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Simulation of Asymmetric digital subscriber line (ADSL) using the Discrete Wavelet Multitone Modulation (DWMT)

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Session XXXX

Simulation of Asymmetric Digital Subscriber Line (ADSL) using the Discrete Wavelet Multitone Modulation (DWMT) and Performance Comparison

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Abstract

The Multi-Carrier Modulation is a technique used in breaking up the frequency spectrum into multiple sub-carriers, each of which is orthogonal to the other sub-carriers. The discrete multi-wavelet transform (DMWT) reduces the computation complexity and improves the performance efficiency. Most of the multi-carrier transmission systems use different techniques such as OFDM and single-carrier modulation techniques such as QAM for the ADSL technology. The bit error rate is poor, and the performance, flexibility, compatibility, and operational issue may arise during the information transmission. The DMT techniques combined with the ADSL can overcome these problems. The DMT partitions a broadband channel into many virtually independent, narrowband subchannels and maximizes the ADSL system's bit rate. The implementation of wavelet in the ADSL system improves the suitability, flexibility, and complexity of the multi-tone ADSL system. The paper compares the existing ADSL system problems with the DMWT-ADSL system. The main objective of this project work is to comparatively study the traditional multi-tone ADSL with the DWMT-ADSL, which provides a clear understanding of the application of wavelets in the broadband communication system. This paper is intended to share the results of the study. The method used is via simulation using MATLAB Simulink programs. We performed a detailed study of the ADSL system. The result of the simulation of the ADSL provides a broad view of how it works and transmits the data over the AWGN channel and demonstrates and documents the bit errors. The BER is the performance metrics compared using Meyer, DB-2 wavelets where the DB-2 shows low BER.

Introduction

Multi-carrier modulation (MCM) is the technique that splits the frequency spectrum into multiple sub-carriers; each sub-carrier is orthogonal. The most popular multi-carrier modulation is the discrete multi-tone modulation which is used in asymmetrical digital subscriber lines (ADSL). The MCM technique provides high transmission data rates and robust inter symbol interference (ISI) by decomposing the high bandwidth into a narrow band subchannel. Each sub-channel will experience flat fading and small ISI. The performance of the ADSL transceiver is compared by taking the probability of bit error rate and using the signal-to-noise ratio in various channel models such as Additive White Gaussian Noise (AWGN), Rician, and Cable model using either MATLAB, SIMULINK, VHDL, or using Digital Signal Processing Kit.

Authors (Nguyen & Nguyen), compared the performance of the Daubechies wavelet-based multi-carrier modulation with the FFT-based system multi-carrier modulation in the asymmetrical digital subscriber line (ADSL). In (Ibraheem & Khamiss, 2008), (Salih, 2011) , the authors used discrete multi-tone (DMT) modulation with error correction and detection techniques to achieve the low bit error rate for the DMT FFT-based conventional ADSL system where the downstream and upstream transmission rate is recorded for the specified BER and SNR. Authors (Zhang, Shi, & Tang, 2007) improved the quality of data transmission by improving the property of the logging cable under the terrible downhole environment. In (Maghrebi, Lotfizad, & Ghanbari, 2007), the authors introduced the non-rectangular QAM with the combination of the fast Hadamard transform without prefix found the better BER performance as compared with the rectangular-QAM. The research on the Discrete Wavelet multi-carrier modulation-based ADSL compared the performance with the conventional techniques in terms of BER and SNR. There is also different research on ADSL (Farrukh, Baig, & Junaid Mughal, 2012), (Khan, Baig, & Nawaz, 2015) channel equalization techniques used with the combination of the DWMT ADSL. Similarly, The Wavelet-based ADSL researchers implemented different levels of 64-QAM (Kumar, 2018) ,16-QAM, 32-QAM, and 128-QAM (Rohit Bodhe & Joshi, 2012).

The current status of the ADSL system's performance analysis can be found to compare conventional ADSL with DWMT based ADSL for different channel models using the different levels of QAM modulation. However, those research works are not wide enough in the case of discrete wavelet-based ADSL. The comparative study of the performance for different types of available wavelets is still wide open; hence, this research focuses on the comparative study for different wavelets.

Most of the conventional ADSL performance problems can be overcome using ADSL technology's discrete wavelet multi-carrier modulation. The multi-carrier modulation technology with the combination of the cyclic prefix increased the bandwidth, and the channel equalization increased the performance of the conventional ADSL transmission. The discrete wavelet-based multi-carrier modulation used the wavelet transform techniques to increase the performance—the performance varies depending upon the types of discrete wavelets used.

Literature Review

The Wavelet-based OFDM provides better spectral efficiency than the conventional OFDM because of eliminating the cyclic prefix in W-OFDM. The high-speed W-OFDM can be used in high-speed wireless data transmission such as LTE, 5G etc. The author (Sunkara & Bhargava, 2018) proposed the W-OFDM where the translation-invariant Wavelet transform (TIWT) was used in place of the DWT to enhance the spectral efficiency and found the TIWT-OFDM is superior to the existing OFDM systems like DFT-OFDM and DWT-OFDM systems. The authors (Alshammary, 2016) investigated the influence of Wavelet and Fast Fourier Transform (FFT) on WLAN IEEE.802.11.a system with Orthogonal Frequency Division Multiplexing where the OFDM is used to simulate the proposed system's performance using BPSK, DPSK, QPSK, DQPSDK, QAM16, and QAM64 modulation algorithms.

The authors (Nguyen & Nguyen) compared the performance of the wavelet-based multi-carrier modulation with the FFT-based system multi-carrier modulation in the asymmetrical digital subscriber line (ADSL) using the Daubechies wavelet to compare the performance of the ADSL. The wavelet-based discrete multi-tone systems are used to control the performance of the ADSL systems. In (Ibraheem & Khamiss, 2008) Authors used discrete multi-tone (DMT) modulation with error correction and detection techniques to achieve the low bit error rate for the DMT FFT-based conventional ADSL system. We know that discrete wavelet transform (DWT) analyzes the signal with frequency bands with different resolutions by decomposing the signal into approximation and detail coefficients.

The authors (Zhang, Shi, & Tang, 2007) improved the quality of data transmission by improving the property of the logging cable under the terrible downhole environment. The ADSL transmission system logging cable improved the data transmission rate. The imbalance between the twisted copper pair produces the noise where the authors used the Hadamard transform instead of FFT to the ADSL system with 129 AWGN noisy channels. The authors (Maghrebi, Lotfizad, & Ghanbari, 2007) introduced the non-rectangular QAM with the combination of the fast Hadamard transform without prefix found the better BER performance than the rectangular-QAM. Similarly, (Ravishankar & College) Modell Heuristic Stein's Unbiased Risk Estimate estimates the crosstalk noise and Bayesian risk minimization threshold function for three different channel AWGN, 24 ADSL NEXT, and 24 ADSL FEXT used the wavelet denoising techniques to improve the performance of the broadband ADSL transmission system. The authors implemented the non-parametric wavelet denoising technique to cancel the NEXT and FEXT crosstalk in the ADSL receiver.

The author (Salih, 2011) used the discrete multi-wavelet transform ((DMWT) to enhance the BER of the discrete multi-tone (DMT) ADSL transmission systems under the AWGN channel, and the performance is measured in terms of BER. He simulated the DMT-ADSL models without using equalization. (Rohit Bodhe & Joshi, 2012) compared the discrete wavelet transform with the Fast Fourier Transform multi-tone modulation for different modulation schemes such as 16-QAM, 32-QAM, 64-QAM, and 128-QAM to develop the OFDM system. They found that DWT-IDWT based OFDM transmitter and Receiver achieve better performance in terms of Bit Error Rate (BER) for the AWGN channel, which proves that all the wavelet performs better over the IFFT-FFT implementation. The author (Kumar, 2018) compared the single carrier QAM and multi-carrier OFDM in the multipath channel where the performance is measured on three different channels, including AWGN, Rayleigh, and Rician channels, found that the 64-QAM overcame the problems of ISI, ICI, and orthogonality.

(Farrukh, Baig, & Junaid Mughal, 2012) The discrete wavelet multi-tone transceiver for the ADSL channel promises greater sub-channel spectral containment than the FFT-based conventional discrete multi-tone system. The purposed model used channel equalization but did not require the cyclic prefixing; hence it is spectrally efficient where the AWGN channel with crosstalk is modeled on MATLAB. Authors (Khan, Baig, & Nawaz, 2015) implemented the overlap frequency domain equalization (OFDE) in DWMT modulated ADSL system, and the performance is compared with the time-domain equalization (TDE) techniques. The minimum mean square error (MMSE) based OFDE for the downlink ADSL channel with lower complexity and BER performance compared to the TDE. The Authors (Katiyar & Padmaja, 2016) compared the performance of the wire ADSL using the time and frequency domain equalizer in terms of the symbol error rate, and they found that the least mean square algorithm performed better than zero-forcing algorithms. (Rehman & Singh, 2019) proposed the channel encoding technique by adding redundant bits to the transmitted data where the degradation of the information bit due to the interference, noises, and SNR can be correct or detected by implementing the discrete multi-tone modulator.

Multi-Carrier Modulation

The MCM technologies developed after the evolution of OFDM. There are different variants of the OFDM: discrete multi-tone (DMT), multi-carrier CDMA (MC-CDMA), wavelet OFDM, and Discrete Wavelet Multitone (DWMT). The MCM techniques are used in digital communication systems, including ADSL, 802.11a, 802.11n wireless LAN, Digital Audio Broadcasting, digital video broadcasting, WiMAX, and Power line communications.

DFT based: Discrete Multitone Modulation Techniques

In the conventional DFT-based DMT ADSL, the channel bandwidth is divided into N-numbers of sub-channels. The input serial bit stream is also converted into N-parallel sub-streams. The SNR of the sub-channel is below the threshold, and then no bits are allocated to the sub-channels. After the assigned parallel bits are mapped on the constellation using the QAM. N-QAM symbols are then modulated using the 2N point IFFT to generate the real samples for transmission via the copper wire channel. The cyclic prefix absorbs any multipath interference by extending the length of the symbols. The channel can be modeled using finite impulse response (FIR) and the gaussian channel, additive white gaussian noise (AWGN). The channel's output is the product of the impulse response of the channel and the transmitted signals. At the receiver end, the cyclic prefix samples are discarded, and the remaining samples are passed through the FFT, which divides the received samples into N sub symbols. The resultant signal is then demodulated to recover the original data bits and converted into serial bit streams parallel to the serial conversion process.

Wavelet-Based: Discrete Wavelet Multitone Modulation techniques

The problem with the FFT-based DMT is the inter-carrier interference at a significant level. The Discrete wavelet transform provides good spectral shaping. Therefore, it reduces the inter-carrier interferences and the sensitivity to narrowband interferences. The broadband transmission system based on the discrete wavelet multi-tone (DWMT) for modulating and demodulating signal is discrete wavelet transform. The DWMT can be implemented on the wireless communication system.

Wavelet transform in MCM

The wavelet transform is a technique used to analyze data in both the time and frequency domains, which can concurrently supply time and frequency information, resulting in a time-frequency representation of the signal. Wavelets are noted for their compact support (localization) in the time and frequency domains and superior orthogonality.

Wavelet transform has recently been presented as a suitable analysis system for complex digital wireless communication systems, with benefits such as transform flexibility, less sensitivity to channel distortion and interference, and greater spectrum use. Wavelets have found applications in channel modeling, transceiver design, data representation, data compression, source and channel coding, interference reduction, signal denoising, and energy-efficient networking. The transmission power is lowered due to the application of wavelet transform. Discrete Wavelet Transforms are one sort of wavelet transform that has been proposed as a platform for replacing IFFT and FFT.

Digital Subscriber Line

DSL is a wireline transmission technology that transmits data faster than traditional copper telephone lines installed to homes and businesses, and DSL-based broadband service provides a transmission rate ranging from several hundred Kbps. The availability and speed of the DSL service may depend on the distance from home or business to the closest telephone company facility. Types of DSL are (Akujuobi & Sadiku, 2007) : ADSL (Asymmetrical Digital Subscriber Line)- ADSL allows faster downstream data transmission over the same line used to provide voice service without disrupting regular telephone calls on that line. Businesses use SDSL (Symmetrical Digital Subscriber Line) for services such as video conferencing, which needs significant bandwidth both upstream and downstream. HDSL (High Bit-Rate Digital Subscriber Line) provides asymmetric connection where upstream speed and downstream speed are the same and range from 1.544 Mbps to 2.048 Mbps for a distance of 12,000–15,000 ft. Symmetric connections are more used in applications such as videoconferencing to transmit the upstream data as heavy as data sent downstream. VDSL (Very High Bit-rate Digital Subscriber Line) is also the fastest of all xDSL flavors and provides transmission rates of 13–52 Mbps downstream and 1.5–2.3 Mbps upstream over a single copper-pair wire, at a distance of 1,000–4,500 feet from the service provider's premises. CDSL (Consumer Digital Subscriber Line) is another version of DSL service, trademarked by Rockwell Corp; that is somewhat slower than Asymmetric DSL (ADSL) - up to 1 Mbps downstream, probably less upstream - and has the advantage that a splitter does not need to be installed at the user's end.

Discrete Multi-tone (DMT) in ADSL

DMT is a method of separating a DSL signal so that the usable frequency range is separated into 256 frequency bands (or channels) of 4.3125 kHz each. DMT uses the fast Fourier transform (FFT) algorithm for modulation and demodulation. Discrete multi-tone has become the accepted standard for ADSL modulation. DMT techniques are used to split the frequency spectrum into equally spaced subchannels. The reason the DMT line coding has several advantages that lend exceptionally well to ADSL. These advantages include rate adaptation as a function of the signal-to-noise ratio (SNR), adjustable bit rates, and inherent immunity to impulse noise and radio frequency interference (RFI). A DMT transceiver can monitor as well as to adapt to UTP varying conditions and, in addition, continually update to maintain optimum performance. This is how DMT systems transmit the best possible signal and data rate. DMT also copes well when faced with the adverse conditions of impulse noise. The BER is compared for different values of SNR and different wavelets.

Method

DMT Transmitter and Receiver

In our work, we divided the channel into numerous Quadrature Amplitude Modulation (QAM) subchannels in the ADSL modem that uses DMT modulation. The DMT block diagram shown in Fig. 1 is used in the ADSL modem. After that, the assigned bits were mapped to sub-symbols using the QAM modulation method. QAM mapped the input bits into QAM symbols. The N/2 sub-symbols are duplicated with their conjugate symmetric counterparts to form Hermitian symmetry. The obtained time-domain samples are called a DMT symbol to obtain the real samples after IFFT; a guard period between DMT symbols is used to prevent inter-symbol interference, which is implemented by appending a symbol with its last v samples, which is called a cyclic prefix (CP). Circular convolution can be implemented in the Discrete Fourier Transform (DFT) domain by using FFT, and then those D/A converted signal is passed to the channel. The Receiver performed the replica of the transmitters block. The equalizer is used at the Receiver to remove the co-channel interferences.

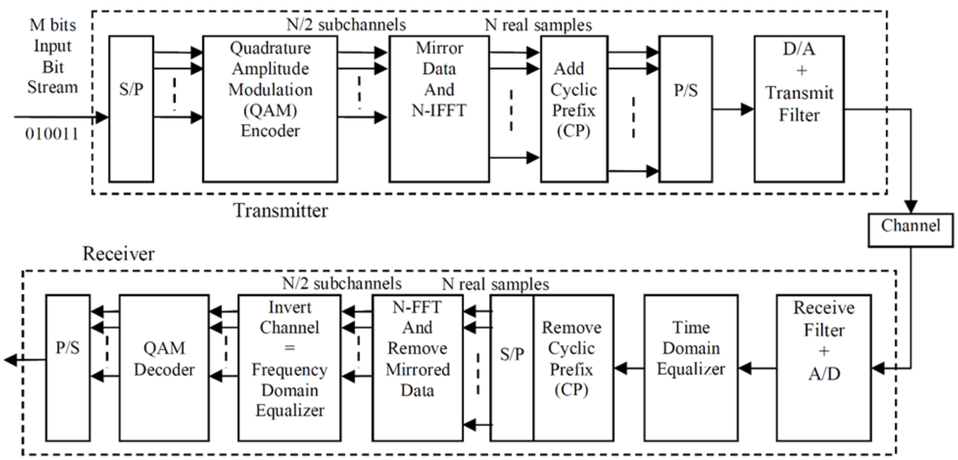

Figure 1.*FFT Based DMT ADSL Transceiver*

Wavelet-based Discrete multi-tone modulation ADSL transceiver

In wireless applications, a system based on Discrete Wavelet Multitone (DWMT) has been proposed for modulating and demodulating the needed signal utilizing the Discrete Wavelet Transform as a basis function. Fig. 2 shows the block diagram for the DWMT system model. It

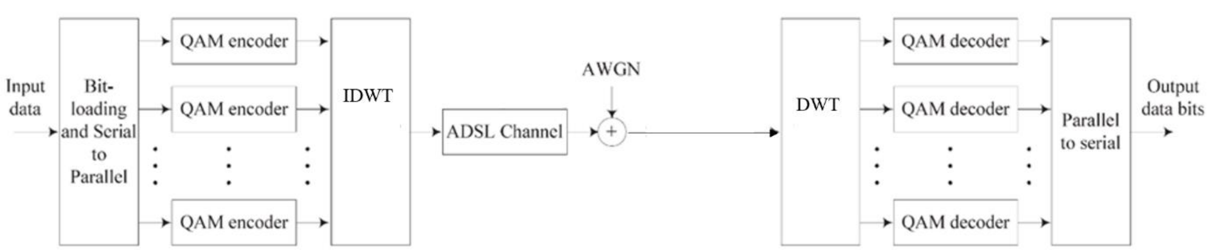

Figure 2.*Wavelet Based DMT ADSL Transceiver*

splits the input data bitstream into several parallel bits. There discrete wavelet packet transform is used in the DWMT transceiver. The FFT-based conventional ADSL system where the DWT replaces the FFT to obtain the DWMT ADSL.

Experiment and Results

After a detailed study of the block diagram of the FFT and DWMT based ADSL transceiver. The experiment is carried out for the FFT-based ADSL transceiver system. The Bernoulli Binary generator is used to generate the random input to this system. The number of samples is fixed during this experiment while the sample per frame is constant, i.e., 1552. The sample time for this experiment is 1/5000 sec. The DMT modulator consists of the 16 modulator bank, and the Inverse discrete wavelet transforms at the transmitter side. The inverse discrete wavelet transform reconstructs a single sub-band with smaller bandwidths and slower sample per rate. We can apply different wavelet transform such as Haar, Daubechies, Symlets, Coiflets etc while performing the experiment (Mayer, db2 are used). The 7 numbers of bits per symbol are selected.
The AWGN channel consists of the Additive while Gaussian noise is an input signal and can be real or complex. Different values of SNR or Eb/No change on the transmission channels. The reverse process is performed at the receiver side, and the bit error rate is calculated. The BER for the FFT-based and Discrete wavelet (Mayer and db2)based ADSL system for 8 different experiments are calculated and tabulated in Table 1 for the record. The plot in Figure 3. clearly shows the performance comparison between FFT and DWT (Mayer and db2) based on ADSL.

Table 1 *BER Comparison Between FFT and DWT for ADSL*

			FFT_BER in (%)	DWT_BER in (%)	
Exp.	SNR (dB)	Number of Total Bit sent	BER_FFT	BER_DWT_Mayer	BER_DWT_db2
1	20	5432	50.0226%	49.7680%	49.1753%
2	21	5432	50.0235%	49.6907%	49.1753%
3	22	5432	50.0247%	49.7165%	49.1753%
4	25	5432	50.0175%	49.8969%	49.2525%
5	26	5432	50.0170%	49.8711%	49.2525%
6	29	5432	50.0169%	49.8196%	49.2010%
7	30	5432	50.0154%	49.8454%	49.2010%
8	33	5432	50.0172%	49.8196%	49.2010%

Conclusion and Future Work

In this work, The conventional FFT-based ADSL shows relatively poor performance compared with the discrete wavelet-based ADSL system. The discrete Wavelet-based ADSL has low BER as compared to conventional ADSL. Hence, discrete wavelet-based ADSL shows better performance as compared with FFT-based ADSL. The most important point found during this research is that the performance varies based on the discrete wavelet used during the ADSL transmission.

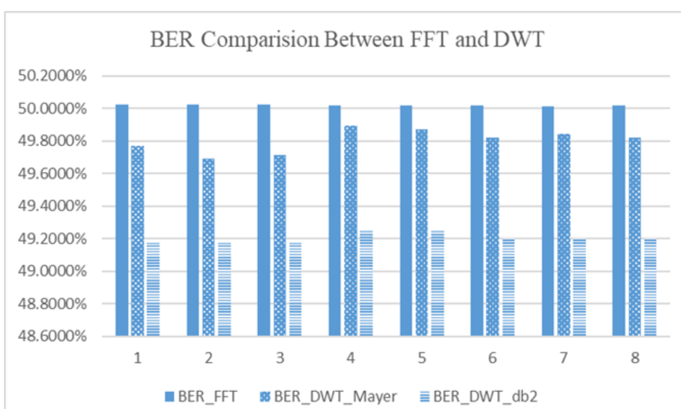

Figure 3. *The BER comparison plot for FFT and DWT*

The Daubechies-2 and Meyer discrete wavelet-based ADSL's BER is compared for the 2-level wavelet transform. The db2 provides better performance as compared with the Mayer wavelet. The db2 wavelet is designed to put linear trends into only the average component, so it is more efficient for decomposing data with linear gradients while maintaining mutual orthonormality of wavelets and scaling vectors. Future work would be the detailed study of the different levels of wavelet transforms and other parameters in the ADSL system performance research.

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