# VECTOR OFDM ANTENNA DESIGN FOR 5G COMMUNICATION APPLICATIONS WITH IMPRESSED PSNR

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**Abstract-** The introduction of 5G mainly deals with the design of best wireless environment which is free from restrictions and obstacles of prior technologies. It provides reduced battery consumption with increased system level spectrum efficiency. The fast development in 5G results in the demand of antenna design possessing improved properties with increased data rate. This lead to various designs for achieving an antenna design with high data rate and minimized errors. In this paper, a VOFDM antenna is designed with improved values of average PSNR for 5G technology. It provides advanced processing of signals generating enhanced energy efficiency with the mitigation of cyclic prefix data rate overhead. The threshold value along with the signal peak and transmit power of VOFDM are estimated. The simulation results are compared with other conventional OFDM systems in terms of bit error rate and the proposed antenna design exhibited improved results.
**Keywords:** 5G, OFDM, VOFGM, PSNR, CCDF.

## 1 INTRODUCTION

The continuous growth in data usage, wireless user devices and the demand for improved quality influences the evolution of cellular network generation. The increase in device, data and its transfer rate paves the way for 5G networks [1-3]. 5G technology is expected to tackle the issues in communication and also addresses the performance parameters like speed, reliability, latency, spectral efficiency, power consumption and capacity density [4, 5]. 5G is considered to be the major developmental concept leading to a step variation in the ability of mobile networks specifically in higher frequency utilization, radio access technology, minimal latency, improved reliability and antenna improvements [6, 7]. The 5G infrastructure base station utilizes the spectrum which is flexibly allocated as well as implements antennas for various devices on the basis of time division focusing radiation [8, 9]. In 5G, frequency around 50 GHz is taken into account and this offers specific challenges. The 5G antenna is smaller providing increased gain with low directivity and broad radiation pattern when compared to previous technologies [10, 11].

The design of antennas for fulfilling the need of high speed networks is an important task. In 5G systems, antennas demand wideband range aiding in device miniaturization [12].Various wave bands from 10 GHz to 100 GHz are utilized at present by the 5G communication networks. Due to the presence of various propagation attributes in the wave bands, designing and implementing antenna array as well as the incorporation with active wave circuits are regarded as crucial factors. They are designed to achieve appropriate power gain as well as spatial resolution for communication with increased throughput [13]. Various antennas are designed with the aim of providing the requirements of 5G technology.

In [14], a multi-layered cavity backed antenna array with eight elements is proposed and achieved minimized transmission line losses. Due to the presence of multiple layers, the structure is complicated. In addition, the antenna generated reduced impedance bandwidth with larger antenna size. [15] designed another antenna utilizing four elemnt array with the bandwidth of 22% and 16.67% for 45 GHz and 28 GHz respectively. This antenna design exploited a combination of parallel and series feed mechanism for exciting the needed modes resulting in complex structure. Antennas in [16, 17] generated bandwidths of 7 GHz and 10.2 GHz respectively. They are small sized antennas with high gain but are not applicable for long distance communications. [18] reported an array antenna design which operates at 28 GHz. It utilized series type feeding mechanism thereby minimizing the count of needed controllers but provides a narrow bandwidth. Antenna designed in [19] is a multi layered structure with a gain of 15 dBi. It exploits the structure of meta-material lens yet has complex four layers. Certain multiple antenna array designs are presented in [20-22] which utilized open end slots supporting specific frequency bands.

The need for supporting updated services focused by 5G resulted in the adoption of orthogonal frequency division multiplexing (OFDM) by researchers [23]. Generally, it is known that the OFDM waveforms are applicable for communication offering increased flexibility in the radio resource management and radio system design. Furthermore, the utilization of OFDM dependent waveforms for radar as well as sensing purposes is receiving greater interest [24-26]. Vector OFDM (VOFDM) is a generalized form of OFDM that utilizes vector values instead of scalar values. This paper proposes a VOFDM antenna design for 5G communication. The proposed system offers improved bit error rate and reduces cyclic prefix data rate overhead. The improved average PSNR values of the proposed system are also obtained.

The arrangement of paper is: Section 2 elucidates the related works. Proposed framework is described in section 3. Results and discussion are explained in section 4. Finally, work summary is mentioned in section 5.

## 2 RELATED WORKS

Qing-Xin et al [27] presented a dipole array antenna for the enhancement of gain in 5G communication. It utilized a bow tie along with parasitic patches for enhancing the antenna gain with the expansion of transverse radiation aperture. The gain of the designed antenna was increased when compared to other single side directors. The antenna was fed by the substrate integrated waveguide.

Libin et al [28] introduced an antenna system of orthogonal mode composing of two tightly placed antenna pairs. This pair was arranged in a face-to-face way in the back and front portion of the substrate. With the aid of orthogonal mode, these antennas had improved diversity performance and isolation. Fabrication as well as measurement of the prototype was carried out.

Anping et al [29] introduced a traditional loop antenna for 5G applications. The antenna was divided and a coupled-loop antenna was developed forming three coupling parts. In addition to the first and second resonance modes, a new resonance mode was excited within the first as well as second mode. The combination of these three modes generated a wide operating band covering the complete frequency range.

Muhammad et al [30] introduced a circular microstrip patch antenna of dual band. The antenna possessed resonating frequencies of 45 GHz as well as 28 GHz with bandwidths 1 GHz and 1.3 GHz respectively. It was compact in size and generated a radiation efficiency of 98.75% along with a maximal gain of 13.5 dB. The major objective of this design was to tackle the issues of reduced performance as well as design complexity.

## 3 PROPOSED METHODOLOGY

5G is a significant concept for assisting today's real world applications like education, transportation, economic growth, power grid, employment and industry. It interconnects every digital and electronic appliances and enables remote control of these appliances. It offers increased resolution as well as bidirectional bandwidths of large range for making advance billing interface more effective as well as attractive with specific allotment of various paths for transferring data.

### 3.1 Architecture of 5G

Generally, most of the wireless users remain indoor during maximum time and remain in outdoor for minimal time. At present, in the 5G architecture, the base station is in the middle of the cell and communicates with the users whether they remain in outdoor or indoor. Considering the indoor users communicating with the base station at outside, the signals pass across building walls which leads to increased penetration loss resulting in data rate damage, spectral efficiency as well as energy efficiency related to wireless transmissions. The architecture of 5G concept is given in figure 1.

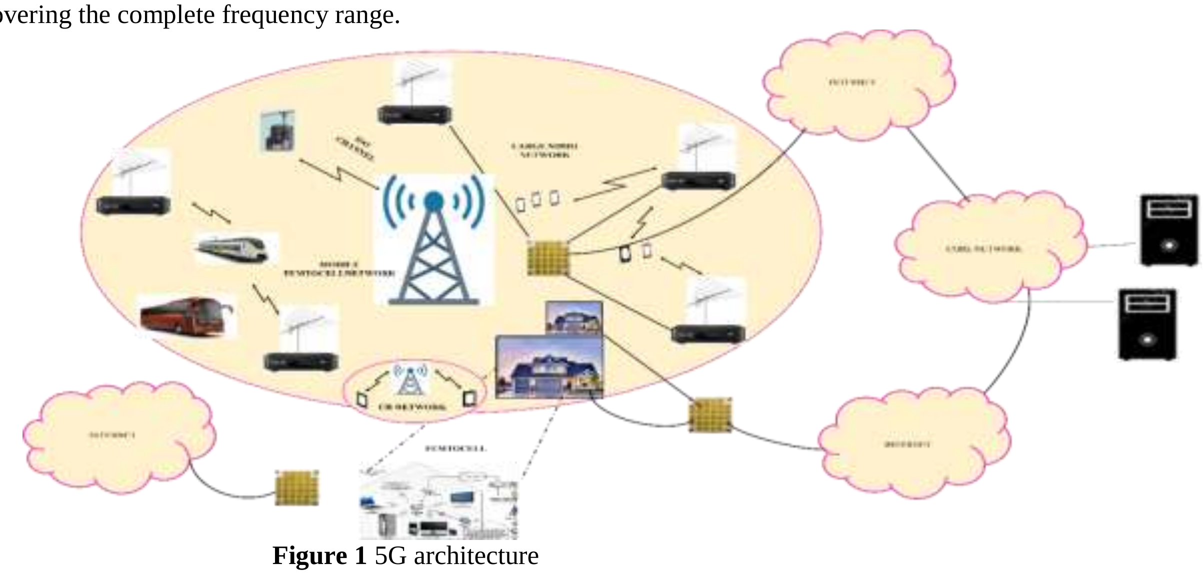

**Figure 1** 5G architecture

It potentially exploits large capacity gains leading to higher array of antennas. The base station at outdoor is equipped with increased antenna arrays along with specific antenna elements dispersed around the cells. The users at outdoor are generally equipped with restricted number of antenna elements and collaborate with one another forming a virtually large antenna array.

### 3.2 Challenges in 5G Concept

The 5G technology is subjected to various challenges which are represented in figure 2.


**Figure 2** Challenges in 5G

The most important challenge regarding 5G technology is the scarcity of radio frequency spectrum allotted for communication. The communication frequency utilize ultra high frequency band ranging from megahertz to gigahertz. This frequency spectrum is utilized heavily resulting in difficult acquisition. Increased energy consumption is yet another challenge in advanced wireless concepts. The increased consumption of energy in wireless communication system leads to increased carbon emission. In addition, the consumption of energy by the base station accounts to 70% of the electricity bill. Added to this, increased data rate and mobility, average spectral efficiency, diverse quality of service neccesities, experience of users are regarded as major challenges.

### 3.3 System Model of VOFDM

The VOFDM is the generalization of OFDM and is initially proposed for single transmit antenna designs. It collects multipath diversity and combats spectrum nulls in the channels. Similar to OFDM systems, the processing of data blocks is carried out in blocks of VOFDM system given in figure 3.

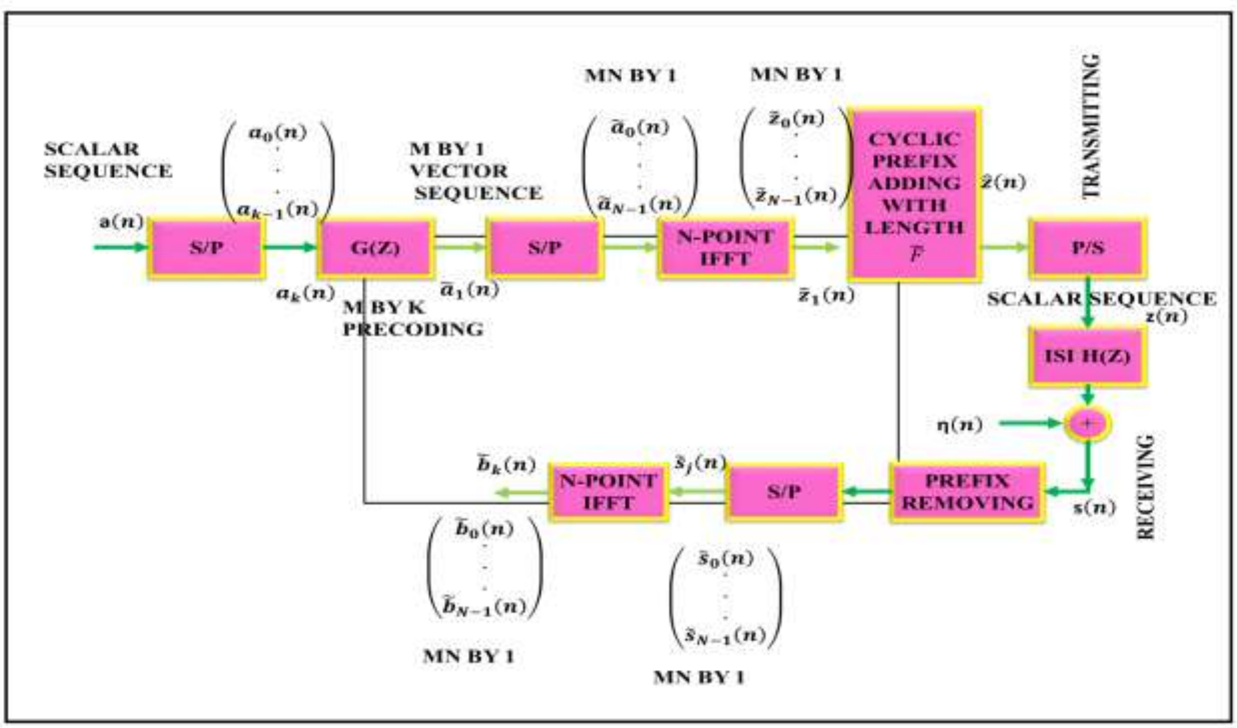


**Figure 3** Vector OFDM system

Every OFDM block carries $N$ symbols $\{A_0, A_1, \ldots . A_{N-1}\}$ in which $N = FM$ where $F$ indicates vector FFT size as well as $M$ indicates vector size. Initially, the $N$ symbols are blocked as $F$ vectors with each vector length $M$.

$$A_f = \left[\bar{A}_0^f, \bar{A}_1^f, \ldots\ldots, \bar{A}_{M-1}^f\right]^T \quad (1)$$

$$= \left[A_{fM}, A_{fM+1}, \ldots\ldots, A_{(f+1)M-1}\right]^T \quad (2)$$

Where, $f = 0,1, \ldots\ldots, F-1$.

Taking inverse FFT of these vectors, we get

$$a_p = \left[\bar{a}_0^p, \bar{a}_1^p, \ldots\ldots, \bar{a}_{M-1}^p\right]^T \quad (3)$$

$$= \frac{1}{F}\sum_{f=0}^{F-1} A_f \, exp\left(\frac{j2\pi pf}{F}\right) \quad (4)$$

$$= \left[z_{pM}, z_{pM+1}, \ldots\ldots, z_{(p+1)M-1}\right]^T, p = 0,1, \ldots\ldots, F-1 \quad (5)$$

The vectors $\{a_{F-Q}, a_{F-Q+1}, \ldots., a_{F-1}, a_0, a_1, \ldots\ldots, a_{F-1}\}$ are transmitted in a serial manner across the channel in the order of symbol as in (6) after the insertion of cyclic-prefix vectors.

$$z_{N-QM}, z_{N-QM+1}, \ldots\ldots, z_{N-1}, z_0, z_1, \ldots\ldots, z_{N-1} \quad (6)$$

Assume that the time invariant channel impulse response is of finite length $L+1$. If $L \leq QM$, the $N$ symbols are modeled as,

$$s_n = \sum_{k=0}^{L} h_k \, z_{(n-k)(N)} + \omega_n, n = 0,1, \ldots., N-1 \quad (7)$$

Here, the average energy of $z_n$ is 1 and $\{h_k : k = 0,1, \ldots\ldots, L\}$ denotes the estimate of channel impulse response for the processed OFDM block. $n_{(N)}$ indicates n mod N as well as $\omega_n$ represents the bias obtained due to the approximation of time variant channel impulse response with time invariant estimate and the complex additive white Gaussian noise. The original data symbols are extracted by an inverse operation. Initially, $\{s_0, s_1, \ldots\ldots, s_{N-1}\}$ are blocked as $M \times 1$ vectors.

$$b_p = \left[\bar{s}_0^p, s_1^p, \ldots\ldots, \bar{s}_{M-1}^p\right]^T \quad (8)$$

$$= \left[s_{pM}, s_{pM+1}, \ldots\ldots, s_{(p+1)M-1}\right]^T, p = 0,1, \ldots\ldots, F-1 \quad (9)$$

Taking FFT of $F$ vectors, the output vectors are obtained as,

$$B_f = \left[\bar{Y}_0^f, \bar{Y}_1^f, \ldots\ldots, \bar{Y}_{M-1}^f\right]^T \quad (10)$$

$$= \sum_{p=0}^{F-1} b_p \, exp\left(-\frac{j2\pi pf}{F}\right), f = 0,1, \ldots., F-1 \quad (11)$$

If $a(z)$ and $b(z)$ represent the z-transforms of the input as well as output vectors, then $b(z) = H(z)a(z)$. If $\tilde{F} = \lceil F/M \rceil$ is the order of $H(z)$in which $\lceil \omega \rceil$ considers the smallest integer greater than or equal to $\omega$.

**3.4 Estimation of Threshold in VOFDM**

In VOFDM system, the optimized threshold value is determined by the peak value. The peak values at the transmitter are measured and the values are send to the clipper. On the accurate reception of peak values, clipping is carried out without considering the receiver's impulsive noise properties. Utilizing $n$ symbols as well as $N$ subcarriers to be reshaped as $N = M \times F$, the information bits are generated, mapped as well as blocked. The VOFDM symbol $\{a^{(k)}\}$ is generated and the corresponding peak value $\max(k)$ is estimated. Hence, $\{a^{(k)}\}$ is transmitted across the channel in which it undergoes contamination with noise vector $\{n^{(k)}\}$ for producing received signal $\{s^{(k)}\}$. Here, $\{a^{(k)}\}, \{n^{(k)}\}$ and $\{s^{(k)}\}$ are vectors in which $k = 0,1,2, \ldots\ldots, n$.

The $\max(k)$ is sent as a part of control messages to the receiver. In the receiver, the $\max(k)$ value is extracted by the peak estimator and varies the threshold in a dynamic manner. The minimized symbol peak in VOFDM is exploited for simplifying the impulsive noise detection as well as cancellation at receiver.

**3.5 Signal Peak and Transmit Power in VOFDM**

The overall power consumed indicates the combination of both the static as well as dynamic power.

$$P_{tot} = P_0 + P(t) \quad (12)$$

Where, $t$: transmitted traffic load

$P_0$: consumed power in idle state

$P(t)$: increasing function of load

The traditional OFDM systems exhibit the total power representing the sum of power consumed by circuit blocks as well as the linear power amplifier. Practically, the energy efficiency of the power amplifier is low in wireless systems. Moreover, the energy efficiency relies on factors like hardware elements, operating frequency, consumption of power and load characteristics. The energy efficiency is defined as,

$$\eta_E = \frac{P_0}{P_{dc}} \quad (13)$$

Here, $P_0$ : average output power

$P_{dc}$: power consumed by amplifier

VOFDM utilizes minimal IFFT size when compared to traditional OFDM. The complimentary cumulative distribution function (CCDF) is applied for the accurate determination of VOFDM peak symbol. The CCDF is regarded as the probability of the value at which the peak of VOFDM symbol exceeds a particular value $Max_0$ and is given as,

$$CCDF = 1 - P_s\{Max \leq Max_0\} = P_s\{Max > Max_0\} \quad (14)$$

The approximate estimation of values denotes the average system performance.

### 3.6 PSNR for VOFDM

The average value of PSNR is maximized with the minimization of the product of distortion in the users' signals and is given by,

$$Average\ PSNR = min_P \prod_{k=1}^{K} MSE_k \qquad (15)$$

In which, $P$ indicates the power assignment matrix where $(k, n)$ entry represented as $P_{k,n}$ is the power allotted for the user $k$ in the subcarrier $n$. Optimization of average PSNR value exploits the following restrictions.

i) $\sum_{n=1}^{N} P_{k,n} = P$ for all $k$ and

ii)$n \in \{1,2, \dots, N\}, S_n = \{k' | P_{k,'n} \neq 0\}$,$\|S_n\| =$ 1 or 2, in which $\|S_n\|$ indicates cardinality of the set $S_n$. Consider the following factors,

i) Let $P_k^{(i)}$ represent the set of subcarriers allotted for the user $k$ during $i$-th iteration.

ii) Let $\rho_n^{(i)}$ and $\rho_n^{(i)\prime}$ represent the users assigned for subcarrier $n$ during $i$-th iteration.

iii) Let $\Omega$ represent the users for improving average PSNR with the gain of subcarrier.

Consider $\Omega = \{1,2, \dots . K\}$ and then,

$$\rho_n^{(0)}, \rho_n^{(0)\prime} = argmin_{(k,l)\in\Omega, k\neq l}\{z_{k,l,n} + z_{l,k,n}\} \qquad (16)$$

The allocation of power of user $k$ is denoted by,

$$P_{k,n}^* = \left[\frac{1}{\lambda_k} - \frac{1}{\eta |H_{k,n}|^2 / z_{k,n}}\right]^+, \forall n \in A_k^i \qquad (17)$$

$P_{k,n}$ is zero when the subcarrier $n$ is assigned to $k$ and this occurs when SNR is low.

## 4 RESULTS AND DISCUSSION

Numerical results for certain theoretical as well as simulation plots of bit error rate (BER) versus $E_b/N_0$ for conventional OFDM systems and VOFDM system are presented. The vector size considered for VOFDM is $K = M = 2$.

The number of channels allotted is 256 and the plots for bit error rate versus $E_b/N_0$ for channel A, B as well as C are represented in figures 4,5 and 6. The bit error rates of BPSK uncoded OFDM, BPSK precoded OFDM, QPSK precoded OFDM and VOFDM are compared.

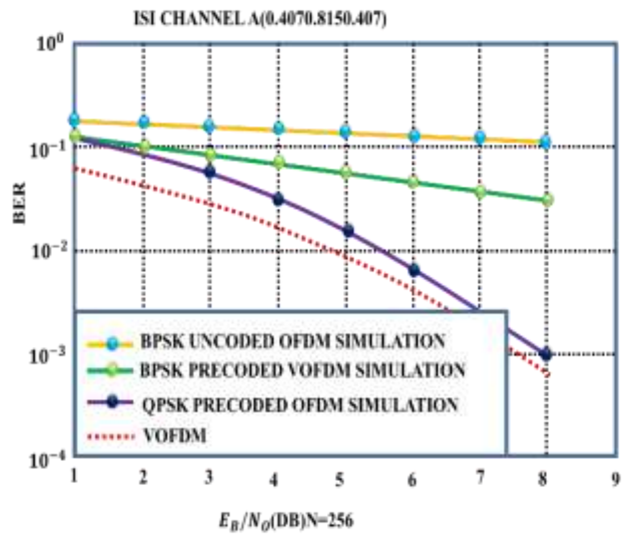


**Figure 4** BER of channel A

Figure 4 indicates the plot of BER Vs $E_b/N_0$ for the proposed VOFDM with other conventional OFDM systems related to channel A. The rate considered for precoded OFDM system is ½ and the vector size is given by $M = 2$ and $K = 1$. The proposed system saves the data rate overhead by half when compared to other traditional systems.

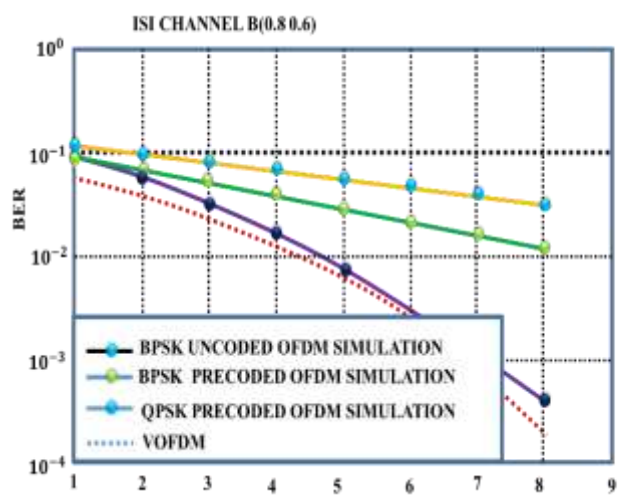


**Figure 5** BER of channel B

Figure 5 indicates the plot of BER Vs $E_b/N_0$ for the proposed VOFDM with other conventional OFDM systems related to channel B. The plot clearly indicates that the performance for channel B is much better than that of channel A.

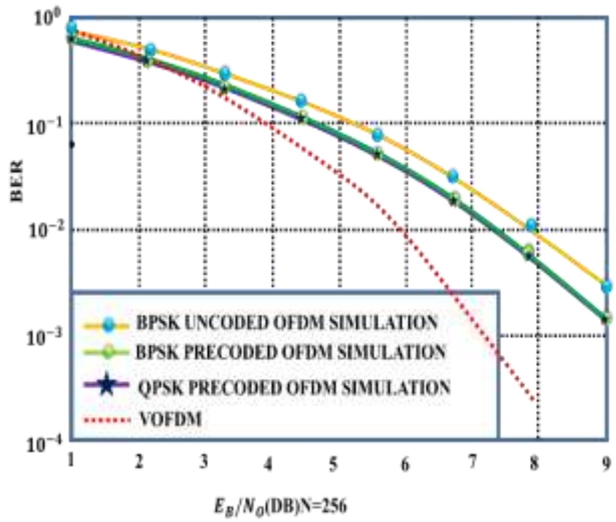


**Figure 6** BER of channel C

Figure 6 represents the plot of BER Vs $E_b/N_0$ for the proposed VOFDM with other conventional OFDM systems related to channel C. In addition the cyclic prefix length is reduced to half by the proposed VOFDM.

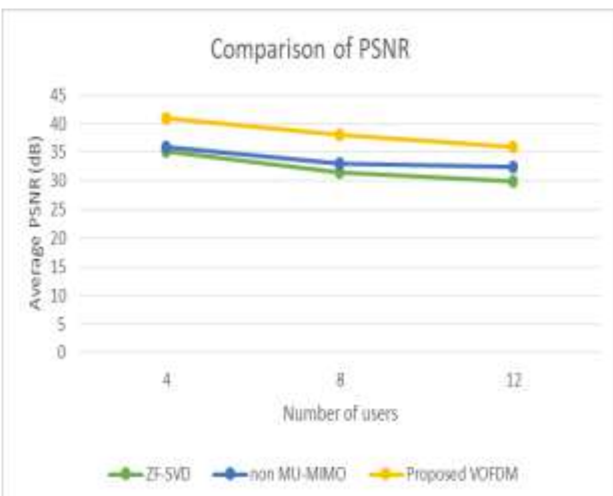


**Figure 7** Comparison of PSNR

Figure 7 indicates the comparison of PSNR values of the proposed VOFDM with ZF-SVD and non MU-MIMO systems. The value of SNR considered is 15 dB and the proposed system exhibits improved values of average PSNR. With the increase in number of users, the mean square error value increases and hence the average PSNR value decreases.

## 5 CONCLUSION

5G technology is a burgeoning technology which offers improved data rate with reduced latency period. This paper presents a VOFDM antenna system with improved value of average PSNR for 5G applications. The system provides variable size of inverse FFT and hence tackles the complexity with energy efficiency. When compared with conventional systems, the proposed system offers reduced cyclic prefix data rate overhead. Comparison of the proposed system with other OFDM systems in terms of bit error rate is performed which in turn revealed efficient results.

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