# Concepts and Brief Survey of Conventional and Wavelet OFDM: Review

N.A. Galande, A.M. Shah.

*Abstract*— **Orthogonal Frequency Division Multiplexing uses multiple carriers to transmit data. Generally, in other communication system if we use single carrier to transmit data then frequency selective channel introduces ISI at the receiver. So in Conventional OFDM cyclic prefix is added and that cyclic prefix uses nearly 20% to 25% of total bandwidth. In the other side in wavelet OFDM cyclic prefix is not required so total bandwidth is used in wavelet OFDM. Because of using total bandwidth, wavelet increases spectral efficiency and gives good orthogonality, because of it BER performance of wavelet OFDM can be improve.**

*Index Terms*— **OFDM, IFFT, FFT, BER, Wavelet Transform, Cyclic prefix**

## I. Introduction

Day by day demand for fast data rate is increasing and it is possible because of development in technology. In single carrier communication all channels are frequency selective, so at the receiver end equalizer should be used. But that equlizatation may amplify noise greatly in frequency where channel response is poor. As a result single carrier performance is affected due to high attenuation in some bands since all used frequency has given equal importance. In OFDM multicarrier are used, because of it there is no need of signal enhancement at receiver. Power and rate depends on the response of that particular channel.

In OFDM all subcarriers are modulated by using different convolutional techniques i.e. phase shift keying, quadrature phase shift keying and quadrature amplitude modulation. BPSK, QPSK used for low rate and for higher data rate higher modulation techniques are used i.e. M-PSK, M-QAM. OFDM can be used in both wired as well as wireless communication. Wireless standard include IEEE 802.11 a/g/n, IEEE 802.15.3a (UWB), IEEE 802.16 d/e, IEEE 802.20 (MWBA), etc. in all this systems by using OFDM efficiency of systems can be increased [3].

In OFDM all subcarriers are orthogonal to each other. That orthogonality gives simultaneity to all subcarrier [1]. In OFDM total data is broken into number of parallel streams and processed at different frequency. In conventional OFDM IFFT and FFT algorithms are used to multiplex the different signals. By adding cyclic prefix ISI is minimized, that cyclic prefix plays very important role in conventional OFDM. If cyclic prefix is not used then some starting bits of transmitted data gets overlapped on each other, then at the receiver it is impossible to get that overlapped bits, so if cyclic prefix is added then data is not lost. However CP reduces the usable BW [2]. Below fig. 1a, 1b, 1c and 1d explain total function of cyclic prefix respectively. In these figure L is the channel impulse response length and N is the total numbers of bits are transferred in single symbol. If data is transferred without CP then L-1 numbers of bits are overlapped with next symbols L-1 number of bits [14].

By using wavelet transform signal can be analyzed in both time and frequency domain. If orthogonality is lost then it causes ISI and ICI in subcarriers because of multipath propagation in conventional OFDM .In wavelet OFDM CP is not required and because of it, wavelet OFDM saves BW. Wavelet gives overlapping property so it doesn’t lose orthogonality[1].

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## II. LITERATURE SURVEY

60 years ago research of OFDM started. In [1] authors have compared BER (bit error rate) performance of conventional OFDM and wavelet OFDM. In LTE (long term evolution) wavelet OFDM can improve BER performance instead of using conventional OFDM.

In [2] authors have compared performance of Fourier-Based and Wavelet-Based OFDM for DVB-T systems. They got that the DWT-OFDM is best than FFT-OFDM in AWGN and Rayleigh fading channels. They found that for AWGN channel, the gain in term of energy per bit to noise ratio Eb/No was improved by about 5 dB when the system used Haar wavelet compared to FFT OFDM with a cyclic prefix (CP) of 1/4-th the total OFDM symbol period, for the same BER of 0.001.

In [3] authors used wavelet transform to increase efficiency of 5G communication. In conventional OFDM Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) is used to provide orthogonality, but it gives up to only N points on the unit circle in Z plane. If sampling frequency changes slightly which is not located on these N points then these interference spreads into sub channels, due to such interference performance of OFDM degrades [6].

In [4] authors compared BER performance of DWT OFDM over that of FFT OFDM in presence of phase noise. They used Haar Biorthogonal wavelet. They found that DWT



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OFDM provides comparatively better BER performance than that of FFT OFDM in presence of phase noise.

Concept of Cyclic prefix:

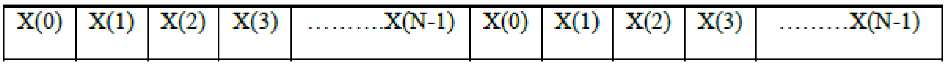


Fig.1a Transmitted signal without CP.

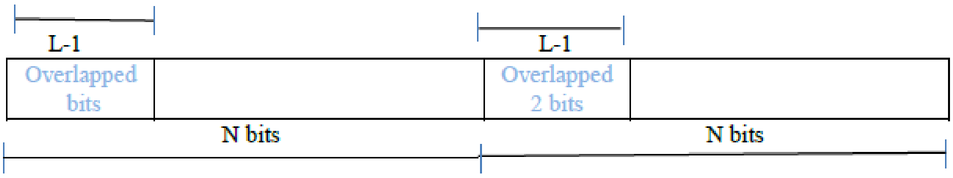


Fig.1b Received signal without CP.

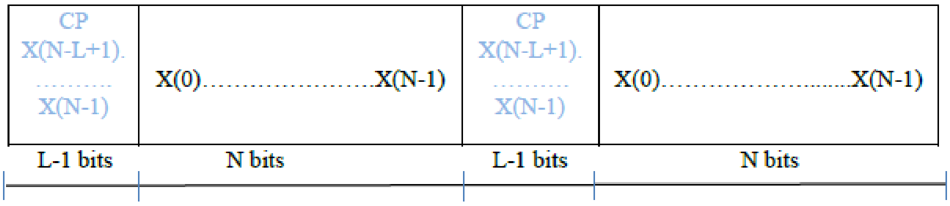


Fig.1c Transmitted signal with CP.


Fig.1d Received signal with Cyclic Prefix

In [9], author used wavelet packet modulation for OFDM and presented the performance comparison of both the techniques.

In [10], author gives comparison of different modulation technique by using ISI/ICI measurement. In [11], wavelet modulation has been proposed for multicarrier communication. In [12], author proposed multimode transmission using wavelet modulation and OFDM.

## III. FOURIER BASED OFDM SYSTEM

Fourier based OFDM system also called as conventional OFDM. In this system IFFT and FFT used to convert data from serial to parallel and vice versa. In the conventional OFDM continuous data is converted into digital by using encoder.

Practically, in OFDM Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) are used for the implementation because less number of computations required in FFT and IFFT. Multiple replicas of the signal are received at the receiver end because of the time dispersive nature of the channel, so frequency selective fading results and to reduce this interference cyclic prefix is used, which is called cyclic prefix [14].

Cyclic prefix is nothing but the copy some ending bits at the starting of the symbol. Condition for loss of orthogonality is channel delay spread should be limited in cyclic prefix [1].

In Fig. 2, the data *{dk}* is processed by *M*-ary modulator and serial to parallel conversion given to IFFT, with *N* subcarriers.

Its output is the sum of the information signals in the discrete time signal as given by equation number (1) [2]:

$$Xk = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} Xm e^{j2\pi km/N} \quad \text{.................(1)}$$

Where $\{x_k|0 \le k \le N-1\}$ is a sequence in the discrete time domain, $\{Xm|0 \le m \le N-1\}$ are complex numbers in discrete frequency domain. At the receiver cyclic prefix is removed and by taking FFT we get original signal $X_m$ [2].

$$Xm = \sum_{k=0}^{N-1} Xk \, e^{-j2\pi km/N} \quad \text{... ................ (2)}$$

## IV. WAVELET BASED OFDM

As shown in fig. 3 there is not major change in wavelet OFDM than conventional OFDM. In wavelet OFDM the IFFT and FFT blocks are replaced by inverse discrete wavelet transform (IDWT) and discrete wavelet transform (DWT)



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respectively. In wavelet OFDM cyclic prefix is not needed because wavelet itself has overlapping nature. So it provides better orthogonality to all subcarriers hence it improves spectral efficiency of transmission. In wavelet cyclic prefix is not needed so bandwidth is saved nearly about 20% to 25% [2].

As shown in above fig. 3 IDFT of M-ary modulated data is taken and transferred by considering AWGN channel. The output of the inverse discrete wavelet transform (IDWT) can be given as equation number (3) [13]:

$$s(k) = \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} s_m^n 2^{\frac{m}{2}} \psi(2^m k - n) \;.......\; (3)$$

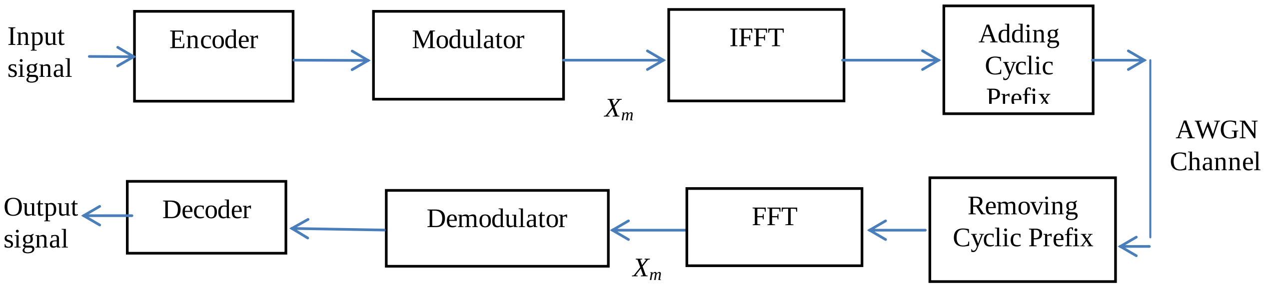


Fig.2 Block diagram of conventional OFDM.


Fig. 3 Block diagram of Wavelet OFDM

Where s_m^nare the wavelet coefficients and ψ(t) is the wavelet function with compressed factor m times and shifted n times for each subcarrier (number k, $0 \leq k \leq N-1$).The wavelet coefficients gives the representation of signals in scale and position or time. The scale is related to the frequency. Low scale represents compressed wavelet which means that the signal is rapidly changing, or the signal is in high frequency.

On the other side, high scale represents stretched wavelet which means that the signal is slowly changing, or the signal is in low frequency. Thus, Xm can be represented to $s_m^n$ before it is processed to IDWT. At the receiver side, the process is inversed. The output of discrete wavelet transform (DWT) is given as equation number (4) [2].

$$s_m^n = s(k) 2^{\frac{m}{2}} \; \psi(2_k^m - n) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (4)$$

$s_m^n$ can be decoded to $X_m$ before the recovery of data to demodulator.

## V. BER PERFORMANCE OF OFDM

BER stands for Bit Error Rate. The BER is defined as the number of erroneous bits in a transmission channel over the total number of transmitted bits that in a given transmission. BER is a unit less it is, sometimes, used interchangeably with the probability of error. But there is a difference between the two. The probability of error (Pe) is defined as the theoretical expectation of the bit error rate for a given system. BER is an empirical record of a system's actual bit error performance. The BER is directly affected by the SNR. SNR is analogous to Eb/No. Thus BER is inversely proportional to the Eb/No. The lower the SNR, the lower is the Eb/No; the lower the Eb/No, the higher is the BER. Thus, higher the BER the slower is the effective data rate. The conclusion is that the lower the SNR, the slower the effective data rate [5].

BER= No. of erroneous bits / Total no. of bits sent

In a communication system, the receiver side BER may be affected by these factors: transmission channel noise, interference like Inter Channel and Inter Symbol Interference, distortion, bit synchronization problems, attenuation, wireless multipath fading, etc. There are methods to reduce the BER and may be improved by choosing a strong signal strength (unless this causes cross-talk and more bit errors), by applying channel coding schemes such as redundant forward error correction codes and also by choosing a slow and robust modulation scheme or line coding scheme. Lower BER means better QoS in a system. The BER value in a system should be less. The numbers of methods are being adopted to reduce the BER in a system [5].



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## VI. CONCLUSION:

This paper gives importance of cyclic prefix in conventional OFDM and how that CP consumes transmission bandwidth of system. Further it explains the comparison of conventional OFDM and Wavelet OFDM. In that comparison wavelet OFDM can give better performance than Fourier based OFDM in certain parameters i.e. BER and spectral efficiency.

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