DESIGN IMPLEMENTATION OF ORTHOGONAL FREQUENCY DEVISION MULTIPLEXING SIGNALLING

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CERTIFICATE

This is to certify that the work entitled, "**Design Implementation of Orthogonal Frequency Division Multiplexing Signaling** " submitted by BISWAJIT MOHANTY in partial fulfillment for the award of degree of **Bachelor of Technology** in ECE of Jaypee University of Information Technology has been carried out under my supervision. This work has not been submitted partially or wholly to any other University or Institute for the award of this or any other degree or diploma.

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Biswajit Mohanty

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LIST OF ABBREVIATIONS

OFDM: Orthogonal Frequency Divison Multiplexing

MATLAB: Matrix Labrotories

IDFT: Inverse Discrete Fourier Transform

IFFT: Inverse Fast Fourier Transform

DVB: Double Vestigial Side band

FEC: Forward Error Correction

TDM: Time Divison Multiplexing

FDM: Freuency Divison Multiplexing

QPSK: Quadrature Phase Shift Keying

BPSK: Binary Phase Shift Keying

IQ: In-phase Quadrature Phase

QAM: Quadrature Amplitude Modulation

CP: Cyclic Prefix

ISI: Inter Symbol Interference

BPF: Band Pass Filter

ABSTRACT

This paper describe OFDM and its application to mobile communications. OFDM is a modulation and multiple access technique which promises to be a key technique for achieving the high data capacity and spectral efficiency requirements for wireless communication systems of near future.This paper will review the fundamentals behind OFDM technique and simulation of OFDM Transmitter and OFDM receiver has been done successfully in Matlab.

1. *INTRODUCTION*

ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM) is a special case of Frequency Division Multiplexing. OFDM is a combination of modulation and multiplexing. Multiplexing generally refers to independent signals, those produced by different sources. In OFDM the question of multiplexing is applied to independent signal but these independent signals are a subset of one main signal . In OFDM the signal is first split into independent channels, modulated by data and then re-multiplexed to create the OFDM carrier. The main concept of the OFDM signals is the orthogonality of the sub carriers. Since all the carriers are either sine or cosine wave and the area of the curves under one time period is zero, hence signals are orthogonal.OFDM transmit data as a set of parallel low bandwidth (100Hz-50KHz) carriers. The frequency spacing between carriers is made to be the reciprocal of the useful symbol period. The resulting carriers are orthogonal to each other provided correct time windowing at the receiver is used. The carrier is independent of each other even though their spectra overlap. OFDM can be easily generated using an IFFT and received using aFFT.High data rate system are achieved by using a large number of carriers(i.e. 2000-8000 as used in DVB).OFDM allows for a high spectral efficiency as the carrier power and modulation scheme can be individually controlled for each carriers. However in broadcast system these are fixed due to the one way communication. In most communication system two way communication is required and multiple users must be supported. OFDM can be applied in a multiuser application providing a highly flexible, efficient communication system The system design of a multi-user OFDM system is dependent on the intended application and hardware complexity. This paper presents multi-user OFDM in a more general form and outlines some of the Potential techniques that could be used to make it a highly efficient and reliable communication system.OFDM systems are more bandwidth efficient as compared to the corresponding FDM systems.

1.1 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 communication. Many 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 these 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 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.The 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 combining the results by adding the two subintegrals 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.

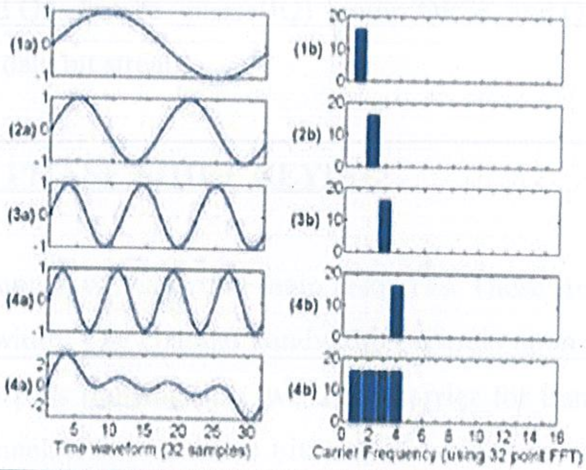

Fig. 1 shows the construction of an OFDM signal with four subcarriers

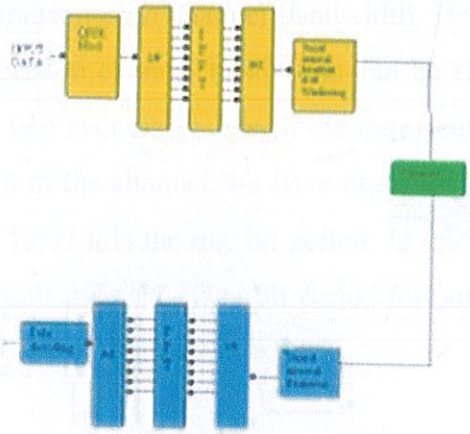

Fig. 2 OFDM Generation And Reception

2. BASIC TRANSMITTER SECTION

2.1 MODULATER :-

Once each subcarrier has been allocated bits for transmission, they are mapped using a modulation scheme to a subcarrier amplitude and phase, which is represented by a complex In –phase and Quadrature –phase(IQ) vector. QPSK and QAM are basically used to modulate incoming data bit stream.

QUARDRATURE PHASE SHIFT KEYING

In communication systems, we have two main resources. These are the transmission power and the channel bandwidth. The channel bandwidth depends upon the bit rate or signaling rate f_b. In digital band pass transmission, we use a carrier for transmission This carrier is transmitted over a channel. If two or more bits are combined in some symbols, then the signaling rate will be reduced. Thus, the frequency of the carrier needed is also reduced. This reduces the transmission channel bandwidth. Hence, because of grouping of bits in symbols, the transmission channel bandwidth can be reduced. In QUADRATURE PHASE SHIFT KEYING, two successive bits in the data sequence are grouped together. This reduces the band width of the channel.We have observed that the bandwidth of BPSK signal is equal to$2f_b$. Here, $T_b=1/ f_b$ is the one bit period. In QPSK, the two waveforms $b_e(t)$ and bo(t) form the base band signals. One bit period for both of these signals is equal to $2T_b$. Therefore, bandwidth of QPSK signal will be

$$BW = 2 \cdot 1/2\ T_b = fb$$

Hence the band width of QPSK signal is half of the bandwidth of BPSK signal. Earlier, we have observed that noise immunity of QPSK and BPSK is same. This shows that in spite of the reduction in bandwidth in QPSK, the noise immunity remains the Same as compare to BPSK.

2.2 SERIAL TO PARALLEL CONVERSION

Data to be transmitted is typically in the form of a serial data stream. In OFDM, each symbol typically transmits 40 - 4000 bits, and so a serial to parallel conversion stage is needed to convert the input serial bit stream to the data o be transmitted in each OFDM symbol. The data allocated to each symbol depends on the modulation scheme used and the number of subcarriers. For example, for a subcarrier modulation of 16-QAM each subcarrier carries 4 bits of data, and so for a transmission using 100 subcarriers the number of bits per symbol would be 400.When an OFDM transmission occurs in a multipath radio environment, frequency selective fading can result in groups of subcarriers being heavily attenuated, which in turn can result in bit errors. These nulls in the frequency response of the channel can cause the information sent in neighboring carriers to be destroyed, resulting in a clustering of the bit errors in each symbol. Most Forward Error Correction (FEC) schemes tend to work more effectively if the errors are spread evenly, rather than in large clusters, and so to improve the performance most systems employ data scrambling as part of the serial to parallel conversion stage. This is implemented by randomizing the subcarrier allocation of each sequential data bit. At the receiver the reverse scrambling is used to decode the signal. This restores the original sequencing of the data bits, but spreads clusters of bit errors so that they are approximately uniformly distributed in time. This randomization of the location of the bit errors improves the performance of the FEC and the system as a whole.

2.3 FREQUENCY DOMAIN CONVERSION

After the subcarrier modulation stage each of the data subcarriers is set to an amplitude and phase based on the data being sent and the modulation scheme; all unused subcarriers are set to zero. This sets up the OFDM signal in the frequency domain. An IFFT is then used to convert this signal to the time domain, allowing it to be transmitted. In the frequency domain, before applying the IFFT, each of the discrete samples of the IFFT corresponds to an individual subcarrier. Most of the subcarriers are modulated with data. One of the key bullets in the OFDM propaganda is the existence of an efficient and simple implementation of transmitter and receiver. This structure is realized through the Discrete Fourier Transform (DFT) and itsinverse (IDFT). The computation of DFT and IDFT are themselves are performed by fast Fourier transform (FFT) techniques.

2.4 GUARD PERIOD

For a given system bandwidth the symbol rate for an OFDM signal is much lower than a single carrier transmission scheme. Forexample for a single carrier BPSK modulation, The symbol rate corresponds to the bit rate of the transmission. However for OFDM the system bandwidth is broken up into Nc subcarriers, resulting in a symbol rate that is Nc times lower than the single carrier transmi-ssion. This low symbol rate makes OFDM naturally resistant to effects of Inter-Symbol Interference (ISI) caused by multipath propagation. Multipath propagation is caused by the radio transmission signal reflecting off objects in the propagation environment, such as walls, buildings, mountains, etc. These multiple signals arrive at the receiver at different times due to the transmission distances being different. This spreads the symbol boundaries causing energy leakage between them. The effect of ISI on an OFDM signal can be further improved by the addition of a guard period to the start of each symbol. This guard period is a cyclic copy that extends the length of the symbol waveform. Each subcarrier, in the data section of the symbol, (i.e. the OFDM symbol with no guard period added, which is equal to the length of the IFFT size used to generate the signal) has an integer number of cycles. Because of this, placing copies of the symbol end-to-end results in a continuous signal, with no discontinuities at the joins. Thus by copying the end of a symbol and appending this to the start results in a longer symbol time. Figure shows the insertion of a guard period. The OFDM time-domain samples at the output of IFFT, {x1, x2,..., x N-1}, are subsequently guard padded by enough samples to eliminate the interference between adjacent OFDM symbols caused by the delay-spread of themultipath channel. Hence, for each OFDM symbol, some of the time-domain samples of the OFDM symbol are cyclically added from its end to the beginning. Figure indicates how the channel's delay spread causes Inter-Symbol Interference (ISI) and how the cyclic prefix(CP) eliminates this ISI. Finally, the parallel time-domain samples are converted to the serial time-domain.

3. BASIC RECEIVER SYSTEM

3.1 GUARD BAND REMOVAL

The guard band is added in the transmitter section to overcome the problem of inter symbol interference. The inter symbol interference arises due to dispersion of bits. In the receiver section due to inter symbol interference the bits present at the of the message may be lost. To overcome this in this block the cyclic prefixes removed and added at the end of the message bits, so as to get the original bit stream. The effect of ISI on an OFDM signal can be further improved by the addition of a guard period to the start of each symbol. This guard period is a cyclic copy that extends the length of the symbol waveform. Each subcarrier, in the data section of the symbol, (i.e. the OFDM symbol with no guard period added, which is equal to the length of the IFFT size used to generate the signal) has an integer number of cycles. Because of this, placing copies ofthe symbol end-to-end results in a continuous signal, with no discontinuities at the joins. Thus by copying the end of a symbol and appending this to the start results in a longer symbol time, results in a continuous signal, with no discontinuities at the joins. Thus by copying the end of a symbol and appending this to the start results in a longer symbol time.

3.2 FAST FOURIER TRANSFORM

This block is used to bring the frequency domain signal into time domain. The formula to compute fast fourier transform is given as

$$W = e^{2\pi i/N}$$

$$H_n = \sum_{k=0}^{N-1} W^{nk} h_k$$

In other words, the vector of hk's is multiplied by a matrix whose (n,k)th element is theconstant W to the power n k. The matrix multiplication produces a vector result whose components are the Hn's. This matrix multiplication evidently requires N2 complex multiplications, plus a smaller number of operations to generate the required powers of W. So, the discrete Fourier transform appears to be an O(N 2) process. These appearances are deceiving! The discrete Fourier transform can, in fact, be computed in O(N log2 N) operations with an algorithm called the fast Fourier transform, or FFT.

3.3 QPSK DEMODULATOR

This is synchronous reception. Hence, the coherent carrier is to be recovered from the received signal s(t). The received signal s(t) is first raised to the 4^{th} power,i.e.s^4 (t). After that, it allowed to pass through band pass filter (BPF) which is centered around $4f_c$. The output of the band pass filter is a coherent carrier of frequency $4f_c$. This is divided by 4 and it provides two coherent quardrature carriers are applied to two synchronous demodulators. These synchronous demodulators consist of multiplier and an integrator.

The incoming signal is applied to both the multipliers. Here, the integrator integrates the product signal over two bit interval (i.e.,$T_s=2T_b$). At the end of this period, the output of integrator is sampled. The output of the two integrators are sampled at the offset if one bit period, T_b Hence, the output of the multiplexer is the signal b(t). This means that the odd and even sequences are combined by multiplexer.

4. MATLAB SIMULATION WITH SOUND INPUT

Fig.3 shows one example of the graphs generated by the current MATLAB code. The upper left plot is the input sound file. After modulation, the corresponding OFDM trans-mission is shown on the upper right. For this example, a perfect channel was assumed which means that the received signal (lower right) exactly matches the transmitted. Finally the received OFDM signal is demodulated to reproduce original input data.

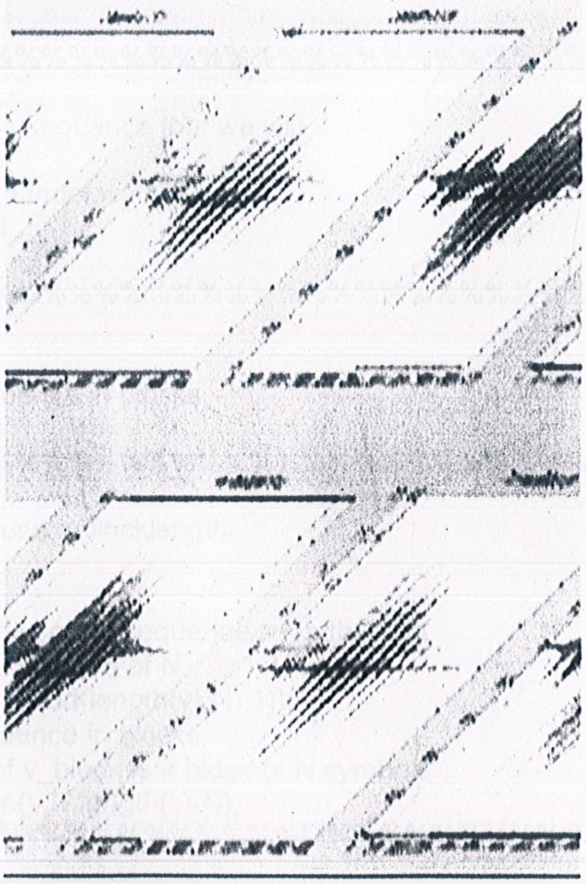

Fig.3 MATLAB Simulation with Sound

MATLAB IMPLEMENTATION

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
%
% Loading audio
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
% Load the sound sequence that we will
% use for testing.
[v,fs] = wavread('handel.wav');
% Let's listen to it...
soundsc(v,fs);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
%
% Divide the sequence in blocks
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
% We choose to use a blocklength
% of N = 1024.
N = 1024;
% Add zeros to the sound sequence such that the
% total length is a multiple of N.
v = [v; zeros(1024-mod(length(v),N),1)];
% Divide the sequence in blocks.
% Each column of v_block is a block of N symbols
v_block = reshape(v,N,length(v)/N);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
%
% The channel
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
impulse_response = [ <<removed for handout>> ];
```

Figure 4: MATLAB implementation: Initialization. Loading audio and dividing it into blocks.The channel impulse response is known at the receiver, so we give it here

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
%
% Transmit the signal over the channel. We use a
% trivial transmitter and receiver.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
% Initialization
x = zeros(size(v_block,1),1);
y = zeros(size(v_block,1),1);
v_tilde_block = zeros(size(v_block));
% Now do all operations per block
for i=1:size(v_block,2)
x = trivial_transmitter(v_block(:,i));
y = lti_channel(x);
v_tilde_block(:,i) = trivial_receiver(y);
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
%
% Check the result.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
% Put all blocks back together in one sequence.
v_tilde = reshape(v_tilde_block,size(v));
% ... and listen to what we received.
soundsc(v_tilde,fs);
```

Figure 5: MATLAB implementation: Transmission using the trivial transmitter and receiver

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
%
% Trivial transmitter.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
function x = trivial_transmitter(v)
x = v;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
%
% Trivial receiver.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
function v_tilde = trivial_receiver(y)
v_tilde = y;
```

Figure 6: MATLAB implementation: A trivial transmitter and receiver.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
%
% OFDM transmitter.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
function x = ofdm_transmitter(v,nu)
% The receiver needs nu as an additional argument
% to know how long the cyclic prefix needs to be
% Resampling
v_down = resample(v,7,8);
% (We could compute the factors 7/8 from the function arguments
```

```
% but we cheat a bit here...)
% Inverse DFT
x_prime = ifft(v_down);
% Apply the cyclic prefix
x = [x_prime(end-nu+1:end); x_prime];
```

Figure 7: MATLAB implementation: OFDM transmitter

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
%
% OFDM receiver.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
function v_tilde = ofdm_receiver(y,nu,impulse_response)
% The OFDM receiver has 2 additional arguments, the length
% of the cyclic prefix and the impulse response of the
% channel.
% Remove the cyclic prefix
y_cut = y(nu+1:end);
% DFT
Y = fft(y_cut);
% Scale
H = fft(impulse_response,length(Y));
v_tilde_down = Y./H.';
% ...we are still working in the "downsampled regime"
% We know that v_tilde_down is real, but MATLAB keeps it as a
% complex variable.
v_tilde_down = real(v_tilde_down);
v_tilde = resample(v_tilde_down,8,7);
v_tilde = v_tilde(1:1024);
% (Again, we could have computed the upsampling factor and the
% block length from the function arguments, but we cheat a bit
% to keep the code easy.)
```

Figure 8: MATLAB implementation: OFDM receiver.

5. CONCLUSION

This Paper presents the basis of the future technology in mobile communications. The OFDM systems as mentioned in the project will form the 4th generation of mobile communication in which the bandwidth requirement will be half the today's need. This system will also improve the data transmission rates as well as the fidelity of the system. Simulation of this type of system in Rayleigh fading channel will improve the concept of global connectivity as no obstruction will be able to stop signal reaching to the mobile subscriber. Thus this system is the need of the hour. With the increasing number of the mobile users, this system will become the biggest technology in the coming times.

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