OFDM (Orthogonal Frequency Division Multiplexing) SIMULATION USING MATLAB

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***ABSTRACT*— This paper discusses the design and implementation of an OFDM modem used in wireless communication. The transmission of binary and text file using OFDM with its protocol as well as system parameters have been explained in detail. This technique has high transmission rates over wire line and wireless channels with protection from multipath fading which can turn out to be a predicted technique in fourth Generation (4G) mobile phones. It is an Ideal technique for bandwidth hogging applications like Video Conferencing, DAB, DVB, etc. Multi-user capacity possible using MC-CDMA. For the most part, Orthogonal Frequency Division Multiplexing (OFDM) is the standard being used throughout the world to achieve the high data rates necessary for data intensive applications that must now become routine. The bit error rate and the ISI in multipath environment in conventional techniques such as QAM are very high which can be reduced by implementing the OFDM technique Also, in the paper result of simulation, future work and conclusion has been provided.

Keywords— OFDM, significance, orthogonality, generation, reception, spectrum, advantage, disadvantage, simulation.

I. INTRODUCTION

A common problem found in high-speed communication is inter-symbol interference (ISI). ISI occurs when a transmission interferes with itself and the receiver cannot decode the transmission correctly. Because the signal reflects from large objects such as mountains or buildings, the receiver sees more than one copy of the signal. In communication terminology, this is called multipath. Since the indirect paths take more time to travel to the receiver, the delayed copies of the signal interfere with the direct signal, causing ISI. This project will focus on Orthogonal Frequency Division Multiplexing (OFDM) research and simulation. OFDM is first studied by Chang PATANG in 1966.OFDM is especially suitable for high-speed communication due to its resistance to ISI. As communication systems increase their information transfer speed, the time for each transmission necessarily becomes shorter. Since the delay time caused by multipath remains constant, ISI becomes a limitation in high-data-rate communication. OFDM avoids this problem by sending many low speed transmissions simultaneously. For example, Figure.1 shows two ways to transmit the same four pieces of binary data. Suppose that this transmission takes four seconds. Then, each piece of data in the left picture has duration of one second. On the other hand, OFDM would send the four pieces simultaneously as shown on the right. In this case, each piece of data has duration of four seconds.
This longer duration leads to fewer problems with ISI. Another reason to consider OFDM is low-complexity implementation for high-speed systems compared to traditional single carrier techniques.

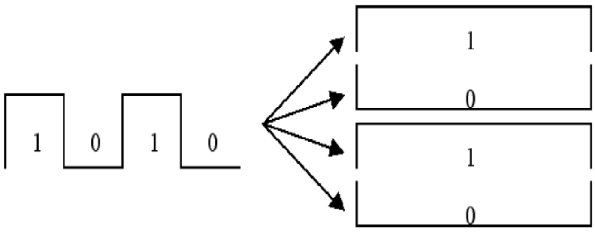

Fig.1 Traditional vs. OFDM communication

II. SIGNIFICANCE

With the rapid growth of digital communication in recent years, the need for high-speed data transmission has increased. New multicarrier modulation techniques such as OFDM are currently being implemented to keep up with the demand for more communication capacity. The processing power of modern digital signal processors has increased to a point where OFDM has become feasible and economical. Examining the patents, journal articles, and books available on OFDM, it is clear that this technique will have an impact on the future of communication. Some examples of current applications using OFDM include GSTN (General Switched Telephone Network), Cellular radio, DSL & ADSL modems, DAB (Digital Audio Broadcasting) radio, DVB-T (Terrestrial Digital Video Broadcasting), HDTV broadcasting, HYPERLAN/2 (High Performance Local Area Network standard), and the wireless networking standard IEEE 802.11 .

III. ORTHOGONALITY

Signals are orthogonal if they are mutually independent of each other. Orthogonality is a property that allows multiple information signals to be transmitted perfectly over a common channel and detected, without interference. Loss of orthogonality results in blurring between these information signals and degradation in communications. Many common multiplexing schemes are inherently orthogonal. Time Division Multiplexing (TDM) allows transmission of multiple information signals over a single channel by assigning unique time slots to each separate information signal. During each time slot only the signal from a single source is transmitted preventing any interference between the multiple information sources. Because of this TDM is orthogonal in nature. In the frequency domain most FDM systems are orthogonal as each of the separate transmission signals are well spaced out in frequency preventing interference. Although these methods are orthogonal the term OFDM has been reserved for a special form of FDM. The subcarriers in an OFDM signal are spaced

as close as is theoretically possible while maintain orthogonality between them. OFDM achieves orthogonality in the frequency domain by allocating each of the separate information signals onto different subcarriers. OFDM signals are made up from a sum of sinusoids, with each corresponding to a reserved for a special form of FDM. The subcarriers in an OFDM signal are spaced as close as is theoretically possible while maintain orthogonality between them. OFDM achieves orthogonality in the frequency domain by allocating each of the separate information signals onto different subcarriers. OFDM signals are made up from a sum of sinusoids, with each corresponding to a subcarrier. 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. Fig2. (1a), (2a), (3a) and (4a) show individual subcarriers, with 1, 2, 3, and 4 cycles per symbol respectively. The phase on all these subcarriers is zero. Note, that each subcarrier has an integer number of cycles per symbol, making them cyclic. Adding a copy of the symbol to the end would result in a smooth join between symbols. (1b), (2b), (3b) and (4b) show the FFT of the time waveforms in (1a), (2a), (3a) and (4a) respectively. (4a) and (4b) shows the result for the summation of the 4 subcarriers. Shows the construction of an OFDM signal with four Sets of functions are orthogonal to each other if they match the conditions of orthogonality.

If any two different functions within the set are multiplied, and integrated over a symbol period, the result is zero, for orthogonal functions. Another way of thinking of this is that if we look at a matched receiver for one of the orthogonal functions, a subcarrier in the case of OFDM, then the receiver will only see the result for that function. The results from all other functions in the set integrate to zero, and thus have no effect.

Equation (1) shows a set of orthogonal sinusoids, which represent the subcarriers for an unmodulated real OFDM signal

$S_k(t)$= Sin (2 pi k $f_o t$) $\quad 0<t<T$ where k=1,2,3….
=0otherwise (1)
Where
fo= carrier spacing,
M = number of carriers,
T =symbol period.

Since the highest frequency component is *Mfo*the transmission bandwidth is also *Mfo*. These subcarriers are orthogonal to each other because when we multiply the waveforms of any two subcarriers and integrate over the symbol period the result is zero. Multiplying the two sine waves together is the same as mixing these subcarriers. This results in sum and difference frequency components, which will always be integer subcarrier frequencies, as the frequency of the two mixing subcarriers has integer number of cycles.

Since the system is linear we can integrate the result by taking the integral of each frequency component separately then

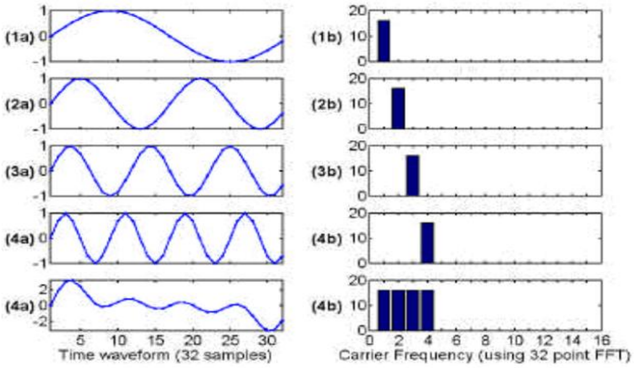

Fig.2 Time domain and Frequency domain construction of an OFDM signal

combining the results by adding the two sub-integrals. The two frequency components after the mixing have an integer number of cycles over the period and so the sub-integral of each component will be zero, as the integral of a sinusoid over an entire period is zero. Both the sub-integrals are zeros and so the resulting addition of the two will also be zero, thus we have established that the frequency components are orthogonal to each other.

IV. PROPERTIES OF OFDM

A) Spectrum and performance

Unshaped QPSK signal produces a spectrum such that its bandwidth is equal to (1+ α) Rs. In OFDM, the adjacent carriers can overlap in the manner shown here. The addition of two carriers, now allows transmitting 3Rs over a bandwidth of -2Rs to 2Rs or total of 4Ts. This gives a bandwidth efficiency of 4/3 Hz per symbol for 3 carriers and 6/5 for 5 carriers. As more and more carriers are added, the bandwidth approaches, So the larger the number of carriers, the better. Here is a spectrum of an OFDM signal. Note that the out of band signal is down by 50 dB without any pulse shaping. The BER of an OFDM is only exemplary in a fading environment. We would not use OFDM is a straight line of sight link such as a satellite link. OFDM signal due to its amplitude variation does not behave well in a non-linear channel such as created by high power amplifiers on board satellites. Using OFDM for a satellite would require a fairly large back off, on the order of 3 dB, so there must be some other compelling reason for its use such as when the signal is to be used for a moving user.

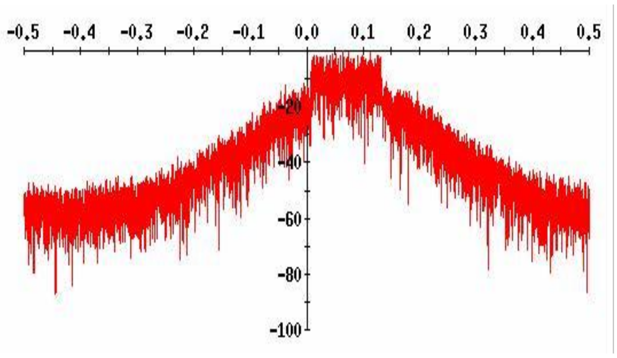

Fig.3 The spectrum of an OFDM signal with 1024 sub-carriers.

B) Bit Error Rate performance

The BER of an OFDM is only exemplary in a fading environment. We would not use OFDM is a straight line of sight link such as a satellite link. OFDM signal due to its amplitude variation does not behave well in a non-linear channel such as created by high power amplifiers on board satellites. Using OFDM for a satellite would require a fairly large back off, on the order of 3 dB, so there must be some other compelling reason for its use such as when the signal is to be used for a moving user.

C) *Peak to average power ratio (PAPR)*

If a signal is a sum of N signals each of max amplitude equal to 1V, then it is conceivable that we could get maximum amplitude of N that is all N signals add at a moment at their max points.

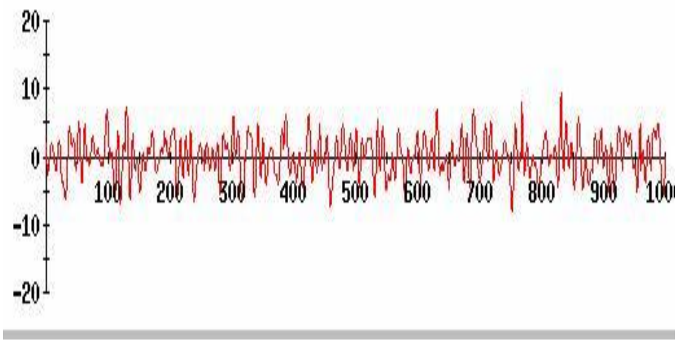

Fig.4 OFDM signal is very noise like. It looks just like a composite multi-FDM signal.

For an OFDM signal that has 128 carriers, each with normalized power of 1 w, then the max PAPR can be as large as log (128) or 21 dB. This is at the instant when all 128 carriers combine at their maximum point, unlikely but possible. The RMS PAPR will be around half this number or 10-12 dB. This same PAPR is seen in CDMA signals as well. The large amplitude variation we see in Fig. 1 increases in-band noise and increases the BER when the signal has to go through amplifier non-linearities. Large back off is required in such cases. This makes use of OFDM just as problematic as Multi-carrier FDM in high power amplifier applications such as satellite links.

D) Synchronization

The other problem is that tight synchronization is needed. Often pilot tones are served in the sub- carrier space. These are used to lock on phase and to equalize the channel.

E) Coding

The sub-carriers are typically coded with Convolutional coding prior to going through IFFT. The coded version of OFDM is called COFDM or Coded OFDM

V. OFDM GENERATION AND RECEPTION

OFDM signals are typically generated digitally due to the difficulty in creating large banks of phase lock oscillators and receivers in the analog domain. Figure.5 shows the block diagram of a typical OFDM transceiver. The transmitter section converts digital data to be transmitted, into a mapping of subcarrier amplitude and phase. It then transforms this spectral representation of the data into the time domain using an Inverse Discrete Fourier Transform (IDFT). The Inverse Fast Fourier Transform (IFFT) performs the same operations as an IDFT, except that it is much more computationally efficiency, and so is used in all practical systems. In order to transmit the OFDM signal the calculated time domain signal is then mixed up to the required frequency. 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 subcarriers 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 interchangeably.

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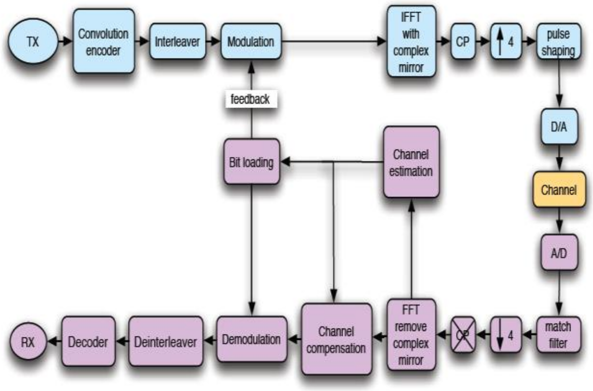

Fig.5 The block diagram of a typical OFDM System

VI. PROTECTION AGAINST TIME OFFSET

To decode the OFDM signal the receiver has to take the FFT of each received symbol, to work out the phase and amplitude of the subcarriers. For an OFDM system that has the same sample rate for both the transmitter and receiver, it must use the same FFT size at both the receiver and transmitted signal in order to maintain subcarrier orthogonality. Each received symbol has *TG* + *TFFT* samples due to the added guard period. The receiver only needs *TFFT* samples of the received symbol to decode the signal. The remaining *TG* samples are redundant and are not needed. For an ideal channel with no delay spread the receiver can pick any time offset, up to the length of the guard period, and still get the correct number of samples, without crossing a symbol boundary. Because of the cyclic nature of the guard period changing the time offset simply results in a phase rotation of all the subcarriers in the signal. The amount of this phase rotation is proportional to the subcarrier frequency, with a subcarrier at the nyquist frequency changing by 180degree for each sample time offset. Provided the time offset is held constant from symbol to symbol, the phase rotation due to a time offset can be removed out as part of the channel equalisation. In multipath environments ISI reduces the effective length of the guard period leading to a corresponding reduction in the allowable time offset error.

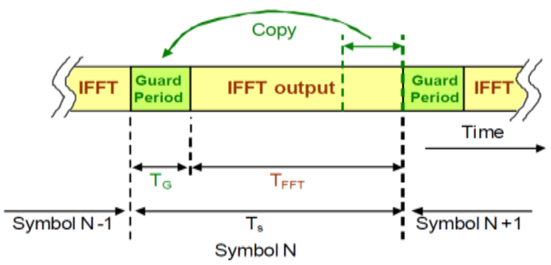

Fig.6 Guard period insertion

VII. PROTECTION AGAINST ISI

In an OFDM signal the amplitude and phase of the subcarrier must remain constant over the period of the symbol in order for the subcarriers to maintain orthogonality. If they are not constant it means that the spectral shape of the subcarriers will not have the correct sinc shape, and thus the nulls will not be at the correct frequencies, resulting in Inter-Carrier Interference. At the symbol boundary the amplitude and phase change suddenly to the new value required for the next data symbol. In multipath environments ISI causes spreading of the energy between the symbols, resulting in transient changes in the amplitude and phase of the subcarrier at the start of the symbol. The length of these transient effects corresponds to the delay spread of the radio channel. The transient signal is a result of each multipath component arriving at slightly different times, changing the received subcarrier vector. Figure shows this effect. Adding a guard period allows time for the transient part of the signal to decay, so that the FFT is taken from a steady state portion of the symbol. This eliminates the effect of ISI provided that the guard period is longer than the delay spread of the radio channel. The remaining effects caused by the multipath, such as amplitude scaling and phase rotation are corrected for by channel equalization.

VIII. ADVANTAGES

1. Makes efficient use of the spectrum by allowing overlap.
2. By dividing the channel into narrowband flat fading sub channels, OFDM is more resistant to frequency selective fading than single carrier systems are.
3. Eliminates ISI and IFI through use of a cyclic prefix.
4. Using adequate channel coding and interleaving one can recover symbols lost due to the frequency selectivity of the channel.
5. Channel equalization becomes simpler than by using adaptive equalization techniques with single carrier systems.
6. It is possible to use maximum likelihood decoding with reasonable complexity.
7. OFDM is computationally efficient by using FFT techniques to implement the modulation and demodulation functions.
8. Is less sensitive to sample timing offsets than single carrier systems are.
9. Provides good protection against cochannel interference and impulsive parasitic noise.

IX. DISADVANTAGES

1. The OFDM signal has a noise like amplitude with a very large dynamic range; therefore it requires RF power amplifiers with a high peak to average power ratio.
2. It is more sensitive to carrier frequency offset and drift than single carrier systems are due

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 1 Issue 6, August - 2012

X. SIMULATION FLOWCHART

Figure.4 shows a simplified flowchart of the MATLAB simulation code

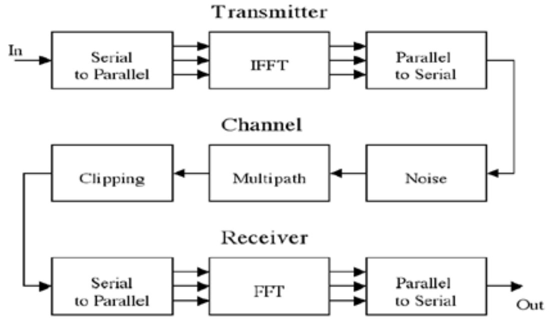

Fig.7 The simulation block diagram of OFDM

XI.RESULT OF MATLAB SIMULATUION

The MATLAB simulation accepts inputs of binary data and text files. It then generates the corresponding OFDM transmission, simulates a channel, attempts to recover the input data, and performs an analysis to determine the transmission error rate. In order to compare OFDM to a traditional single carrier communication system, a 16-QAM simulation can be performed. These simulations are dynamic, allowing the user to set parameters determining the characteristics of the communication system. The graphs and the plots as a result of performing simulation of OFDM have been shown:

1. BINARY DATA TRANSMISSION AND RECEIPTION

Fig.8 Binary file transmission &receiption using OFDM by using GUI

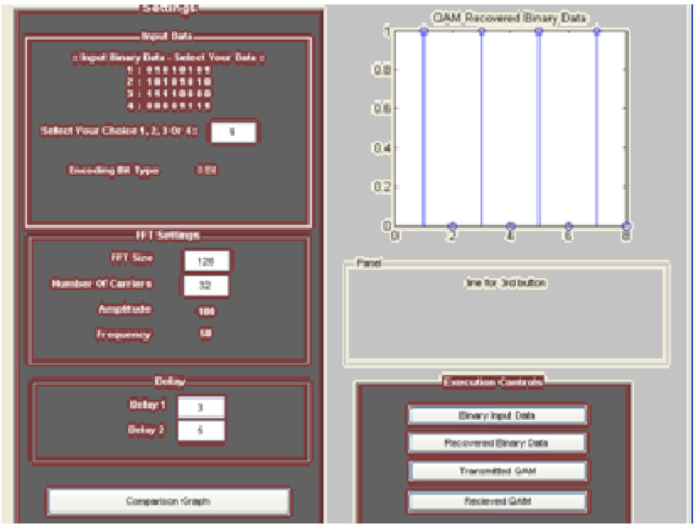

Fig.9 Binary file transmission &receiption using QAM by using GUI

3. SIMULATION OF TEXT FILE

A) Original Text

This is a text file for testing OFDM. You will see that OFDM can handle multipath channels much better than QAM. The reason is that OFDM spreads the data across a broad frequency band so each frequency component can carry less data.

Thank you for trying OFDM!

B) *Simulation Result of OFDM Transmission*

This is a text file for testing OFDM. You will see that OFD] can handle multipath channels much better than QAM. The reason is that OFDM spreads the data across a broad frequency band so each frequency component can carry less data.

Thank you for trying _FDM!

C) *Simulation Result of 16-QAM Transmission*

Tlis_ms_e$xext$ªle$jo"xesding_OGDM._]oezYll$¶Te$xhat$? DMgPm_hamdle$multipath$ §Xamn %ls_mucX$¦dtterxham U??._Xle$udar^_ms hat$?GDM `eads_xhe $hata$eban#b_e$ fqnQd$ª qdqtenchf`md$¶^_ eabX$ª qdqtench g^_0o^%nt$ §Pm gPqqxlesb_hata-_U?? lar_xhedata$g^_# Tntr`ted $¥qn%nd$¥$v

OFDM transmission had a very low bit error rate of 0.0699% so only four errors were caused by the multipath channel. 16-QAM incurred a 23.0% bit error rate. Since a character is represented by eight bits, every character had two bits in error on average. This resulted in Unintelligible received text.

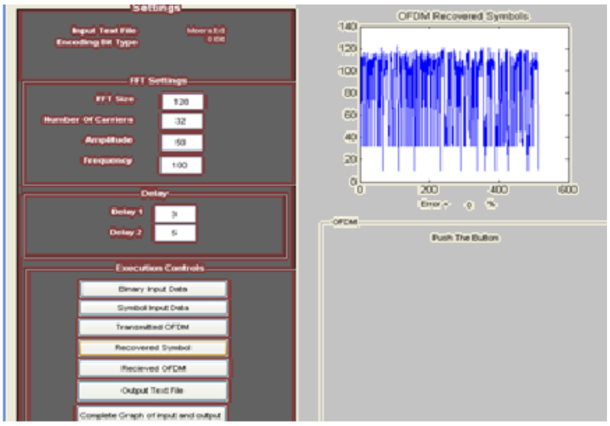

Fig.10 Text file transmission & receiption using OFDM by using GUI.

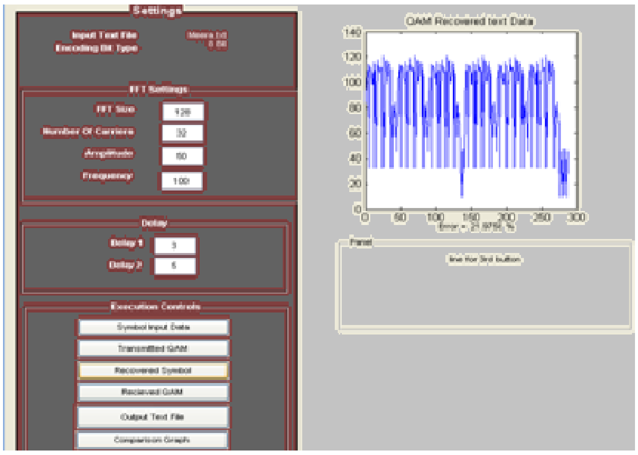

Fig.11 Text file transmission & receiption using QAM by using GUI.

XII. CONCLUSION

This paper proves that OFDM is better suited to a multipath channel than a single carrier transmission technique such as 16-QAM. Future research may be based on this project. These extensions may include channel phase shift detection and correction, error correction by coding, adaptive transmission, peak to average power ratio considerations, DSP implementation and marine transportation

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