Orthogonal Wavelet Division Multiplexing (OWDM) for Efficient wireless communication: An Overview

Diksha[1], Satnam Singh[2], Ritika[3]
[1]*Research scholar, Sri Sai College of Engineering and Technology, Badhani, Punjab*
[2]*Professor & HOD, Sri Sai College of Engineering and Technology, Badhani, Punjab*
[2]*AP, Sri Sai College of Engineering and Technology, Badhani, Punjab*

Abstract—**Orthogonal Wavelet Division Multiplexing (OWDM) is a multi-carrier modulation scheme that exploits wavelet transforms in place of conventional Fourier transforms, as use in Orthogonal Frequency Division Multiplexing (OFDM). OWDM doesn't need a cyclic prefix, thus improves bandwidth efficiency.The over-lapping nature of wavelets reduces inter-symbol and inter-carrier interference. Therefore, it is considered a promising alternative to OFDM, especially in scenarios demanding high data rates and low latency. This paper explains the overview, structure, and application of OWDM technique for efficient wireless communication.**

Keywords— **OFDM, OWDM, ISI, ICI, BER.**

I. Introduction

Orthogonal Wavelet Division Multiplexing (OWDM) and Orthogonal Frequency Division Multiplexing (OFDM) are both multi-carrier modulation schemes, however they vary significantly in their implementation and performance.OFDM relies on the Discrete Fourier Transform (DFT), using sinusoidal basis functions butOWDM utilizes the Discrete Wavelet Transform (DWT), which employs wavelets that are localized in both time and frequency.OFDM also requires a cyclic prefix (CP) to combat inter-symbol interference (ISI), which reduces spectral efficiency however OWDM doesn't need a cyclic prefix, saving bandwidth and improving efficiency. Due to the cyclic prefix overheadOFDM has moderate spectral efficiency but OWDM has higher spectral efficiency because wavelets overlap and minimize redundancy. Therefore, OFDM is more prone to inter-carrier interference (ICI) in time-varying channels however OWDM offers better resilience against interference. OFDM however is simpler to implement due to well-established algorithms like FFT whereas OWDM has slightly higher complexity because wavelet transform computations are less straightforward [1,2].In summary, OWDM offers potential advantages like better spectral efficiency, interference resistance, and performance in time-varying channels. However, its complexity and limited adoption compared to the mature and widely-used OFDM pose challenges. Researchers are actively exploring OWDM as an alternative to OFDM to address the challenges of 5G, such as high data rates, low latency, and energy efficiency.

II. OWDM Applications

Orthogonal Wavelet Division Multiplexing (OWDM) has several promising applications in modern communication systems. Here are some key areas where OWDM is being explored:

i. **5G and Beyond**: OWDM is considered a strong candidate for 5G and future wireless communication systems due to its high spectral efficiency, robustness against interference, and adaptability to dynamic channel conditions.

ii. **Digital Video Broadcasting (DVB)**: OWDM has been investigated as an alternative to OFDM in DVB systems, offering better performance in terms of Bit Error Rate (BER) and noise resilience under various channel conditions.

iii. **IoT and Machine-to-Machine Communication**: OWDM's energy efficiency and low latency make it suitable for Internet of Things (IoT) applications and massive machine-type communications.

iv. **High-Mobility Scenarios**: OWDM's superior time-frequency localization allows it to perform well in high-mobility environments, such as vehicular communication systems and high-speed trains.

v. **Underwater and Satellite Communication**: OWDM's robustness to channel impairments makes it a potential candidate for challenging environments like underwater acoustic communication and satellite systems.

These applications highlight OWDM's versatility and potential to address the demands of next-generation communication technologies [3].

III. Structure of OWDM

A wavelet is a waveform of well limited duration that has an average value of zero.Wavelet transform can generate sub-carriers of diverse bandwidth and symbol length. The capability of wavelets to assemble the time-frequency tiling, in a manner that reduces the channel disturbances,reduces the effect of noise and interference on the signal. Fourier analysis involves of breaking up a signal into sine waves of various frequencies; similarly, wavelet analysis is the breaking up of a signal into shifted and scaled versions of the original (or mother) wavelet. There are varieties of wavelets found in literature including bothorthogonal and bi-orthogonalwavelets, many of which can in fact be describedentirely on the basis of linear algebras [4].The advantageofwavelettransforms overothertransformssuch as Fourier transform is that it is discrete both in time as well as scale. The transform is implemented using filters. One filter of the analysis (wavelet transform) pair is a low-pass filter (LPF), while the other is a high-pass filter (HPF). Each filter has a down-sampler after it, to make the transform efficient. The DWT of a signal 'y' is calculated by passing it through a series of filters. First the samples are passed through a low pass filter with impulse response "g" resulting in a convolution of the two:

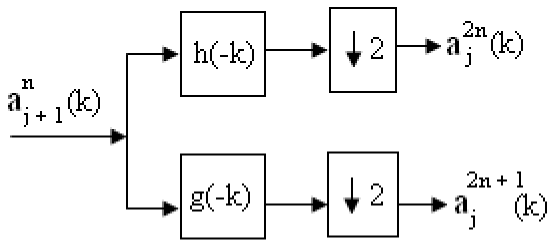
$$y[n] = (x * g)[n] = \sum_{k=-\infty}^{\infty} x[k]g[n-k] \qquad (iii)$$

The signal is also decomposed simultaneously using a high-pass filter "h". The output gives the detail coefficients (from the high-pass filter) and approximation coefficients (from the low-pass). The filter outputs are then sub sampled by two. The outputs of the low-pass filter and the high-pass filter are shown below and are the convolutions of the input data with the respective filter responses:

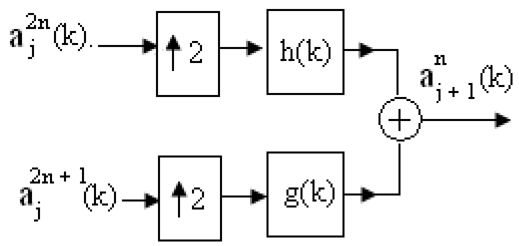
$$y_{LPF}[n] = (x * g)[n] = \sum_{k=-\infty}^{\infty} x[k]g[2n-k] \qquad (iv)$$

$$y_{HPF}[n] = (x * h)[n] = \sum_{k=-\infty}^{\infty} x[k]h[2n-k] \qquad (v)$$

Figure 1 shows the block diagram for the implementation of wavelet transform



(a)



(b)

Fig. 1: Single stage of (a) Wavelet Transform (b) Inverse Wavelet Transform

Wavelet transform is equivalent to filtering a signal with a low pass and high pass filter bank, while the IWT is equivalent to combining a low pass and high pass signal into one signal.

In OWDM model, inverse discrete wavelet transform (IDWT) and discrete wavelet transform (DWT) have replaced the IFFT and FFT OFDM system. Due to the overlapping nature of wavelet properties, the wavelet based does not need cyclic prefix to deal with delay spreads of the channel. As a result, it has higher spectral containment than that of OFDM. The OWDM transceiver is illustrated in Figure 2.

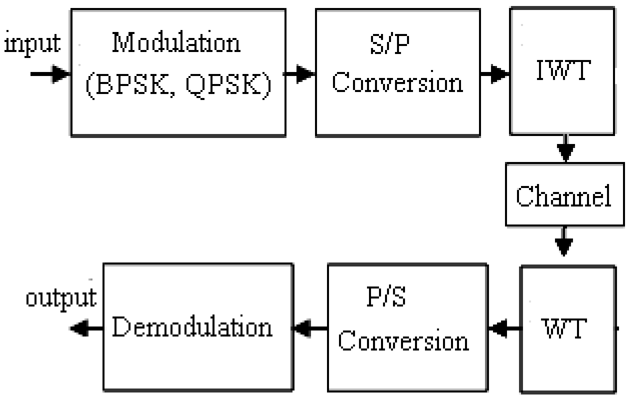


Fig.2. OWDM Transceiver

The incoming signal is first converted from serial to parallel form and then modulated. There is up sampling of signal in each iteration of inverse wavelet packet transformation (IWPT). Now the signal is decomposed one with HPF and the other with LPF. The outputs of HPF and LPF branches are then subsequently added.

The output of the inverse discrete wavelet transform (IDWT) can be represented as:

$$d(k) = \sum_{m=0}^{\infty}\sum_{n=0}^{\infty} D_m^n 2^{\frac{m}{2}} \psi(2_k^m - n)\, vi$$

Where D_m^n are the wavelet coefficients and $\psi(t)$ is the wavelet function with compressed factor m times and shifted n times for each subcarrier (number k, $0 \le k \le N - 1$). The wavelet coefficients are 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 hand, high scale represents stretched wavelet which means that the signal is slowly changing, or the signal is in low frequency. The output of discrete wavelet transform (DWT) is

$$D_m^n d(k) = \sum_{k=0}^{N-1} d(k) 2^{\frac{m}{2}} \psi(2_k^m - n)\, vii$$

IV. Related Work

Design and implementation of Wavelet based OWDM is discussed and analyzed [5].In this paper, a new technique has been demonstrated that couldprovide a more flexible replacement for conventional OFDM with lower complexity while still maintaining the samechannel capacity and SNR characteristics as OFDM.TheOWDM system has advantage that it is convenient to dynamically assign the bandwidth (BW) for each of the sub-bands. The paper compares the technology in terms of SNR and throughput.

Wavelet based ultrawide band (UWB) system is compared with Fourier based UWB [6]. The concept of wavelet transforms as an alternative to the conventional Fouriertransform-based multicarrier UWB system is discussed and analyzed.The use of wavelet increases the spectral efficiency of the system.Therefore, DWT could be considered as attractive technique in future multicarrier UWB systems and other high data rate systems. Various multicarrier systems such as OF**DM**, MC-CDMA and MC-DS-CDMA is described by Haitham J. Taha and M. F. M. Salleh[7]. It also compares these systems with wavelet based OFDM.The main aim of the paper is to gives a survey on multi-carrier transmission techniques i.e. OFDMand the combination of OFDM with Code Division Multiple Access (CDMA). Also, this surveyclarifies how to use Wavelet Transform in OFDM instead of using Fast Fourier Transform

Wavelet Transform based OFDM is designed and various performance criterion such as BER and PAPR are discussedby W. Saad[8]. In this paper, an efficient scheme for the OFDMsystem using wavelet transform is proposed. The results reveal a superiorperformance when compared with traditional OFDM-FFT systemthrough an Additive White Gaussian Noise (AWGN) channel. The systemperformance is described in Bit Error Rate (BER) as a function ofSignal to Noise Ratio (SNR) and the peak-to-average ratio (PAR).Volkan Kumbasar and O. guzKucur[9] compares wavelet based OFDM with conventional OFDM in presence of multipath channel conditions. The performance of wavelet based OFDM is analyzed and compared to conventional Fourier OFDM over multipath Rayleigh fading channels.Results show that Wavelet based OFDM has better bit error rate (BER) performance than conventional OFDM withoutcyclic prefix (CP)

V. CONCLUSION

This paper gives overview and structure of a new technique thatcouldoffer a more flexible replacement for OFDM with reduced complexity while still preserving the similar thechannel capacity and SNR characteristics as OFDM.This paper has highlighted the possibility of thistechnology. The OWDM system has the advantage of being able todynamically allocate bandwidth for each of the sub-bandsdepending on the application (whether it is data forinteractive services, video conferencing, audio data, etc).Of course, there are many other aspects of theOWDMthat need to be compared to OFDM in orderto make it afeasible alternative such as its multipathrejection capabilities,the resilience to frequency and phase noise offsets, etc.

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