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Spectral Efficiency Improvement Techniques in OFDM and UFMC

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Abstract: This article describes about to analyse the spectral efficiency of different modulation techniques in OFDM and UFMC. UFMC is a multi-carrier modulation technique in fifth generation network (5G). In this paper, we review the different modulation techniques in 5G technology and motivate the need of UFMC technique in 5G wireless communication. In 4G OFDM modulation technique, some drawbacks like side band leakages, high Peak to Average Power ratio (PAPR) and spectrum utilization degrades the performance of the system. Another multi carrier technique called Filter Bank Multi carrier (FBMC) which is better than OFDM, have some issues in practical aspects. So by considering the above parameters a move to another technique called Universal Filtered Multi Carrier (UFMC) is used because of good spectrum usage. This paper also explains about the UFMC system model. Based on the Simulation results in MATLAB, the spectrum utilization of UFMC system is much better than OFDM system.
Keywords: UFMC, OFDM, 5G, IFFT, FFT, DAC, ADC and Spectrum efficiency.

I. INTRODUCTION

At present the main data transmission technology in wireless communication system is Orthogonal Frequency Division Multiplexing (OFDM). OFDM is used in LTE/LTE advanced (4G) and IEEE 802.11 (WI-FI) networks. OFDM is a modulation technique with strongly efficient in bandwidth usage. It is immune to multi path fading and Inter Symbol Interference (ISI). The recent advancements in Digital signal processing make the OFDM very popular. Above all advantages, OFDM is having some disadvantages like high Peak to Average Power Ratio (PAPR) and high Bit error rate (BER). The sensitivity of devices used in the OFDM transmitter side such as Digital- to-Analog Converter (DAC) The spectrum utilization of OFDM is not better when compare to other modulation techniques like UFMC. Spectrum efficiency plays a main role in rapid Mobile Broadband Networks (MBB). But in order to meet the higher requirements in 5G, this OFDM technology is not sufficient. So, the evolution of new technologies like Filter Bank Multi Carrier (FBMC) and Universal Filtered Multi Carrier (UFMC) are emerged. However, FBMC is not the right one because large filter length affects the symbol decoding time and having complex receiver structure in MIMO. Also FBMC is not suitable for burst transmissions or delay sensitive applications.

A. OFDM System

Orthogonal frequency division multiplexing (OFDM) is a frequency – division multiplexing (FDM) scheme used as a digital multi-carrier modulation method. In OFDM the entire bandwidth is divided into several sub carriers ,and these sub carriers are transmitted parallely. An OFDM system consists of a transmitter and a receiver

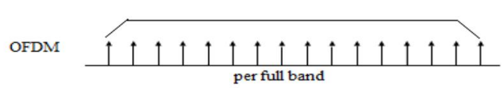

Fig.1. Filtering methods in OFDM

B. OFDM Bascis

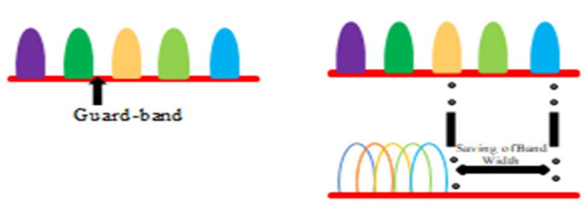

Fig.2. OFDM Basics

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In digital communications, information is expressed in the form of bits. The term symbol refers to a collection, in various sizes, of bits . OFDM data are generated by taking symbols in the spectral space using *M*-PSK, QAM, etc, and convert the spectra to time domain by taking the Inverse Discrete Fourier Transform (IDFT). Since Inverse Fast Fourier Transform (IFFT) is more cost effective to implement, it is usually used instead . Once the OFDM data are modulated to time signal, all carriers transmit in parallel to fully occupy the available frequency bandwidth

C. Orthogonality

Signals are orthogonal if they are mutually independent of each other. Two signals are said to be orthogonal when their dot product is equal to zero. Let's take a sine wave of frequency m and multiply it by sinusoid of a frequency n, where both m and n are integers. The integral or the area under the product is given by:

$$f(t)=\sin mwt\times \sin nwt$$

By simple trigonometric relationship,this is equal to a sum of two sinusoids of frequency (n-m) and (n+m) = 0.5(n-m) + 0.5(n+m).The baseband frequency of each subcarrier is chosen to be an integer multiple of the inverse of the symbol time, resulting in all subcarriers having an integer number of cycles per symbol. As a consequence the subcarriers are orthogonal to each other.

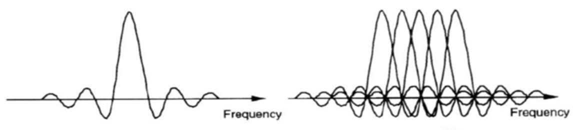

Figure 3 Overlapping of subcarriers in Frequency domain

D. OFDM Transmitter and Receiver

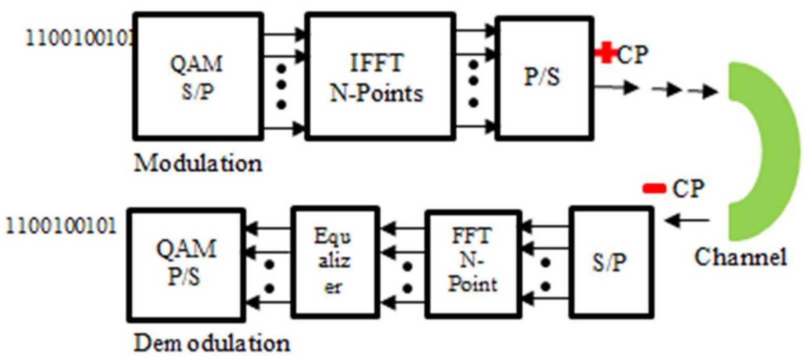

Fig 4. OFDM Transmitter and Receiver

OFDM transmitters generate both the carrier and the data signal simultaneously with purely digital circuits residing in the specialized DSP(Digital Signal Processor) microchips. The specific process of digital signal generation used in OFDM is based on the series of mathematical computations known as an Inverse Fourier Transform, and the process results in the formation of a complex modulated waveform at the output of the transmitter. The incoming serial data is first converted from serial to parallel and grouped into x bits each to form a complex number. The complex numbers are modulated in a base band fashion by the IFFT and converted back to serial data for transmission. A guard interval is inserted between symbols to avoid Inter Symbol Interference (ISI) caused by multipath distortion. The discrete symbols are converted to analog and lowpass filtered for RF up-conversion.

$$f(n) = \sum_{k=0}^{N-1} F(K) \exp\left(\frac{j2\pi kn}{N}\right)$$

The receiver performs the reverse operation of the transmitter, mixing the RF signal to base band for processing, then using a Fast Fourier Transform (FFT) to analyze the signal in the frequency domain. The amplitude and phase of the sub carriers is then picked out and converted back to digital data. The IFFT and the FFT are complementary function and the most appropriate term depends on whether the signal is being received or generated. In cases where the signal is independent of this distinction then the term FFT and IFFT is used.

$$F(K) = \sum_{k=0}^{N-1} f(n) \exp\left(\frac{-j2\pi kn}{N}\right)$$

II. UFMC SYSTEM

UFMC, a generalization of Filtered OFDM and FBMC multi-carrier modulation technique. Generally in filtered OFDM, entire band is filtered where as in FBMC individual sub carriers are filtered. But in UFMC group of sub carriers are filtered . This is the main difference in Filtered OFDM, FBMC and UFMC multi-carrier. Grouping of sub carriers helps in reducing the filter length in UFMC. IN UFMC, to retain the complex orthogonality, QAM is used which works with existing MIMO. The whole UFMC transmitter section is shown in figure 6. Here the full band of 'N' sub carriers are partitioned into several sub bands. Each sub band has a fixed number of sub carriers. In transmitter section no need of employing all sub bands for a transmission. To get rid of from the sub band carrier interfere, Inverse Fast Fourier Transform (IFFT) is used. At each N-point IFFT, sub bands are computed and zeros are allocated for unallocated carriers. IFFT converts frequency domain (Xi) to time domain (xi). After the N-point IFFT, the output can be written as

$$Yi = IFFT\ \{xi\} \qquad (1)$$

Now the time domain signals comes from the IFFT goes to Band filter of length 'L' block. Each sub band output is filtered by band filter of Length 'L' It is expressed as

$$y = H. \sim Q.\ yi \qquad (2)$$

Where H is called toeplitz matrix having dimensions (N+L-1) and '~Q' is called as Inverse Fourier matrix.

Actually band filters uses Chebyshev window/filtering operation. Here parameterized side lobes attenuation is used to filter the IFFT outputs. Now all the outputs from the band filters are summed at the end and passes through the channel.

From the channel the data bits are transmitted to UFMC receiver. UFMC receiver do's 2N-point Fast Fourier Transform (FFT). FFT converts the data of time domain to frequency domain. It is shown in the form of equation

$$\sim Y = FFT\ \{\ [yT, 0, 0, \ldots\ldots\ldots, 0]\ \} \qquad (3)$$

To prevent Inter Symbol Interference (ISI), guard intervals of zeros are added between successive IFFT symbols. ISI is due to transmitter filter delay.
To receive N length frequency domain signal 'Y', even sub carriers are discarded. Now the data goes for equalization process and the original data bits are retrieved by symbol demapping. It is shown in the UFMC receiver section figure 6

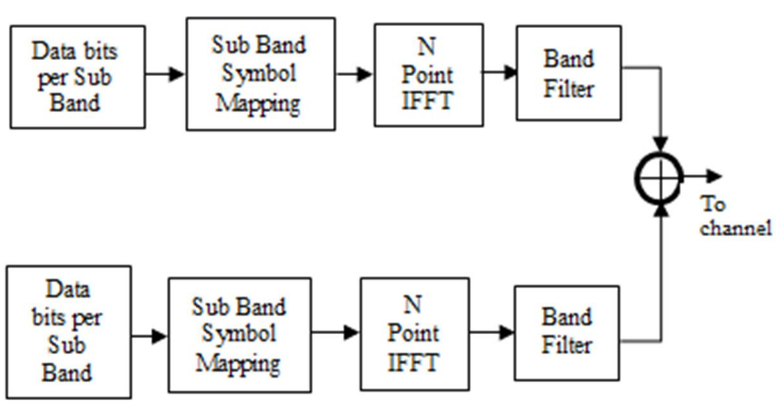

FIG 6 UFMC Transmitter

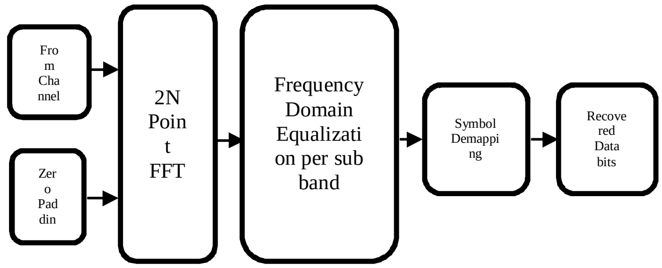

FIG 7 UFMC Recievr:

III. LITERATURE SURVEY

Wetjie Tan and Atal&2018 [1] proposed "Spectral efficiency of massive MIMO system with multiple sub array antenna" the advantages of this paper is It achieves spectral efficiency more effectively and disadvantages of this paper is Failed to support scalability

Jingon joung and Atal& 2014 [2] proposed "Spectral efficiency and energy efficiency of OFDM "the advantages of this paper is It achieves Energy efficiency , Spectral efficiency and dis advantage of the paper is It cannot be achieved for MIMO

Hyinso and Atal&2016 [3] proposed "Resource block management for uplink UFMC system " the advantages of this paper is It allocates the frequency to user efficiently and the disadvantages of the paper is Produces more side band leakage

Waleed Shahjehan and Atal & 2017 [4] proposed "Universal Filtered Multicarrier for 5G " the advantages of this paper is Bit error rate (BER) is low and dis advantages is Receiver complexity is more

In OFDM the entire bandwidth is divided into number of sub-carriers and these sub carriers are transmitted in parallel to increase symbol duration to achieve high data rates and to reduce ISI and it is shown in the figure 7. An OFDM signal is the sum of all sub carriers signal which are modulated at the sub channels with equal bandwidth.

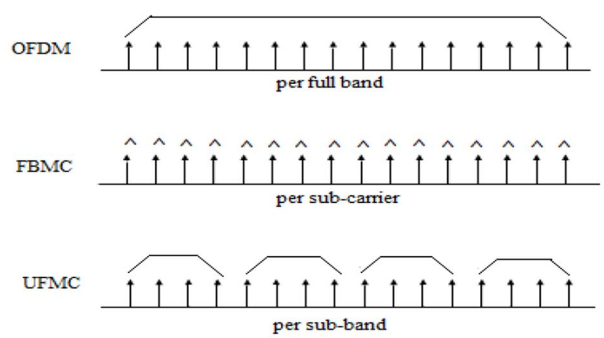

Fig.7. Filtering methods in OFDM, FBMC and UFMC techniques.

High PAPR value and high BER are the major disadvantages in OFDM. The sensitivity of devices used in the OFDM transmitter side like DAC and HPA are very harsh to the signal processing loop which affects the performance of the system The spectrum utilization of OFDM is not good in OFDM because many side lobes might pick up interfering signals, which in turn results in the increase of noise level at the receiver. Both OFDM and FBMC supports MIMO technology, but OFDM has some drawbacks [7]. In OFDM 'Cyclic Prefix' is must to avoid Inter Symbol Interference (ISI) and to convert the channel to a number of sub-carrier channels. But in FBMC, Cyclic Prefix is not used, but it has the capability to convert the channel to a set of sub-carrier channels and to remove ISI. Both OFDM and FBMC supports MIMO system. The primary reason of using OFDM in MIMO system is to remove interference and the main aim of FBMC is to overcome some of the shortcomings in OFDM. FBMC is the betterment of OFDM. So, FBMC is equals to the derivative of OFDM. Both plays a prominent role in the area of wireless communication modulation techniques. But by using filter banks it has possible to get our desired results than OFDM. In Massive MIMO FBMC concept, the complexity of the system and delay can be reduced by reducing the sub-carriers. In Massive MIMO FBMC system, Analysis can be done at Receiver side and Synthesis at Transceiver side. The sub-carriers spectral localization in OFDM are weak which might results in spectral leakages and also interference issues with unsynchronized signals.

A. Route Map

In section 1 introduction about ofdm and ufmc and section 2 literature survey and section 3 system model and section 4 improvement techniques for spectral efficiency and section 5 total spectral efficiency and section 6 simulation results and section 7 conclusion.

B. System Model

We consider a MU-MIMO system which consists of one BS and *K* active users. The BS is equipped with *M* antennas, while each user has a single-antenna. In general, each user can be equipped with multiple antennas. However, for simplicity of the analysis, we limit ourselves to systems with single-antenna users. See Figure 5.1.1. We assume that all *K* users share the same time-frequency resource. Furthermore, we assume that the BS and the users have perfect CSI. The channels are acquired at the BS and the users during the training phase. The specific training schemes depend on the system protocols (frequency-division duplex (FDD) or time-division duplex (TDD)). Let $H \in \mathbb{C}M \times K$ be the channel matrix between the *K* users and the BS antenna array, where the *k*th column of *H*, denoted by *hk*, represents the $M \times 1$ channel vector between the *k*th user and the BS. In general, the propagation channel is modeled via large-scale fading and small-scale fading. But in this chapter, we ignore large-scale fading, and further assume that the elements of *H* are i.i.d. Gaussian distributed with zero mean and unit variance.

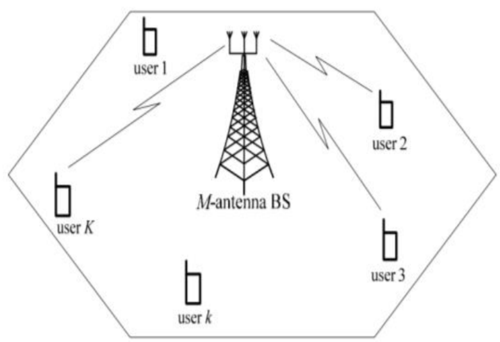

Fig 8 Multi user MIMO Here, *K* single-antenna users are served by the *M*-antenna BS in the same time-frequency resource.

C. Uplink Transmission

Uplink (or reverse link) transmission is the scenario where the *K* users transmit signals to the BS. Let *sk*, where E {|*sk*|2} = 1, be the signal transmitted from the *k*th user. Since *K* users share the same time-frequency resource, the $M \times 1$ received signal vector at the BS is the combination of all signals transmitted from all *K* users:

$$y_{ul} = \sqrt{p_u} \sum_{k=1}^{K} h_u s_k + \text{n} \qquad (3.2)$$

$$= \sqrt{p_u} + H_s + \text{n} \qquad (3.3)$$

where *p*u is the average signal-to-noise ratio (SNR), $n \epsilon \mathbb{C}M \times 1$ is the additive noise vector, and $s = [s1 \ldots sK]T$. We assume that the elements of *n* are i.i.d. Gaussian random variables (RVs) with zero mean and unit variance, and independent of *H*.

From the received signal vector *y*ul together with knowledge of the CSI, the BS will coherently detect the signals transmitted from the *K* users. The channel model is the multiple-access channel which has the sum-capacity [16]

$$c_{ul,sum} = \log 2 \; det(I_k + p_u H^H H). \quad (3.4)$$

The aforementioned sum-capacity can be achieved by using the successive interference cancellation (SIC) technique. With SIC, after one user is detected, its

signal is subtracted from the received signal before the next user is detected

D. Downlink Transmission

Downlink (or forward link) is the scenario where the BS transmits signals to all *K* users. Let $x \in \mathbb{C}M \times 1$, where E {||*x*||2} = 1, be the signal vector transmitted from the BS antenna array. Then, the received signal at the *k*th user is given by

$$y_{dl,k} = \sqrt{p_u} h_k^T + s_k \qquad (3.5)$$

where *pd* is the average SNR and *zk* is the additive noise at the *k*th user. We assume that *zk* is Gaussian distributed with zero mean and unit variance. Collectively, the received signal vector of the *K* users can be written as

$$y_{dl} = \sqrt{p_u}\, H^T x + z, \quad (3.6)$$

where ydl = [ydl,1 *y*dl,2 . . . *y*dl,*K*]*T* and *z* = [*z*1 *z*2 . . . *zK*]*T* .The channel model is the broadcast channel whose sum-capacity is known to be

$$c_{sum} = max_{qk} \log 2 \; det(I_M + p_d H^* D_q H^T) \quad (3.7)$$

Dq is the diagonal matrix whose *k*th diagonal element is *qk*. The sum-capacity can be achieved by using the dirty-paper coding (DPC).

IV. IMPROVEMENTS TECHNIQUES FOR SPECTRAL EFFICIENCY

A. Maximum-Ratio Combining Receiver

With MRC, the BS aims to maximize the received signal-to-noise ratio (SNR) of each stream, ignoring the effect of multiuser interference. The *k*th column of the MRC receiver matrix *A* is:

$$a_{mrc,k} = arg\ max_{ak\in C} \frac{power(desried\ signal)}{power(noise)}$$

and equality holds when ***a**k* = const · ***h**k*, the MRC receiver is: ***a**mrc,k* = const · ***h**k*. Plugging *a*mrc,*k* into , the received SINR of the *k*th stream for MRC is given by

$$SINR_{mrc,k} = \frac{p_u \|hk\|^4}{p_u \sum_{K\prime\neq K}^{k} |h_K^H H_{K\prime}|^2 + \|H_K\|^2}$$

B. Zero-Forcing Receiver

By contrast to MRC, zero-forcing (ZF) receivers take the Interuser Interference into account, but neglect the effect of noise. With ZF, the multiuser interference is completely nulled out by projecting each stream onto the orthogonal complement of the interuser interference. More precisely, the *k*th column of the ZF receiver matrix satisfies:

$$\begin{cases} a_{zf,k}^H h_k \neq 0 \\ a_{zf,k}^H h_{k'} = 0, & \forall k' \neq k \end{cases}$$

The ZF receiver matrix, which satisfies for all *k*, is the pseudo-inverse of the channel matrix *H.* With ZF, we have $Y_{UL}^{\wedge}=(H_H H)-1H_{HYul}$=√puS+$(H_H H)-1H_H$n.

This scheme requires that *M* ≥ *K* (so that the matrix ***HHH*** is invertible). We can see that each stream (element) of ***y***˜ul is free of multiuser interference. The *kth* stream of ***y***˜ul is used to detect *sk*:

$$Y_{ul,k}^{\wedge}=\sqrt{pu}Sk+n^{\wedge}k,$$

where n˜*k* denotes the *k*th element of (***HHH***)-1 ***HHn***. Thus, the received SINR of the *k*th stream is given by

$$SINR_{zf,k} = \frac{p_u}{[(H^H H)^{-1}]_{kk}}$$

C. Minimum Mean-Square Error Receiver

The linear minimum mean-square error (MMSE) receiver aims to minimize the mean-square error between the estimate ***AH y***ul and the transmitted signal ***s. More precisely,***

$$A_{mmse} = \underset{A\in C^{M\times K}}{argmin}\, E\{\| A^H y_{ul} - s \|^2\}$$

$$= \underset{A\in C^{M\times K}}{argmin} \sum_{k=1}^{K} E\{|a_k^H y_{ul} - s_k|^2\}$$

where *ak* is the *k*th column of *A*. Therefore, the *k*th column of the MMSE receiver matrix is [47].

$$a_{mmse,k} = \underset{a_k \in C^{M\times 1}}{argmin} \quad E\{|a_k^H y_{ul} - s_k|^2\}$$

$$= \mathrm{cov}(y_{u1}, y_{u1})^{-1}\,\mathrm{cov}(s_k, y_{u1})^H$$

$$= \sqrt{p_u}(p_u HH^H + I_M)^{-1} h_k,$$

where cov(v1,v2) =E {v1$v$$H$2 } , where v1 and v2 are two random column vectors with zero-mean elements. It is known that the MMSE receiver maximizes the received SINR. Therefore, among the MMSE, ZF, and MRC receivers, MMSE is the best. At high SNR (high pu), ZF approaches MMSE, while at low SNR, MRC performs as well as MMSE. Furthermore, the received SINR for the MMSE receiver is given by

$$SINR_{mmse,k} = p_u h_k^H (p_u \textstyle\sum_{i\neq k}^{K} h_i h_i^H + I_M)^{-1} h_k$$

V. SIMULATION RESULTS

By comparing snr and ber parameters in ofdm the snr is increasing while the ber is decreasing . i.e the snr is inversely proportional to ber.

SNR vs BER analysis of OFDM for M-ary PSK

SNR(dB)	BER			
	BPSK	QPSK	8PSK	16PSK
0	0.4	0.2	0.32	0.39
2	0.32	0.15	0.29	0.37
4	0.3	0.08	0.23	0.3
6	0.28	0.033	0.17	0.29
8	0.24	0.009	0.1	0.23
10	0.18	0.0015	0.05	0.19
12	0.13	0	0.018	0.04
14	0.075	0	0.0042	0.075
16	0.04	0	0.0004	0.0019

SNR vs BER analysis of OFDM for M-ary QAM

SNR(dB)	BER		
	8QAM	16QAM	32QAM
0	0.16	0.25	0.3
2	0.1	0.2	0.24
4	0.06	0.15	0.19
6	0.022	0.1	0.15
8	0.006	0.06	0.1
10	0.0007	0.03	0.06
12	0	0.008	0.03
14	0	0.0016	0.009
16	0	0	0.001

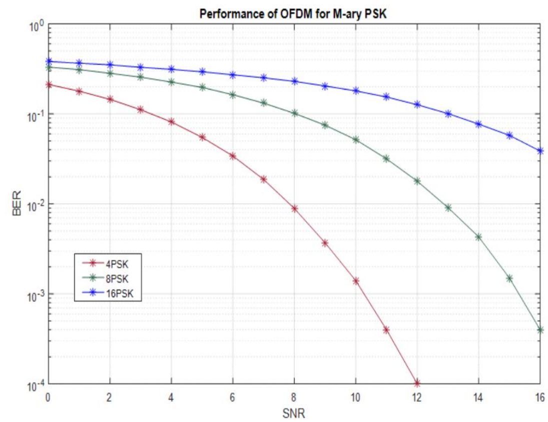

Fig 10 performance analysis of ofdm in M-ary psk By comparing snr and ber paramnets in ufmc the snr is increasing and ber is decreasing .

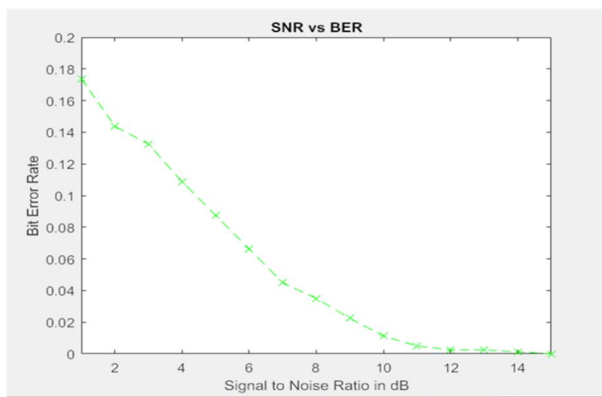

Fig 11 snr vs ber In ufmc

Based on simulation results. We can know that the capacity will increase as the transmitted power increases. We will analyze the relationship between capacity and the number of antennas which is shown in figure 5.2.1.The simulation is done with SNR equal to 5dB, while channel is assumed as Rayleigh fading and both transmit side and receive side have perfect channel state information.

The spectral efficiency of all of these three precoding schemes increases as the number of transmitted antennas increases. P-ZF has the best performance, while ZF is not far behind. In particular, when the number of transmitted antennas goes to infinite, performance of ZF approaches to that of MMSE.

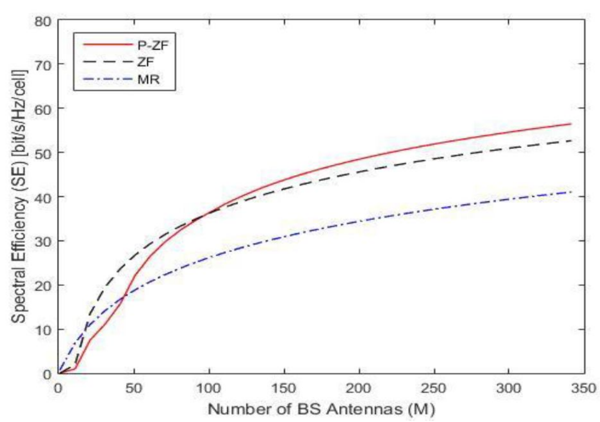

Fig 11 spectral efficiency vs number of antennas

The capacity of MRC is relatively lower than others. Moreover, when the number of antennas is smaller than 250, the slopes of these three curves are relatively large. However, the spectral efficiency increases slightly when the number is larger than 250. From this figure 7.2.1, we can see that the spectral efficiency cannot increase infinitely with the limitation of power consumption. A large amount of antennas contributes to high power consumption as well as cost for hardware devices. When the number of antennas goes infinity, the interference among users will dominant the system performance. Under this condition, the more users in cells, the stronger inter-cell inference will produce. The system cannot linear increase as the number of antennas increases. These two simulation figures illustrate how the capacity is influenced by transmitted power and number of antennas.

VI. CONCLUSION

We have investigated the performance of OFDM system and MATLAB Simulation was employed to investigate performance trends. Thus, Orthogonal Frequency Division Multiplexing is a form of multi-carrier modulation technique with high spectral efficiency, robustness to channel fading, immunity to impulse interference, uniform average spectral density, less non linear distortion and we obtain a better quality signal at the receiver.

The system performance of wireless communication system has been improved significantly in terms of capacity, latency, Reliability. We firstly analyzed the history of wireless communication system. Introduced the importance of MIMO and massive MIMO , system model and problem formulation. By combining results of Massive MIMO, we present that massive MIMO remarkably improves the spectral efficiency and energy efficiency. We mainly focused on spectral efficiency for various BS antenna configurations in MIMO and massive MIMO systems. There are still some aspects that should be done in the future.

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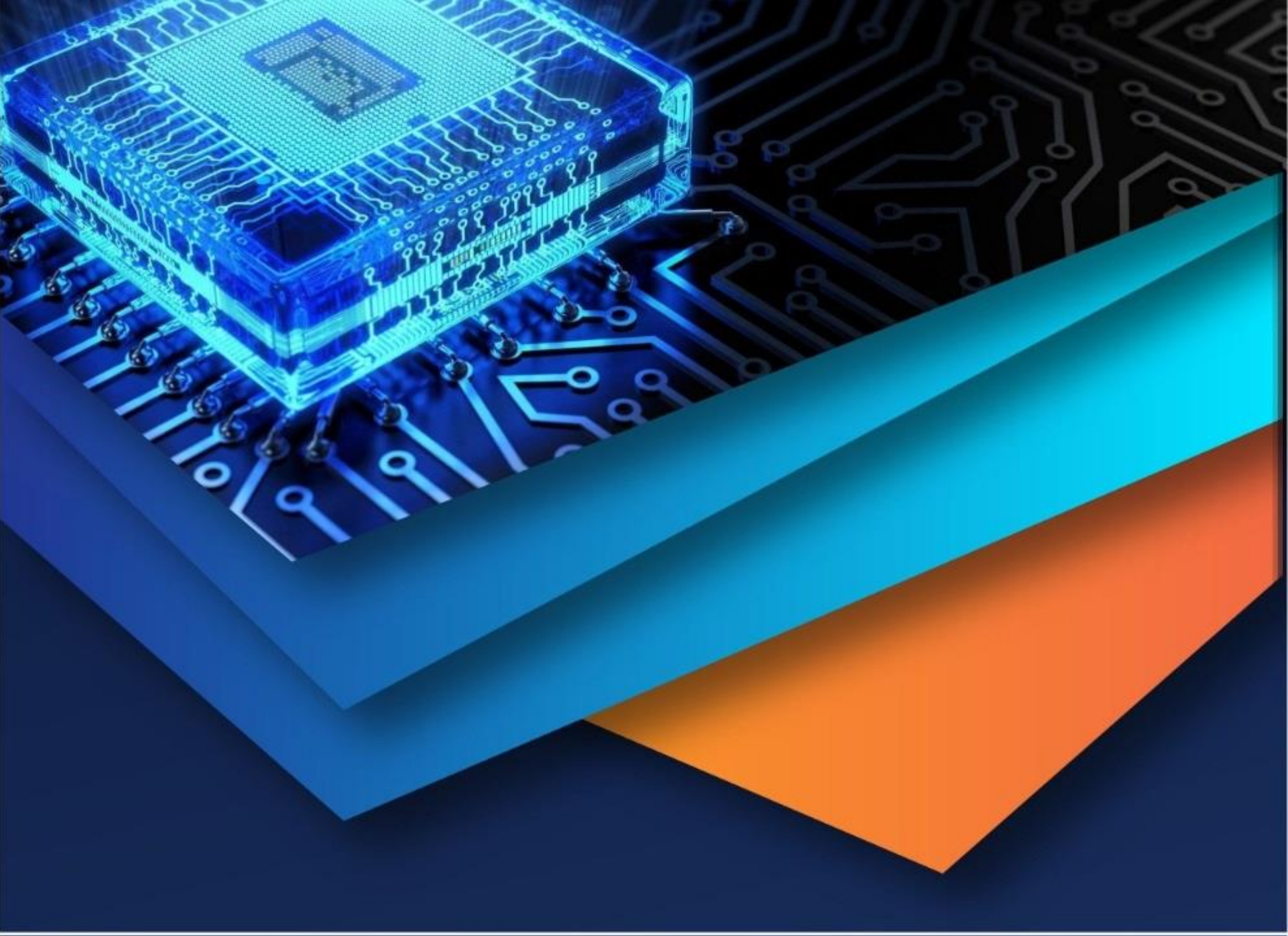

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