

# Review Analysis for Implementation of SC-FDMA over WiMAX Broadband Networks

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**Abstract**— WiMAX (Worldwide Interoperability for Microwaves Access) is a key technology which builds a base for next generation of mobile broadband networks. WiMAX and Long Term Evolution (LTE) standards are the two main contenders in the 4G wireless scenario. WiMAX air Interface adopts Orthogonal Frequency Division Multiple Access (OFDMA) for Uplink and Downlink transmission. Single Carrier Frequency Division Multiple Access, which utilizes single carrier modulation and frequency domain equalization is a technique which has similar performance and same overall complexity as those of OFDM, in which peak-to-average power ratio is a major drawback. The main advantage of SC-FDMA is its lower PAPR due to its single carrier structure. In this paper, we do a systematic analysis on the implementation of SC-FDMA in WiMAX PHY layer (UPLINK).

**Keywords**— OFDM, WiMAX, SC-FDMA, PHY, 4G, LTE, PAPR

## I. INTRODUCTION

WiMAX is an IEEE 802.16 standard based technology responsible for bringing the Broadband Wireless Access (BWA) to the world as an alternative to wired broadband. The WiMAX standard 802.16e provides fixed, nomadic, portable and mobile wireless broadband connectivity without the need for direct line of sight with the base station. WiMAX systems are based on versions *d* and *e* of the [1] IEEE802.16 standard which defines a physical (PHY) and medium access control (MAC) layers for broadband wireless access systems operating at frequencies below 11GHz. IEEE 802.16 [2] physical (PHY) layer is characterized by Orthogonal Frequency Division Multiplexing (OFDM), Time Division Duplexing, Frequency division Duplexing, Quadrature Amplitude Modulation and Adaptive Antenna Systems. 3GPP long term evolution (LTE) has adopted orthogonal frequency division multiplexing access (OFDMA) for downlink transmission and single carrier frequency division multiple access (SCFDMA) for uplink. This is to compensate for a drawback with normal OFDM, which has a very high peak to average power ratio (PAPR). High PAPR requires expensive and inefficient power amplifiers with high requirements on linearity, which increases the cost of the terminal and drains the battery faster SCFDMA. In WiMAX, OFDMA is used both on the downlink (DL) and the uplink (UL). There are

many reasons for choosing the OFDMA such as the multipath handling capability, scalability of operation in different bandwidths, capability to handle different data rates, and the ability to easily combine with multiple antenna techniques. Mainly, the OFDMA enables relatively simple channel compensation techniques in frequency selective fading channels which make it popular. In addition, frequency diversity and channel feedback can be used effectively to improve robustness and throughput [3].

The ability of OFDM systems to integrate well with multiple-input multiple-output (MIMO-OFDM) technology is an important factor in the choice of OFDMA. It is well known that MIMO technology helps achieving high spectral efficiencies as MIMO-OFDM has successfully proven in IEEE 802.11n. But the main drawback of Orthogonal Frequency Division Multiple Access technique is Peak to Average Power Ratio (PAPR). This high peak-to-average power ratio (PAPR) has been the reason for not using OFDMA for the UL in LTE (Long Term Evolution) [3]. The technology used in the UL of LTE, the single carrier frequency division multiple access (SCFDMA), is nothing but a simple modification of OFDMA. Therefore, many of the OFDMA related points are valid for SCFDMA. SCFDMA is a promising technique for high data rate transmission that utilizes single carrier modulation and frequency domain equalization. Single carrier transmitter structure leads to keep the peak to average power ratio (PAPR) as low as possible that will reduce the energy consumption. SCFDMA has similar throughput Performance as OFDMA. Because high PAPR is detrimental to user equipments, SCFDMA has drawn great attention as an attractive alternative to OFDMA for uplink data transmission. It can be regarded as DFT-spread OFDMA (DFTSOFDM), where time domain data signals are transformed to frequency domain by a DFT before going through OFDMA modulation. The main benefit of DFTSOFDM compared to OFDM scheme, is reduced variations in the instantaneous transmit power, implying the possibility for increased power amplifier efficiency, low-complexity high-quality equalization in the frequency domain, and flexible bandwidth assignment [4].

## II. LITERATURE REVIEW

In an OFDM system the data to be transmitted,  $X(0), X(1), \dots, X(N-1)$ , is first modulated, using quadrature phase shift keying (QPSK) or a quadrature amplitude modulation (QAM). The resulting data is then transformed using an  $N$ -point inverse fast Fourier transform (IFFT), and the resulting samples,  $x(0), x(1), \dots, x(N-1)$ , are transmitted over the air [12].

Mathematically, a single sample,  $x(k)$ , can be described using the equation 1:

$$x(k) = \frac{1}{N} \sum_{i=0}^{N-1} X(i) e^{j2\pi ki/N} \dots\dots\dots (1)$$

For a single sample in time, the signal which is transmitted is composed of the summation of all symbols, each multiplied by a phasor term. By using mathematics, it's easy to demonstrate that this summation leads to a *peak-to-average power ratio* (PAPR) that's proportional to  $N$ , the number of subcarriers. An OFDM system uses hundreds or even thousands of subcarriers that leads to a system with a very high PAPR. This is the major drawback of OFDM based PHY layer, creating many challenges on the power amplifier (PA) designer. Real PAs are linear only for a small operating range. When the input signal becomes too strong, a PA move into its saturation region, where the output power is not proportional to the input level for a longer duration. It means that when a peak arises, that causes distortion. The distortion breaks the orthogonality between the subcarriers; causing inter-carrier interference (ICI). The idea of SC-FDMA is to add an  $M$ -point fast Fourier transform block before the  $N$ -point inverse fast Fourier transform of the OFDM system. Generally,  $M$  is selected to be much smaller than  $N$ , so that the FFT only cancels the final IFFT partially, resulting in a single carrier type of signal with, a lower PAPR [5]. OFDM and SC-FDMA can be differentiated on the basis of their transmitter is the DFT mapper. When the mapping of data bits into modulation symbols is completed the transmitter groups the modulation symbols into a block of  $N$  symbols. Then  $N$ -point DFT transforms that symbols from time domain system into frequency domain. The frequency domain samples are mapped to a subset of  $M$  subcarriers where  $M$  is typically greater than  $N$ . Similar to OFDM, an  $M$ -point IFFT is used to generate the time-domain samples of subcarriers, that is followed by cyclic prefix, parallel to serial converter, DAC and RF subsystems.

### OFDMA

Basically OFDMA works on PHY layer of WiMAX. It is implemented on PHY layer for UPLINK and DOWNLINK data transmission. OFDMA enables relatively simple channel compensation techniques in frequency selective fading channels. Frequency diversity and channel feedback can be used effectively to improve robustness and throughput which make it popular. The OFDMA technology is designed to operate under different bandwidth conditions

while still keeping essential basic parameters like the subcarrier spacing constant leading to reuse of baseband algorithms in different implementation scenarios. This is the reason for the use of the term scalable OFDMA. The ability of OFDM systems to integrate well with multiple-input multiple-output (MIMO-OFDM) technology is an important factor in the choice of OFDMA. It is well known that MIMO technology helps achieving high spectral efficiencies as MIMO-OFDM has successfully proven in IEEE 802.11n [6]. Certain disadvantages like high peak-to-average power ratio (PAPR) have been the reason for not using OFDMA for the UL in LTE. For IEEE 802.16, therefore, single carrier modulation was chosen, because of low system complexity. Downlink channel is shared among users with TDM signals. Subscriber unit are being allocated in separate time slots. Access in uplink is being realized with TDMA. In the 2–11 GHz bands, communications can be achieved for licensed and non-licensed bands. The communication is available in NLOS conditions. Physical layer functions are associated with providing service to subscribers. These functions include transmitting data in frames and controlling access to the shared wireless medium, and are grouped into a medium access control (MAC) layer [7].

### SCFDMA

#### Single carrier Modulation

The standard OFDM where the each data symbol is carried by the individual subcarriers, the SC-FDMA transmitter carries data symbols over a group of subcarriers transmitted parallel. That means, the group of subcarriers that carry each data symbol can be viewed as one frequency band carrying data sequentially in a standard FDMA. For the subcarrier mappings, the time domain representation of the IFFT output that will give more insight on the SC-FDMA signals. It can be mathematically shown that the SC-FDMA baseband time domain samples after IDFT or IFFT is the original data symbol set repeated in time domain over the symbol period.

### PAPR

SC-FDMA performs similar performance and complexity as OFDM. But the important factor of SC-FDMA is the low PAPR of the transmit signal. PAPR is the ratio of the peak power to average power of the transmit signal. PAPR is a main issue at the user terminals, and SC-FDMA is the preferred technology for the uplink transmission due to low PAPR. PAPR is related to the power amplifier efficiency at the transmitter, and the maximum power throughput is achieved when the amplifier operates at its saturation point. Lower PAPR, that allows operation of the power amplifier close to saturation, which results in higher throughput. With higher PAPR signal, the power amplifier operating point has to be backed off to lower the signal distortion, and hence lowering amplifier throughput. SC-FDMA modulated signal can be viewed as a single carrier signal, a pulse shaping filter can be used to transmit signal to further improve PAPR.

Orthogonal Frequency Division Multiple Access (OFDMA) and Single Carrier Frequency Division Multiple Access (SC-FDMA) are modified versions of the OFDM and SC/FDE schemes. Broadband channels experience frequency-selective fading, the FDMA techniques can employ channel dependent scheduling to gain multi-user diversity, and due to the fading characteristics of the terminals in different positions are statistically independent, the scheduling techniques assign each terminal to subcarriers with favorable transmission characteristics at the location of the terminal. Single carrier frequency division multiple access (SCFDMA) that utilizes single carrier modulation at the transmitter and frequency domain equalization at the receiver is a technique that has equivalent performance and essentially the same structure as in an OFDMA system. One important advantage over OFDMA is that the SC-FDMA signal has lower peak-to-average power ratio (PAPR) [8]. The WiMAX cellular system uses OFDMA for transmission of signals both from the base station and from the mobile terminals. 3GPP prescribes OFDMA for downlink transmission and SC-FDMA for uplink transmission in the long term evolution (LTE) of cellular systems in order to make the mobile terminal power-efficient [9]. That is the base which can be implemented by us in UPLINK of WiMAX PHY layer..

**SC-FDMA Signal Processing**

Figure-1 shows an SC-FDMA transmitter sending one *block* of data to a receiver. The input of the transmitter and the output of the receiver are complex modulation symbols. Practical systems dynamically adapt the modulation technique to the channel quality, using binary phase shift keying (BPSK) in weak channels and up to 64-level quadrature amplitude modulation (64-QAM) in strong channels. The data block consists of *M* complex modulation symbols generated at a rate *R<sub>source</sub>* symbols/second. The *M*-point discrete Fourier transform (DFT) produces *M* frequency domain symbols that modulate *M* out of *N* orthogonal subcarriers spread over a bandwidth.

$$W_{channel} = N \cdot f_0 \text{ [Hz]} \dots \dots \dots (2)$$

Where *f<sub>0</sub>* Hz is the subcarrier spacing  
The channel transmission rate is

$$R_{channel} = \frac{N}{M} \cdot R_{source} \text{ [Symbols/Second]} \dots \dots \dots (3)$$

If *Q* denotes the bandwidth spreading factor, i.e

$$Q = \frac{R_{channel}}{R_{source}} = \frac{N}{M} \dots \dots \dots (4)$$

then, the SC-FDMA system can handle up to *Q* orthogonal source signals with each source occupying a different set of *M* orthogonal subcarriers. *Y<sub>l</sub>* (*l* = 0, 1, . . . , *N* - 1) represents the frequency domain samples after subcarrier mapping and *y<sub>n</sub>* (*n*

= 0, 1, . . . , *N* - 1) represents the transmitted time domain channel symbols obtained from the inverse DFT (IDFT) of *Y<sub>l</sub>*. The subcarrier mapping block in Figures 1 assigns frequency domain modulation symbols to subcarriers. The mapping process is sometimes referred to as scheduling. Because spatially dispersed terminals have independently fading channels, SC-FDMA and OFDMA can benefit from channel dependent scheduling. The inverse transform (IDFT) in Figures-1 creates a time domain representation, *y<sub>n</sub>*, of the *N* subcarrier symbols.

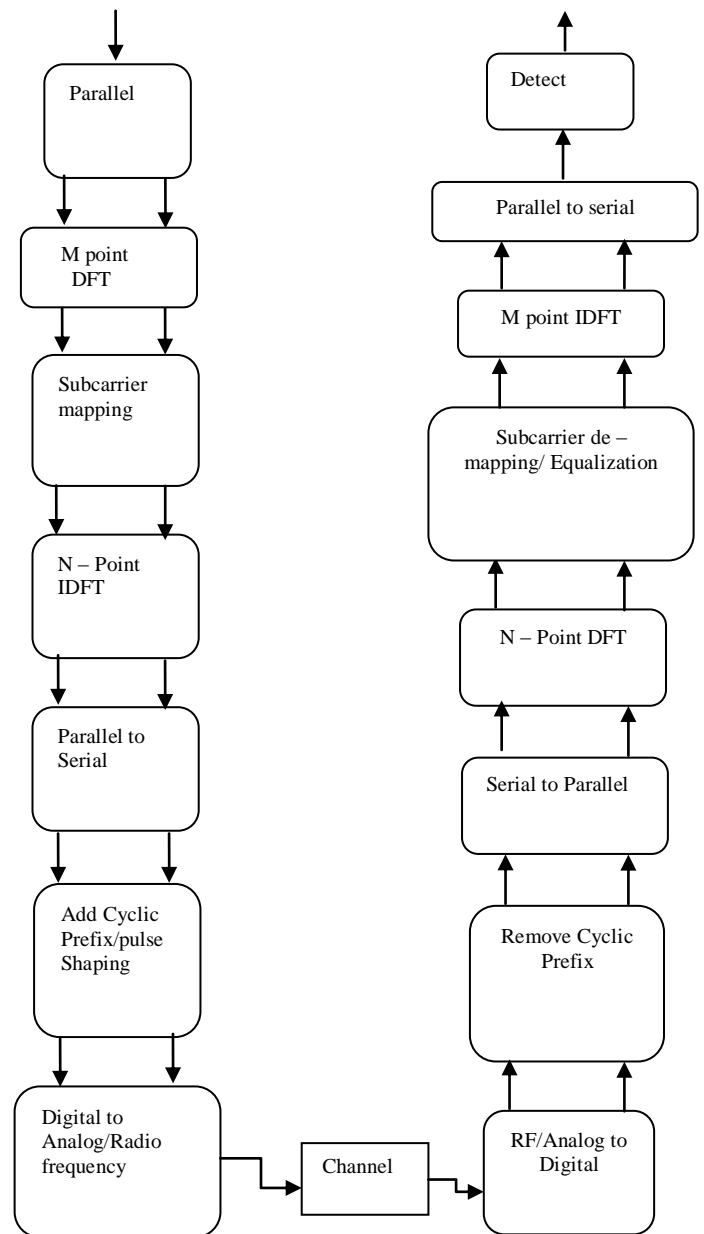


Fig.1 Transmitter and Receiver structure of SC-FDMA and OFDMA System.

The parallel-to-serial converter places  $y_0, y_1, \dots, y_{N-1}$  in a time sequence suitable for modulating a radio frequency carrier and transmission to the receiver.

The transmitter in Figure-1 performs two other signal processing operations prior to transmission. It inserts a set of symbols that referred to as cyclic prefix (CP) in order to provide a guard time to prevent inter-block interference (IBI) due to multipath propagation which is a major problem in air media. The transmitter also performs a linear filtering operation referred to as pulse shaping in order to reduce out-of-band signal energy. The cyclic prefix is a copy of the last part of the block. CP is inserted at the start of each block for two reasons. 1<sup>st</sup> The CP acts as a guard time between successive blocks. If the length of the CP is longer than the maximum delay spread of the channel, the length of the channel impulse response, then, there must not be a problem of IBI. 2<sup>nd</sup>, it is well known that the CP is a copy of the last part of the block; and it converts a discrete time linear convolution into a discrete time circular convolution. Hence, transmitted data propagating through the channel can be modeled as a circular convolution between the channel impulse response and the transmitted data block that in the frequency domain is a point-wise multiplication of the DFT frequency samples. Channel distortion can be removed by the DFT of the received signal can simply be divided by the DFT of the channel impulse response point-wise multiplication of the DFT frequency samples. Then, to remove the channel distortion, the DFT of the received signal can simply be divided by the DFT of the channel impulse response point-wise.

One commonly used pulse-shaping filter is a raised-cosine filter. The frequency domain and time domain representations of the filter are as follows:

$$P(f) = \begin{cases} T, & 0 \leq |f| \leq \frac{1-\alpha}{2T} \\ \frac{T}{2} \{1 + \cos[\frac{\pi T}{\alpha} (|f| - \frac{1-\alpha}{2T})]\} & \dots\dots\dots(5) \\ 0, & |f| \geq \frac{1+\alpha}{2T} \end{cases}$$

$$P(t) = \frac{\sin(\frac{\pi T}{T})}{\frac{\pi T}{T}} \cdot \frac{\cos \frac{\pi \alpha t}{T}}{1 - 4t^2 \alpha^2} \dots\dots\dots(6)$$

Where T is the symbol period and  $\alpha$  is the roll off factor.

Roll-off factor  $\alpha$  range from 0 to 1 and controls the amount of out-of-band radiation. With  $\alpha = 0$ , the filter is an ideal band pass filter that suppresses all out-of-band radiation.

As  $\alpha$  increases, the out-of-band radiation increases. In the time domain, the side lobes of the filter impulse response increase as  $\alpha$  decreases and this increases the peak power of the transmitted signal after pulse shaping. Therefore the choice of filter roll-off factor requires a compromise between the goals of low out-of-band radiation and low peak-to-

average power ratio. The DFT in the receiver of Figure-1 transforms the received signal to the frequency domain in order to recover  $N$  subcarriers.

The de-mapping operation isolates the  $M$  frequency domain samples of each source signal. Because SC-FDMA uses single carrier modulation, it encounters substantial linear distortion manifested as inter-symbol interference (ISI).

The frequency domain equalizer cancels the ISI. The IDFT in the receiver of Figure 1 transforms equalized symbols back to the time domain where a detector produces the received sequence of  $M$  modulation symbols.

Figure-1 indicates that SC-FDMA incorporates the signal processing elements of OFDMA and adds a DFT at the input of the transmitter and a corresponding IDFT at the output of the receiver. Because the SC-FDMA transmitter expands the signal bandwidth to cover the bandwidth of the channel, SC-FDMA is sometimes referred to as DFT-spread OFDMA.

### III. WIMAX SYSTEM MODEL FOR PHY LAYER

The main task of the physical layer is to process data frames delivered from upper layers to a suitable format for the wireless channel. This task is done by the following processing: channel estimation, FEC (Forward Error Correction) coding, modulation, mapping in OFDMA (Orthogonal Frequency Division Multiple Access) symbols, etc [1]. The block diagram for WiMAX system is shown in Fig-2.

#### Randomization

It is the first process which is carried out in the WiMAX Physical layer after the data packet is received from the higher layers and each of the burst in Downlink as well as in the Uplink is randomized. It is basically scrambling of data to generate random sequence in order to improve coding performance and data integrity of the input bits [11].

#### FEC

It basically deals with the detection and correction of errors due to path loss and fading that leads to distortion in the signal. There are number of coding systems that are involved in the FEC process like RS codes, convolution codes, Turbo codes, etc. Basically we will be focusing upon the RS as well as the convolution codes.

#### 1. RS codes

These are non-binary cyclic codes that add redundancy to the data. This redundancy is basically addition of parity bits into the input bit stream that improves the block errors.

#### 2. Convolution Codes

These CC codes introduce redundant bits in the data stream with the use of linear shift registers (m). The information bits are applied as input to shift register and the output encoded bits are obtained with the use of modulo-2 addition of the input information bits. The contents of the shift

register in 802.11a physical layer uses Convolution code as the mandatory FEC [1]. These convolutional codes are used to correct the random errors and are easy to implement than RS codes. Coding rate is defined as the ratio of the input bits to the output bits. Higher rates like 2/3 and 3/4, are derived

from it by employing “puncturing.” Puncturing is a procedure that involves omitting of some of the encoded bits in the transmitter thus reducing the number of transmitted bits and hence increasing the coding rate of the CC code and inserting a dummy “zero” metric into the convolution viterbi decoder on the receive side of WiMAX Physical layer in place of the omitted bits

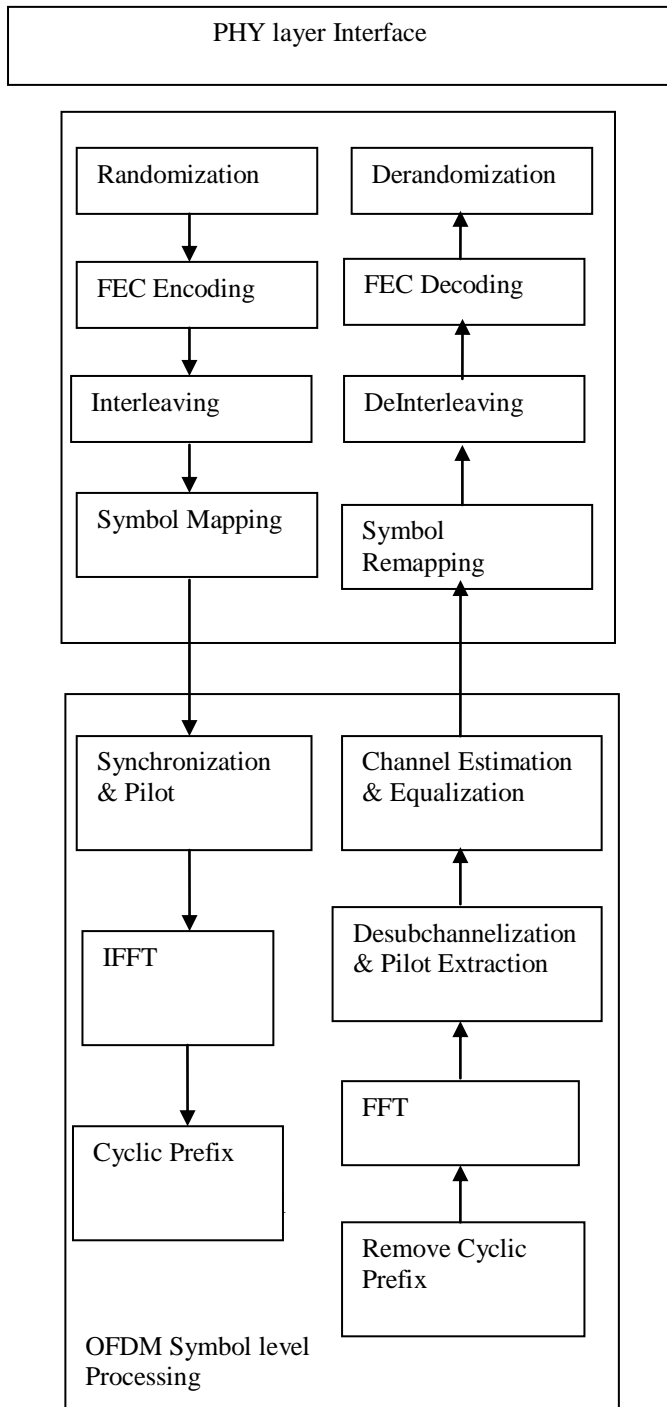


Fig. 2. WiMAX Model for PHY layer with Downlink and Uplink

**Modulation**

This process involves mapping of digital information onto analog form such that it can be transmitted over the channel. Various digital modulation techniques can be used for data transmission, such as QPSK, BPSK, FSK, M-PSK and M-QAM, where M is the number of constellation points in the constellation diagram.

**Pilot Insertion**

Used for channel estimation & synchronization purpose. In this step, pilot carriers are inserted whose magnitude and phase is known to the receiver.

**Inverse Fast Fourier Transform**

An Inverse Fast Fourier transform converts the input data stream from frequency domain to time domain representing OFDM Subcarrier as the channel is basically in time domain. IFFT is useful for OFDM system as it generates samples of a waveform with frequency components satisfying the orthogonality condition such that no interference occurs in the subcarriers. Similarly FFT converts the time domain to frequency domain as basically we have to work in frequency domain [14]. By calculating the outputs simultaneously and taking advantage of the cyclic properties of the multipliers FFT techniques reduce the number of computations to the order of  $N \log N$ . The FFT is most efficient when  $N$  is a power of two.

**Cyclic Prefix**

One way to prevent ISI is basically to create a cyclically extended guard interval in between the data bits, where each of the OFDM symbol is preceded by a periodic extension of the signal itself. When the guard interval is longer than the channel impulse response, or the multipath delay, the ISI can be eliminated.

**Communication Channel**

Communication channels are kind of medium of communication between transmitter and receiver. These channels are mainly divided into fast and slow fading channels. A channel is known as fast fading if the impulse response of the channel changes approximately at the symbol rate of the communication system, whereas in slow fading channel, impulse response stays unchanged for several symbols.

**Receiver Side**

The inverse processes take place at the receiver side. Removing the guard interval becomes equivalent to removing

the cyclic prefix. Performing a FFT on the received samples after the cyclic prefix is discarded; the periodic convolution is transformed into multiplication, as it was the case for the analog Multi Carrier receiver [13]. Then demodulation, deinterleaving as well as FEC decoding using Viterbi Decoder and at last derandomization.

#### **IV Conclusion**

In this paper, we do analysis of WiMAX PHY layer model, and studied the two multiple access technique i.e. OFDMA and SCFDMA. We assessed that we can implement the SCFDMA multiple access technique to reduce the PAPR on UPLINK of PHY layer of WiMAX model using MATLAB simulation model. And by doing Mathematical analysis it is clear that proposed scheme can reduce the PAPR significantly. In the analysis we found that SCFDMA provides a lower PAPR and higher system throughput compared to OFDMA.

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