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Frequency Synchronization Using OFDM in Long Term Evolution

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Abstract: **-- Multi-carrier modulation has been used in many wired and wireless communications. It was used in many military high frequency radios, audio-video broad casting and DSL. Multi-carrier modulation can be digitally implemented using Orthogonal Frequency Division Multiplexing (OFDM).Inter symbol Interference can be completely avoided in OFDM by inserting cyclic prefixes. In OFDM wide band channel breaks into multiple parallel narrow band channels. Fast Fourier transform and Inverse fast fourier transform in the OFDM system makes the circuit simple, cheap and low cost. Long Term Evolution (LTE) introduced by third generation partnership project is an emerging standard for high speed wireless communications. This standard benefits from the OFDM technology in the down link which provides several advantages, includes high bandwidth efficiency, fit to multi-path fading and simplicity of equalizer. OFDM in LTE is a candidate for air interface in fourth generation cellular system. OFDM systems in LTE transforms frequency selective wide band channels into a group of non-selective narrow band channels. OFDM is susceptible to disturbances like CFO. Time and frequency synchronization of OFDM avoids the disturbances in OFDM.Thus synchronization is an essential part in the receiver section of OFDM. The VHDL language is used for coding, Synthesis can be done in Xilinx ISE Design Suite 13.2 and simulation can be done with Model Sim 6.3f.**

Index Terms**—OFDM, ISI, Carrier frequency offset, Long term evolution.**

I. INTRODUCTION

Multi-carrier modulation has been used in many wired and wireless applications. It has been used in many wired and wireless applications. It was used for military HF radios, audio and video broadcasting. In MCM transmitted bit stream is divided into many different sub streams and send over many different sub channels. The data rate of sub channel is less than total data rate. And the corresponding sub channel bandwidth is much less than total system bandwidth. The sub stream are chosen to ensure that each sub channel has a bandwidth less than coherence bandwidth of the channel, so the sub channel experience relatively flat fading. Thus Inter symbol interference (ISI) on each sub channel is small. The sub channel in MCM need not be continuous, so a large continuous block of spectrum is not needed for high rate multicarrier communications. Moreover digital implementation of MCM based on orthogonal frequency multiplexing (OFDM) reduces complexity. It is a digital modulation in which signal is split into several narrow band channels at different frequencies. Fast fourier transform and Inverse fast fourier transform in the OFDM system makes the circuit simple, cheap and low cost. It is used in several applications such as ADSL, a system that makes high bit-rates possible over twisted-pair copper wires. It has recently standardized and recommended for digital audio broadcasting in Europe and terrestrial digital video broadcasting. IEEE802.11a standard i is for wireless local area networks is also based on OFDM.It is especially suited for high speed communication.

OFDM was originally proposed in 1960s as a parallel data transmitting scheme. The basic idea is to divide a single high rate data stream into number of lower rate data stream. Each data stream are modulated in a specific carrier called sub carrier. The data streams obtained from each sub carrier are separated by frequencies. And these sub carriers are orthogonal to one another so as to enhance the spectrum efficiency. In 1980s, OFDM was widely studied in areas as high density recording, high speed modem and digital mobile communication. Since 1990s OFDM has been employed in wide band data transmission. Application of OFDM technology includes asymmetric digital subscriber line(ADSL),high bit rate digital subscriber line(HDSL) and very high speed digital subscriber line(VDSL) in wired systems and digital video broad casting (DVB) in wireless systems. Furthermore it has also been recognized as basic of wireless Local area network.

In order to meet the unprecedented requirement for high Quality of Service (QOS) and high data rate communication as well as emerging multimedia services, telecommunication professionals are currently working towards the fourth generation (4G) wireless communication systems. Long term evolution (LTE) is a 4G wireless broadband technology developed by third generation partnership project .LTE also provides high speed data for mobile phones and data terminals. Long Term Evolution increases the capacity and speed of wireless data network. It provides down link peak rate of 300 Mbits/s and up-link peak rate of 75 Mbits/s. To overcome the effects of multi-path fading problem available in Universal mobile telecommunication systems (UMTS), LTE uses OFDM for down link. And it allows spectrum flexibility. And enables cost efficient solutions for very wide carrier with high peak rates.OFDM symbols are grouped into resource block. Each resource block is 180 KHZ in frequency domain and 0.5ms in time domain. More resource block a user

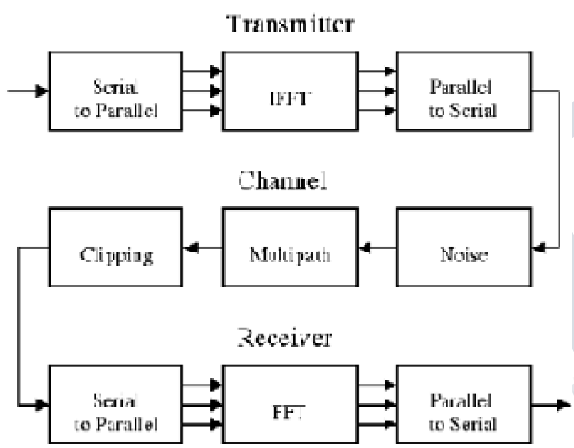

Fig. 1. Block diagram of OFDM system

Gets, higher the modulation used in resource elements, higher the bit rate. OFDM is susceptible to timing and frequency synchronization errors. Carrier frequency offset (CFO) is the major disturbance, it can be estimated and compensated in reception.CFO also generates Inter carrier interference and degrades the performance. Many algorithms had been introduced for CFO estimation and compensation. Accurate estimate of time and frequency offset is important task of OFDM receiver.CFO consists of Integer frequency offset (IFO) and fractional frequency offset (FFO).IFO and FFO can be avoided by time and frequency synchronization at the receiver section. Fractional CFO can be estimated by sine and cosine estimator. Remaining CFO can be estimated and compensated by FFT and decoder section. Efficient implementation of receiver section of OFDM using Cordic and FFT processor performs time and frequency synchronization. Therefore transmitted information can be obtained at the receiver section without any disturbance.

II. LITERATURE REVIEW

The 3GPP LTE [9] downlink system usually supports scalable bandwidths ranging from 1.4 MHz to 20 MHz. The sub-carrier spacing is 15 kHz to restrict the degradation due to Doppler effect. 6 or 7OFDM symbols are allocated in one time slot based on the length of cyclic prefix .Both frequency division duplex and time division duplex modes are employed in 3GPP-LTE systems. Each mode has different frame structures. in FDD one radio frame is 10 ms,which consists of ten 1-ms sub-frames. One sub-frame of FDD is further divided into two 0.5-ms time slots. primary synchronization channel (P-SCH) and secondary synchronization channel (SSCH),are the two synchronization channels provided for synchronization and cell search.LTE supports both FDD and TDD, as well as a wide range of system bandwidths to operate in different spectrum allocations. OFDMA is used in the downlink of LTE systems [11]. Intercarrier interference is avoided in OFDM system through orthogonality of OFDMA.Time and frequency synchronization of OFDM between the terminal and the base station is needed to maintain orthogonality. For frequency synchronization of OFDMA system is required coarse and fine frequency synchronization. Coarse frequency synchronization estimates IFO and fine frequency synchronization estimates FFO.This can be achieved by multiple differential filters and I channel correlators..This can be achieved by multiple differential filters and I channel correlators.Transmitter architecture of MIMO OFDMA [6] system have layer mapper assigns the antenna ports for spatial multiplexing, and it can adapt to the channel environment by using different numbers of layers. The layer-mapped MIMO vector is multiplied by the cyclic delay diversity (CDD) matrix intentionally in order to increase the transmit diversity and improve the open-loop MIMO detection performance. The optimal precoding matrix encoded by the codebook in the user end (UE) and then feedback to the base-station transmitter. Afterwards, the reference signals are inserted as subcarrier pilots to facilitate the synchronization and channel estimation in the receiver. Finally, the OFDM symbol is generated by the FFT processing and then is transmitted via multiple antennas In LTE, [12] the system synchronization is usually the UE performs an initial time and frequency offset estimation by detecting synchronization signals accomplished first in downlink (DL) and then in uplink (UL). The UE can acquire the frame structure of the downlink signal, and read basic system information. Two synchronization signals includes Primary and Secondary synchronization signals are used here.Maximum likelyhood algorithm and Minn algorithms are also used in the receiver design makes the architecture more complex. The advantages of this [5] system consist of high frequency efficiency, robustness to the multipath fading and simplicity of the structure in receiver. However, the general drawback intrinsic to the OFDM-based systems is that they are intensely sensitive to the timing and frequency errors. Therefore, they have to be synchronized exactly with the base transmitting stations (BTS) antenna that requires accurate synchronization blocks to be implemented in the front-end of the UE receiver. In the LTE cellular system, each cell is divided into 168 groups where each group consists of 3 sectors. Information such as the integer carrier frequency offset (ICFO) and the frame timing are also determined simultaneously. The cell search is achieved by the detection and process of two defined synchronization sequences, i.e., Primary and Secondary synchronization sequences. OFDM systems are sensitive to an offset in the carrier frequency than single carrier schemes with the same bit rate. CFO cause loss of orthogonality of the multiplexed signals and interference between adjacent sub-channels (ICI) and introduces a constant increment in the phase of the samples. Therefore a frequency synchronization process is necessary to overcome frequency offset. CFO synchronization usually consists of an acquisition stage followed by a tracking stage[11]. In the first one, an initial estimation of the CFO is obtained and corrected. ICI is usually eliminated by the acquisition stage. If these deviations are not tracked and corrected, constellation points will suffer and degrades the system performance.

III. PROPOSED SYSTEM

Long Term Evolution (LTE) introduced by 3GPP is an emerging standard for high speed wireless communications.LTE uses OFDM in down link section because it provides high bandwidth efficiency, robustness to multi-path fading and simplicity of equalizer.OFDM systems

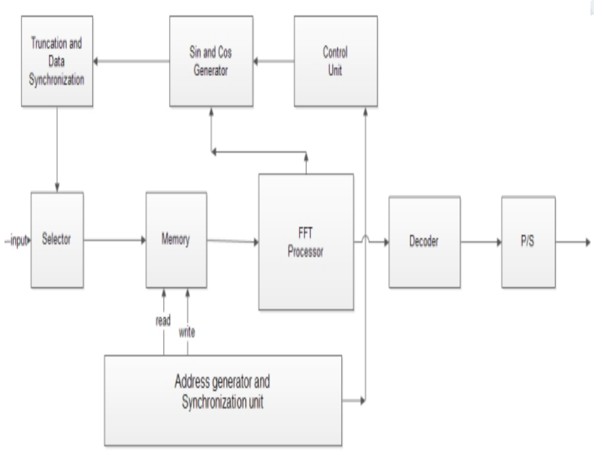

Fig. 2. Block diagram of OFDM Receiver architecture

Are more susceptible to the timing and frequency synchronization errors than their single carrier systems. Carrier frequency offset (CFO) is the error in OFDM.CFO of a received signal consists of an IFO and FFO.In order to avoid the disturbances in OFDM we develop an architecture using FFT processor and cos and sine estimator using CORDIC algorithm. The pre-FFT block avoids the fractional frequency offset by using cordic algorithm. And after that symbols are passed to FFT where time synchronization takes place, thus the residual CFO can be estimated and compensated. Important blocks in Figure 2 is Cos and sine estimator and FFT processor.

A.Cordic architecture

Coordinate Rotation Digital Computer is, a special purpose computer to compute many non-linear and transcendental functions. It can compute trigonometric, logarithmic, exponential, hyperbolic, multiplication, division; square root .It can also be used in areas of digital signal processing, communications, computer graphics. The simplicity of CORDIC is that it can compute above mentioned functions using shifts and additions.

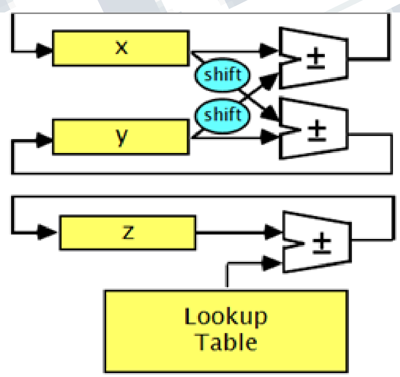

Fig. 3. Cordic Architecture

$$\begin{bmatrix} X_i \\ Y_j \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} X_i \\ Y_j \end{bmatrix} \quad (1)$$

The θ angle rotation can be executed in several steps, using an iterative process. Each step completes a small part of the rotation. Many steps will compose one planar rotation. A single step is defined by the following equation.

$$\begin{bmatrix} X_{n+1} \\ Y_{n+1} \end{bmatrix} = \begin{bmatrix} \cos\theta_n & -\sin\theta_n \\ \sin\theta_n & \cos\theta_n \end{bmatrix} \begin{bmatrix} X_n \\ Y_n \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} X_{n+1} \\ Y_{n+1} \end{bmatrix} = \cos\theta_n \begin{bmatrix} 1 & -\tan\theta_n \\ \tan\theta_n & 1 \end{bmatrix} \begin{bmatrix} X_n \\ Y_n \end{bmatrix} \quad (3)$$

$$\theta_n = arctan\left(\frac{1}{2}\right) \quad (4)$$

$$\sum_{n=0}^{\infty} s_n \theta^n \quad (5)$$

$$S_n = \{+1, -1\} \quad (6)$$

$$\tan\theta_n = S^n \; 2^{-n} \quad (7)$$

$$\begin{bmatrix} X_{n+1} \\ Y_{n+1} \end{bmatrix} = \cos\theta_n \begin{bmatrix} 1 & -S_n 2^n \\ S_n 2^n & 1 \end{bmatrix} \begin{bmatrix} X_n \\ Y_n \end{bmatrix} \quad (8)$$

$$K = \prod_{N=0}^{\infty} cos\left(arctan\left(\frac{1}{2^n}\right)\right) = .607253 \quad (9)$$

$$X_j = K(X_i cos\theta - Y_i sin\theta);$$

$$Y_j = K(Y_i cos\theta + X_i sin\theta) \quad (10)$$

$$\begin{bmatrix} X_{n+1} \\ Y_{n+1} \end{bmatrix} = \cos\theta_n \begin{bmatrix} 1 & -S_n 2^n \\ S_n 2^n & 1 \end{bmatrix} \begin{bmatrix} X_n \\ Y_n \end{bmatrix} \quad (11)$$

$$Z_n + 1 = \theta - \sum_{i=0}^{n} \quad (12)$$

$$S_{n=}\{-1 \; if \; Z < 0; +1 \; if \; Z > 0\} \quad (13)$$

B. Fast fourier transform

The Fast fourier transform is an algorithm that efficiently computes the discrete fourier transform. The DFT of a sequence x(n) of length N is given by,

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{\frac{-j2\pi}{N}} \quad (14)$$

Where $0 \le k \le N-1$ (15)

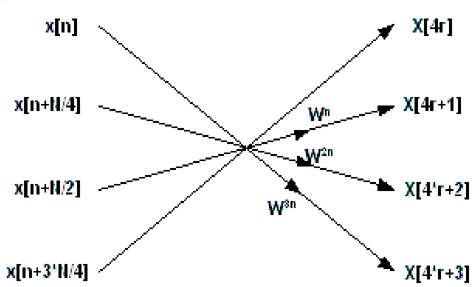

Fig. 4. 4 point FFT

To compute N values of DFT N ^{2} multiplications and N(N-1) complex additions are required.OFDM signal consist of n sub carriers spaced by frequency distance Δf.The total system bandwidth 'B' is divided into N equivalent sub channels. All sub carriers are mutually orthogonal within a time interval of length Ts=1/Δf Since the system bandwidth is subdivided into N narrow band sub channels, the OFDM block duration Ts is N times as large as in case of single carrier transmission system covering the same bandwidth. Guard interval is added at the transmitter section to avoid inter symbol interference. Guard interval is removed in the receiver section. In practical application OFDM signal is generated in first step as a discrete time signal in the digital signal processing part of transmitter. Since the bandwidth of an OFDM signal must be sampled with sampling time Δt=1/B, sample of a signal can be written as,

$$S_n = {}^1\!/_{\sqrt{N}} \sum_{n=0}^{N-1} x(n)\, e^{-j2\pi/N} \quad (16)$$

This exactly defines IDFT .thus correlation at the receiver section can be implemented by means of DFT.And here Radix4 FFT is used.

IV. EXPERIMENTAL RESULTS

Frequency synchronization using OFDM in LTE contains modules such as a memory, address generator and synchronization unit, sine and cos estimator using CORDIC, control unit, FFT processor, decoder, parallel to serial converter. Simulation results of these modules are shown below;

Address generator and synchronization unit is also main part in our architecture it allows the read and write operations and give control signal to cos and sine estimator to select appropriate angle values based on CORDIC.

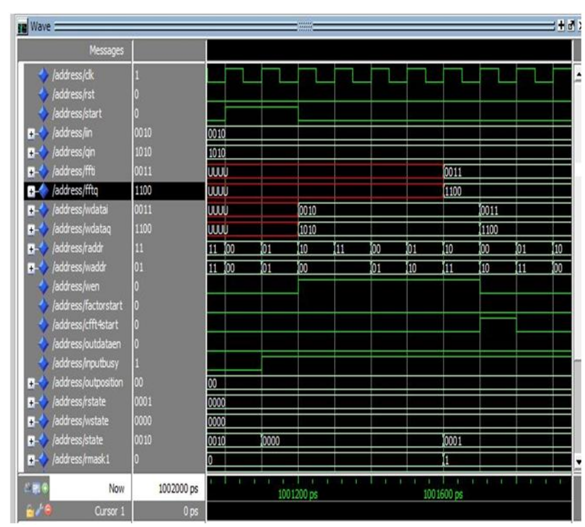

Fig. 1. Simulated waveform of address generator and synchronization unit

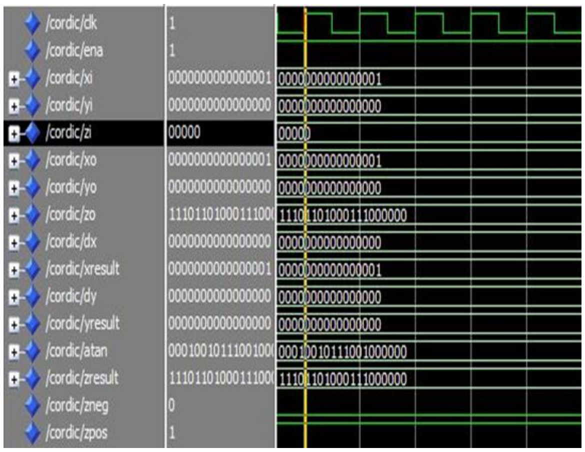

Fig. 2 .Simulated waveform of Cordic Architecture

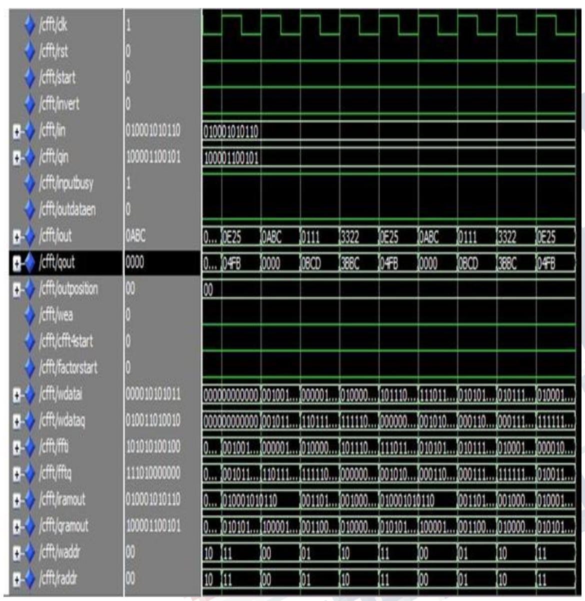

Fig. 3 . Simulated waveform of Receiver section

V. CONCLUSION

Orthogonal frequency multiplexing (OFDM) is an emerging technology for high data rates. It is a form of multi carrier transmission and suited for frequency selective channels. And it is widely used in wireless communications. Long Term evolution (LTE) uses OFDM for down link that is from base station to terminal and to transmit the data over many narrow band carrier.OFDM also vulnerable to many disturbances. One of the major disturbances is Carrier frequency Offset (CFO).Many methods and algorithms are developed to avoid the disturbances in OFDM.But all have certain drawbacks. We can avoid all disturbances by performing time and frequency synchronization. Thus we develop an efficient receiver section with CORDIC architecture and FFT processor.

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