received. The receiver requests the retransmission request initiated by FEC subsystem. Most ARQ Techniques are based on channel estimation [4].

The study of various coding schemes with error control schemes by analyzing the BER and throughput for LTE and proposing a best model suitable for the LTE system improving reliability of system by enhancing the data rate and improving bandwidth utilization of the system.

2. Analysis of Coding Schemes for OFDM Transceiver

Channel coding for wireless communication is fairly a new field of research. The ultimate aim is to apply channel coding to OFDM systems. In this survey two types of coding techniques: Space Time Coding and Bit Interleaved Coded Modulation are taken into account.

Assumptions usually considered for analysis: OFDM with 64 subcarriers, block Fading Environment, 16 QAM modulations. The convolutional coding is preferred for high channel gain [5]. For decoding viterbi decoding is preferred for accuracy [6].

Space Time Coding: Space Time Coding is suited for multiple antenna transmission systems with a quasistatic fading (*i.e.*, block-fading) environment. The coding architecture of STC is shown in **Figure 1**.

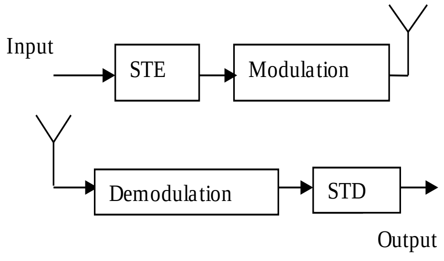
Space Time Encoding: Assumption: The Space time codeword is of length is $M_T XT$ where M_T represents the transmitter antenna and T represents the block length. The Space Time Codeword is given by $S = [s[1], s[2], s[3], \cdots, s[T]]$. The signal model [7] is given by

$$y[k] = \frac{\sqrt{Es}}{MT} Hs[k] + n[k] \tag{1}$$

where $k = 1, 2, 3, \cdots, T$.
E_s is the total energy available.
H is the total transfer function.
$n[k]$ is the Zero Mean Gaussian Noise.
$s[k]$ is the Space Time Codeword.
$Y[k] = [Y[1], Y[2], \cdots, Y[T]]$ and the noise matrix is given by $N = [n[1], n[2], \cdots, n[T]]$.

Space Time Decoding: Assumption: The receiver uses Maximum Likely Hood detection [8] criteria based on perfect channel knowledge.

$$S^* = \arg\min \|Y - HS\|_F^2 \tag{2}$$



STE-Space Time Encoding.
STD-Space Time Decoding.

Figure 1. The coding architecture of STC.

Bit Interleaved Coded Modulation (BICM) The coding architecture of Bit Interleaved Coding Modulation is shown in **Figure 2**.

BICM achieves larger hamming distance which is very much useful in fast fading channel scenarios. BICM achieves larger flexibility in rate adaptation which is desirable for packet data communications. In fast fading scenario receiver diversity will be more beneficial when compared to transmit diversity. BICM is preferred for discrete inputs in fast fading scenario instead of Gaussian inputs.

The Key features of BICM OFDM are interference cancellation and increase in overall system capacity. OFDM BICM offers a better trade-off between energy efficiency and system performance. The important drawback is that most of the BER analysis did not provide accurate results.

From the detailed comparison study between space time code and bit interleaved code in OFDM system it is seen that bit interleaved code outperforms space time code. For Slow varying channels Space Time Coding is better. So Bit Interleaved Coding is suitable for OFDM in fast fading environment [9]. Thus the LTE system data rate and throughput performance is increased. Space Time Codes are suitable for multiple antenna transmission systems with quasi static fading environment [10] but fails to meet the channel characteristics across subcarriers in OFDM system. OFDM do not comply with the widely used quasi static channel model. For OFDM system the channel characteristics is approximated by an independent fast fading channel model thereby leading to significant fading across the subcarriers [11]. So reconsideration of channel coding problem in OFDM must be taken into consideration to improve the reliability and performance of OFDM system.

3. Analysis of Error Control Management Schemes

In this section different error control schemes are compared and suitable scheme for LTE is chosen.

ARQ (Automatic Repeat Request) Scheme: There are three types of ARQ schemes. Stop and wait ARQ, Go-Bach-N ARQ and Selective Repeat ARQ [12].

Stop and Wait ARQ: In Stop and wait ARQ the transmitter sends the codeword to the receiver and waits for the acknowledgement (ACK). The positive acknowledgement indicates that transmitted codeword has been successfully received. The Transmitter sends the next codeword in the queue. A negative acknowledgment (NAK) from the receiver indicates that the transmitted codeword is in error. The transmitter resends the codeword again and again waits for an acknowledgment. Retransmissions will continue until the transmitter receives an ACK. The Stop and wait ARQ procedure is illustrated in **Figure 3**.

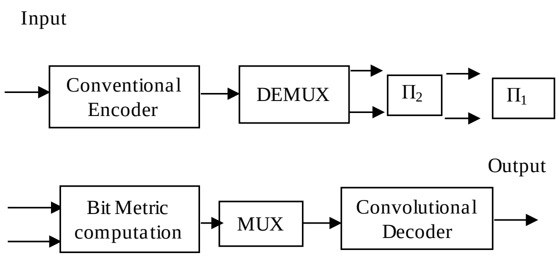


Figure 2. Bit Interleaved Coded Modulation.

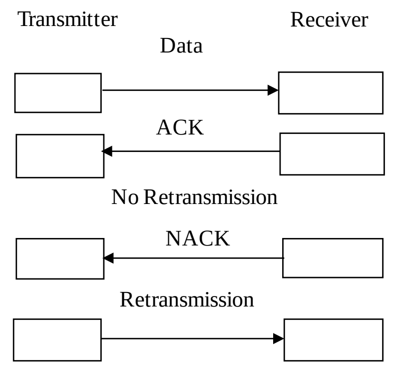


Figure 3. Stop and Wait ARQ.

Throughput of the Stop and Wait ARQ System:

$$\eta = \frac{Pc\left(\frac{k}{n}\right)}{1+\lambda\delta/n} \tag{3}$$

Pc—Probability that received word contains no error.
δ—Bit Rate of the transmitter.
λ—Idle time of the transmitter between two successive transmissions.
k/*n*—The Rate of the Code.

Equation (3) gives the throughput of the Stop and waits ARQ system which is derived by computed by knowing the average of bits that could be transmitted for a codeword to be received correctly.

For data communications systems with high data rates and large round-trip delays, $\lambda\frac{\delta}{n}$ becomes very large because it is impractical to use a very large *n*. In this case, the throughput performance of the stop-and-wait ARQ scheme becomes unacceptable.

Go-Back-N ARQ Scheme: The transmitter continuously transmits codeword in order and then stores the receipt of an ACK/NAK for each.

The acknowledgment for a codeword arrives after a round-trip delay. During this interval, N-1other codeword are also transmitted.

Whenever the transmitter receives a NAK indicating that a particular codeword, it stops transmitting new codeword. Then it goes back to codeword which is in error and proceeds to retransmit the codeword and the N - 1 succeeding codeword. As soon as codeword which is in error is positively acknowledged, the transmitter proceeds to transmit new codeword.

The Go-Back-N ARQ Scheme is illustrated in **Figure 4**. Considering data of the user to be transmittedto the corresponding destination is subdivided into 3 parts.

The main drawback of go-back-N ARQ is that, whenever a received word is detected in error, the receiver rejects the next N - 1 received words, even though many of them may be error free.

The go-back-N ARQ scheme is not suitable for communications systems with high data rates and large round-trip delays. So Selective ARQ scheme is considered to combat the drawbacks of the Go-Back-N ARQ Scheme.

Throughput of Go-Back-N ARQ System:

$$\eta = \frac{Pc\left(\frac{k}{n}\right)}{Pc+(1-Pc)N} \tag{4}$$

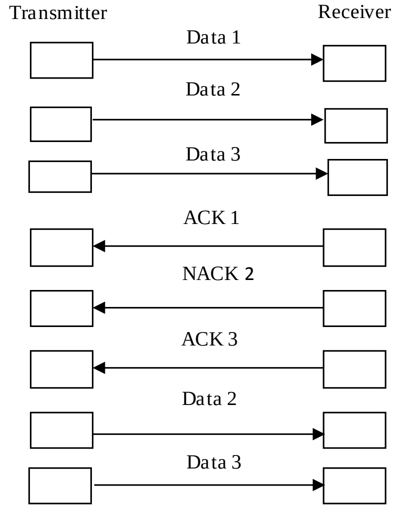


Figure 4. Go-Back-N ARQ.

δ—Bit Rate of the transmitter.
Pc—Probability that received word contains no error. *N*—Round Trip delay.

Selective Repeat ARQ Scheme: In a selective Repeat ARQ error-control system, codeword are a transmitted continuously. The transmitter resends the codeword that are negatively acknowledged. After resending a NAK codeword, they transmitter continues transmitting codeword in the transmitter buffer. In this scheme, a buffer must be provided at the receiver to store the error-free codeword. Codeword must be delivered to the end user in correct order, for point-to-point communications. When the NAK codeword is successfully received, the receiver then releases any error-free codeword in consecutive order from the receiver buffer until the next erroneously received word is encountered. The Procedure of Selective Repeat ARQ is illustrated in **Figure 5**.

Throughput of Selective Repeat ARQ System:

$$\eta = Pc\frac{k}{n} \tag{5}$$

Pc-Probability that received word contains no error. *k*/*n*- The Rate of the Code.

Sufficient receiver buffer storage must be provided in a selective-repeat ARQ system otherwise, buffer overflow will occur and codeword will be lost.

Hybrid ARQ Error Control Schemes: There are two types of Hybrid ARQ Schemes: Type I HARQ Scheme and Type II hybrid ARQ Scheme. The combination of FEC (Forward Error Correction) and ARQ scheme is termed the hybrid ARQ scheme [13]. The function of the FEC system is to reduce the frequency of retransmission by correcting the error patterns which occur most frequently. Proper combination of FEC and ARQ provides higher reliability than an FEC system alone and higher throughput than a system with ARQ.

Type I Hybrid HARQ Scheme: A Hybrid ARQ scheme consists of an FEC subsystem contained in an ARQ system. FEC subsystem reduces the frequency of transmissions by correcting the error patterns which occur more frequently. This increases system throughput performance. If less frequent error pattern is detected the receiver requests for retransmission rather than passing unreliable decoded message to the user. Thus ARQ provides greaterreliability and FEC system provides higher throughput. Type I Hybrid uses a code which is designed for simultaneous error detection and correction. When received word is detected with error, the receiver first correct the errors.

If the number of errors is within the designed error correcting capability the errors will be corrected and decoded message will be delivered to the user or saved in the buffer until it is ready to be passed by the user. If uncorrectable error pattern is found, the receiver rejects the received words and requests for retransmission.

Type I Hybrid ARQ is best suited for communication system in which a fairly constant level of noise and interference is anticipated on the channel [14].

Type I Hybrid ARQ scheme has some drawbacks: When the channel bit error rate is low, no error correction is needed. Thus extra parity bits is required for error correction which results in redundancy in the message being transmitted.

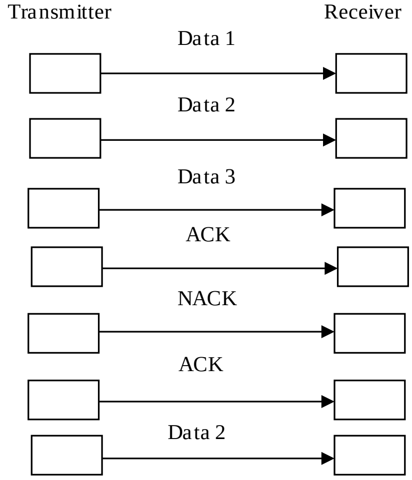


Figure 5. Selective repeat ARQ.

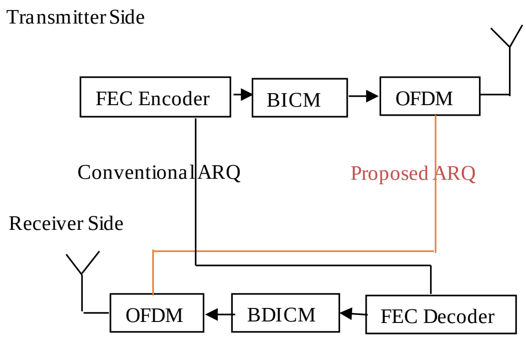


Figure 6. Best system for LTE.

Type II Hybrid HARQ Scheme: The message in its first transmission is coded with parity check bits for error detection only. When the receiver detects the presence of errors in a received word, it saves erroneous word in a buffer and at the same time requests retransmission. The retransmission is not the original codeword but a block of parity check bits which is formed based on original message and error correcting codes. When the block parity check bits are received, it is used to correct he errors in the erroneous word stored in the receiver buffer. If error correction is not successful, the receiver requests a second retransmission may be either a repetition of the original codeword or another block of parity check bits. This depends on the retransmission for error correction.

The drawback of type II HARQ is the evaluation of average number of transmissions due to statistical dependency on different events.

Selective HARQ Method: Selective retransmission method works independent of conventional HARQ with or without FEC. In conventional method the receiver initiates retransmission request if cyclic redundancy check fails. In SHARQ approach modulation layer initiates targeted retransmission of information symbols corresponding to subcarriers that have gain $|H(l)| = \tau$. $|H(l)|$ is the channel norm. τ is the specific threshold of the OFDM subcarrier. Selective retransmission is done for low SNR subcarriers [15].

Decision of information symbols to be retransmitted is made based on channel norm prior to decoding. The receiver performs joint detection of information symbols that undergo selective retransmission by observation made from first transmission and selective transmission. The Selective HARQ method is independent of conventional HARQ method adopted in LTE system offering significant throughput gain.

The drawback of Selective Repeat HARQ scheme is that the retransmission is limited to single partial retransmission of the subcarrier less than the threshold. If the retransmission fails, information is lost, second retransmission does not take place [15].

From the detailed analysis of coding techniques and error control management techniques, the system given in **Figure 6** is best suitable for LTE system.

The System given in **Figure 6** is the best suited for LTE [15] because in the proposed ARQ scheme: Selective HARQ scheme deals with the modulation layer for retransmission thereby improving the performance of the system and BICM coding scheme is suitable for fast fading environment improves the minimization of errors in decoding.

4. Conclusion

The selection of best OFDM transceiver design remains a challenging task. Different coding schemes and error control management schemes are discussed in the literature. From the detailed survey it is concluded that Bit Interleaved Coding Modulation is preferred for space time coding. In case of error control management technique Selective HARQ method is preferred. Choosing the best coding techniques and error control management technique improves the throughput and minimizes the Bit Error Rate of the LTE system.

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