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# Universal Filtered Multicarrier for 5G

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**Abstract—** The future cellular networks intend to achieve even higher data rates and for this reason needs to be more robust against inter channel interference (ICI) and inter symbol interference (ISI). There are certain limitations that would not allow orthogonal frequency division multiplexing (OFDM) to work efficiently for future requirements of cellular networks, which includes machine-to-machine (M2M) communication and Internet-of-things (IoT). In this paper the multiple input multiple output (MIMO) system is implemented with universal filtered multicarrier (UFMC) to increase its efficiency in order to achieve even higher data rates with reduced bit error rate (BER). The research would aim to evaluate the performance of UFMC MIMO for different antenna configurations and digital modulation schemes.

**Keywords—** OFDM, Multicarrier Techniques, 5G, MIMO, UFMC, Digital Modulation.

## I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a 4G standard in which, instead of using a single carrier, multiple sub-carriers that are non-overlapping and orthogonal to each other are used for data transmission. OFDM systems are capable of delivering high data rate, reduce receiver complexity and enhance spectral efficiency. Some basic issues that OFDM has is that it is highly sensitive to carrier frequency offset (CFO) and requires strict synchronization. CFO in OFDM occurs due to inaccuracies of local oscillators and Doppler Effect on the receiver side. The carrier frequency of the transmitter does not match at the receiver and hence the received symbols undergo time-variant phase rotation. Figure shows the block diagram of OFDM architecture.

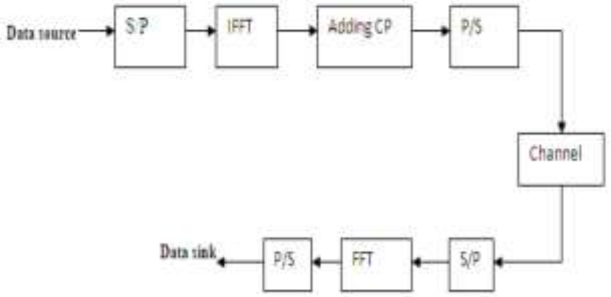


Figure 1. OFDM system block diagram

OFDM is the most prominent and widely used multicarrier modulation technology for broadband communication systems. It is a special form of frequency division multiplexing (FDM). The attraction in OFDM systems is because of its simple and efficient architecture. Moreover, the fast fourier transform (FFT) and Inverse fast fourier transform (IFFT) based modulation and demodulation makes its implementation very simple. The scalar equalization at the receiver side and high spectral efficiency by overlapping the half sub-carrier spectra makes it even more attractive for modern communication systems. One of the main drawbacks due to which OFDM rules out for future communication networks is its high side lobe level and inter carrier interference (ICI).

The working mechanism of an OFDM system is described in Figure 1. First, the serial binary data is converted into several parallel sub-carriers by using a serial to parallel converter. The basic principle of orthogonally between these parallel sub-carriers enables the signal to be separated at the receiver side again. The problem of inter symbol interference (ISI) is solved by inserting a cyclic prefix at the start of each symbol. The cyclic prefix consists of $N$ samples which can be written as $N_{CP}$. These samples are added at the beginning of each OFDM symbol and thus each OFDM symbol block contains $NB = N + N_{CP}$ where $N$ represents the FFT. The frequency domain signal is then converted back to time domain signal by using IFFT and can represented by the equation (1).

$$X_k = \frac{1}{\sqrt{Ns}} \sum_{l=0}^{Ns-1} X(l) e^{\frac{j2\pi lk}{N}} \tag{1}$$

In the above equation the value of $k$ goes from 0 to $N-1$ and Ns represents the total number of sub-carriers. The parallel signal is again converted to series and transmitted through the channel. The received signal $Y(k)$ is hence represented by equation (2).

$$Y(k) = H(k)X(k) + W(k) \tag{2}$$

In equation (2), $Y(k)$ is the received signal, $H(k)$ is the channel impulse response, $X(k)$ is the transmitted signal and $W(k)$ is the additive white Gaussian noise (AWGN).

Physical downlink shared channel (PDSCH) is the channel which is assigned to users and the users data travel in this channel. The channel is not fixed for each user. It is allocated to user when the channel is free on the basis of first come and first get. PDSCH is used for 4G and also proposed for future 5G. QPSK, 16QAM and 64QAM are the modulation schemes used for PDSCH. The type of modulation scheme which will be selected for data transmission depend on the capacity of buffer and condition of the radio channel.

## II. MULTICARRIER MODULATION

The idea of multicarrier modulation was put forward which forms the basic building block of OFDM technique. The concept of multicarrier modulation is that the entire bandwidth $BW$ is divided into small sub-carriers, which are used to modulate and carry data later. The width of the a sub-carrier is given by $\Delta f = \frac{BW}{N_c}$. Where $BW$ is the available bandwidth and $N_c$ is the number of sub-carriers. This concept allows the data to be transmitted in parallel streams, which is obtained by dividing the data into blocks of $N_c$ data symbols. These $N_c$ carriers are then modulated and transmitted through the channel. The symbol duration of a modulated carrier is given by $T_s = \frac{1}{W}$. Thus the entire multicarrier signal can written according to equation (3) as a set of modulated carriers.

$$s(t) = \sum_{k=0}^{N_c-1} x_k \psi_k(t) \tag{3}$$

In equation (3), $x_k$ represents the data symbol modulating the $\mathrm{k^{th}}$ subcarrier, $\psi_k(t)$ is the modulation waveform at the $\mathrm{k^{th}}$ subcarrier and $s(t)$ is the multicarrier modulation signal. Multicarrier waveforms that use orthogonal waveforms for sub-carrier modulation are called orthogonal frequency division multiplexing (OFDM). The orthogonally between the sub-carrier allows them to have overlapping spectrum which enables them to achieve high spectral efficiency. Figure 2 shows the basic implementation technique of multicarrier modulation.

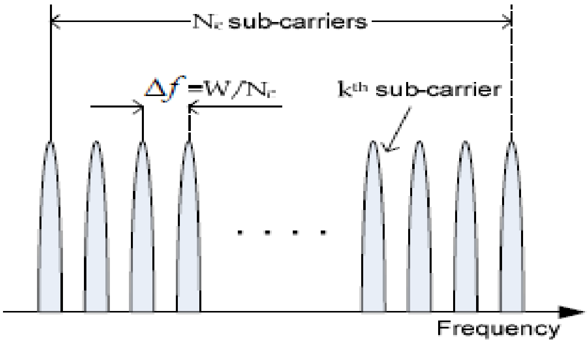


Figure 2. Multicarrier Modulation

## III. LIMITATIONS OF OFDM

### A. *Limitations to frquency and timing offsets*

In order for an OFDM system to maintain orthogonally, it is assumed that both transmitter and receiver are in perfect synchronization with each other and both use the exact same reference signal. The orthogonally is lost in terms of frequency offset, which causes ICI. The offset in time and frequency arise due to drifts in local oscillators, which occur due to temperature and voltage variations. Aside from this, the phase noise added to the signal, which is already distorted due to frequency offset, gets even worse.

### B. *Cyclic Prefix overheads*

For backward compatibility reasons, long term evolution (LTE) standards are used to express the limitations of OFDM systems. A cyclic prefix (CP) is the copy of the last part of the previous symbol, which is attached at the start of each new symbol to increase robustness. Thus, CP adds redundancy to the transmission since the same signal is being transmitted twice. The CP overhead can hence be given using the equation (4).

$$\beta_{overhead} = \frac{T_{CP}}{Tcp + T_{symbol}} \tag{4}$$

International standards are available for the sub-carrier spacing for LTE. The length of CP is directly related to the overhead. Most of the LTE networks use 15 KHz spacing with normal CP now a days.

## IV. NEED OF NEW WAVEFORM FOR 5G

As mentioned earlier that, there are some limitations in OFDM waveform, which makes it not suitable for future 5G. For 5G application scenarios, UFMC alone would not be able to cover them up entirely. For ultra-high speed, anywhere anytime connectivity, high spectral efficiency and multiple device compatibility the MIMO technique combined with UFMC is expected to show the desired results. The digital modulation schemes and number of transmit and receive antennas and their configuration would affect the performance of the system.

## V. UFMC MIMO

A typical 2x2 MIMO system shown in Figure 3 is used to explain the concept of UFMC MIMO. The transmission method is the same as 2x1 Alamouti encoder except for two receive antennas instead of one. In a 2x2 MIMO space-time block coding (STBC) for UFMC, two signals are transmitted on two signal times and are received though two receiver antennas using the four fading channels.

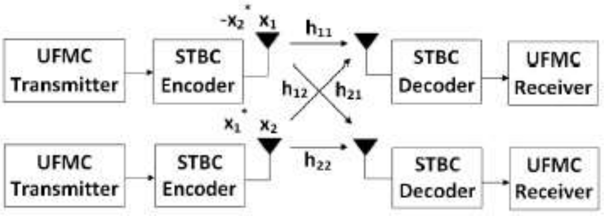


Figure 3. Block diagram of MIMO STBC for UFMC

If the channel gains are represented by $\mathrm{H_{qp}}$ amongst the $\mathrm{p^{th}}$ transmitter and $\mathrm{q^{th}}$ receiver. Thus the mathematical form of the received signal over one time signal can be given by

$$y_1(t) = h_1x_1 + h_2x_2 + w(1) \tag{5}$$

$$y_2(t) = -h_1x_2^* + h_2x_1^* + w(2) \tag{6}$$

The received signal over the second time signal is given by

$$y_1(t) = h_3x_1 + h_4x_2 + w(3) \tag{7}$$

$$y_2(t) = -h_3x_2^* + h_4x_1^* + w(4) \tag{8}$$

In the above equations are independent channel gains. The final received signal can hence be represented by equation (9).

$$y = Hx + w \tag{9}$$

By MIMO and UFMC being explained, show different tests conducted with different UFMC MIMO configurations. By changing the number of antennas at the receiver and transmitter and using multiple digital modulation schemes, the performance of the UFMC MIMO system can be evaluated.

## VI. UFMC MIMO WITH DIFFERENT MODULATIONS

For detailed system performance evaluation, in this section, the number of transmitting and receiving antennas are kept constant while modulation schemes are changed. Each of the graph in Figure 4 have same antenna configuration for different modulation schemes and same is the case for Figure 4 and 5. This test enables the selection of best modulation scheme with a specific antenna arrangement that can used for specific applications.

### A. *1x1 Antenna Configuration*

- Single transmitting antenna
- Single receiving antenna
- Same antenna configuration for all the modulation schemes.
- Different modulation schemes that are QPSK, 16QAM, 64QAM
- PDSCH with 10MHz bandwidth
- BER for QPSK < 16QAM < 64QAM
- Less bit errors are in QPSK
- More bit errors are in 64QAM
- If the bit errors increases more bits will be lost.

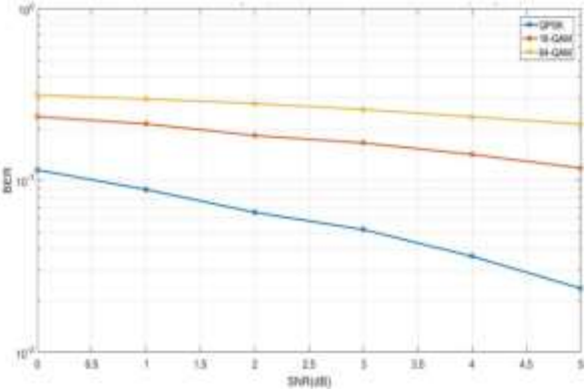
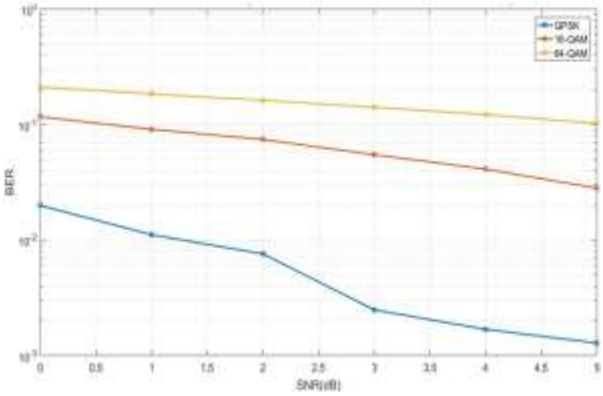


Figure 4. 1x1 Antenna Configuration for QPSK, 16QAM and 64-QAM Modulation

- Two receiving antennas

### B. *2x2 Antenna Configuration*

- Two transmitting antennas
- Different modulation schemes that are QPSK, 16QAM, 64QAM
- PDSCH with 10MHz bandwidth
- BER for QPSK < 16QAM < 64QAM
- Less bit errors are in QPSK
- More bit errors are in 64QAM
- Bit error in 16QAM are in between QPSK and 64QAM



### C. *4x4 Antenna Configuration*

- Two transmitting antennas
- Two receiving antennas
- Same antenna configuration for all the modulation schemes.
- Different modulation schemes that are QPSK, 16QAM, 64QAM
- PDSCH with 10MHz bandwidth
- BER for QPSK < 16QAM < 64QAM
- Less bit errors are in QPSK
- More bit errors are in 64QAM
- Bit error in 16QAM are in between QPSK and 64QAM

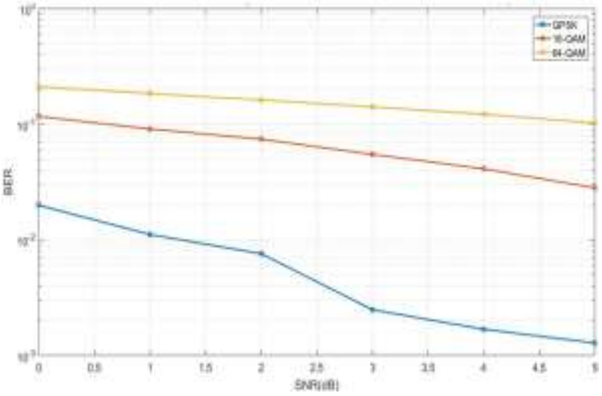


Figure 4. 1x1 Antenna Configuration for QPSK, 16QAM and 64-QAM Modulation

- Same antenna configuration for all the modulation schemes

The above figures show a decrease in BER for all the modulation schemes with increasing SNR. For all the antenna configurations the BER can be decreased by using QPSK modulation.

## CONCLUSION

The tests performed for UFMC MIMO and the limitations of existing OFDM system conclude that the integration of the new candidate waveform UFMC is possible for the existing 4th generation system and for future 5th generation systems. The MIMO systems implementation can enhance the system performance significantly and the future requirements of 5G can be achieved by combining the UFMC and MIMO together to get the desired modulation scheme and antenna configuration to make system more reliable and economical.

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