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Simulation Study and Analysis of OFDM

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ABSTRACT

In this paper, we describe the Orthogonal frequency division multiplexing (OFDM) is an established technique for wireless communication applications. Typical constraints faced during OFDM transmission are: a large peak-to-mean envelope power ratio, which can result in significant distortion when transmitted through a nonlinear device, such as a transmitter power amplifier. We study the effects of clipping and filtering on the performance of OFDM, including the power spectral density, BER, through intensive MATLAB simulation. We have indigenously simulated the effect of multipath fading to ensure that all specifications of OFDM transmission are taken care of. To simulate the modulation of the sub-carriers, we have chosen DQPSK. The way OFDM handles ISI has also been encompassed.

General Terms

Orthogonal frequency division multiplexing (OFDM) for wireless communication.

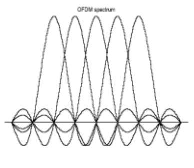
Keywords

OFDM, BER,.

1. INTRODUCTION

It is valuable to discuss the mathematical definition of OFDM. This allows us to see how the signal is generated and how the receiver must operate, and it gives us a tool to understand the effects of imperfections in the transmission channel. OFDM transmits a large number of narrowband carriers, closely spaced in the frequency domain. In order to avoid a large number of modulators and filters at the transmitter and complementary filters and demodulators at the receiver, it is desirable to be able to use modern digital signal processing techniques, such as fast Fourier transform (FFT) [2]. Mathematically, each carrier can be described as a complex wave:

$$s_c(t) = A_c(t)\, e^{j\left[\omega_c t + \phi_c(t)\right]}$$



The real signal is the real part of $S_c(t)$. Both $A_c(t)$ and $f_c(t)$, the amplitude and phase of the carrier, can vary on a symbol by symbol basis. The values of the parameters are constant over the symbol duration

$$s_s(t) = \frac{1}{N}\sum_{n=0}^{N-1} A_N(t)\, e^{j\left[\omega_n t + \phi_n(t)\right]} \qquad \text{-------- (1)}$$

where,

$$\omega_n = \omega_0 + n\Delta\omega$$

This is of course a continuous signal. If we consider the waveforms of each component of the signal over one symbol period, then the variables *Ac(t)* and *fc(t)* take on fixed values, which depend on the frequency of that particular carrier, and so can be rewritten:

$$\phi_n(t) \Rightarrow \phi_n$$
$$A_n(t) \Rightarrow A_n \qquad \text{-------- (2)}$$

If the signal is sampled using a sampling frequency of 1/T, then the resulting signal is represented by:

$$s_s(kT) = \frac{1}{N}\sum_{n=0}^{N-1} A_n e^{j\left[(\omega_0 + n\Delta\omega)kT + \phi_n\right]} \qquad \text{-------- (3)}$$

At this point, we have restricted the time over which we analyze the signal to N samples. It is convenient to sample over the period of one data symbol. Thus we have a relationship:

$$\tau = NT$$

If we now simplify eqn. 3, without a loss of generality by letting w0=0, then the signal becomes:

$$s_s(kT) = \frac{1}{N}\sum_{n=0}^{N-1} A_n e^{j\phi_n}\, e^{j(n\Delta\omega)kT} \qquad \text{-------- (4)}$$

Now Eq. 4 can be compared with the general form of the inverse Fourier transform:

$$g(kT) = \frac{1}{N}\sum_{n=0}^{N-1} G\left(\frac{n}{NT}\right) e^{j2\pi nk/N} \qquad \text{---------- (5)}$$

In eq. 4, the function $A_n e^{j\Phi_n}$ is no more than a definition of the signal in the sampled frequency domain, and *s(kT)* is the time domain representation. Eqns. 4 and 5 are equivalent if:

$$\Delta f = \frac{\Delta\omega}{2\pi} = \frac{1}{NT} = \frac{1}{\tau}$$

This is the same condition that was required for orthogonality. Thus, one consequence of maintaining orthogonality is that the OFDM signal can be defined by using Fourier transform procedures. The IFFT & FFT operations are naturally performed through easily available commands in MATLAB$^{\text{TM}}$

2. OFDM MODEL [6]

All The OFDM system was modeled using MATLAB$^{\text{TM}}$ to allow various parameters of the system to be varied and tested. The aim of doing the simulations was to measure the performance of OFDM under different channel conditions, and to allow for different OFDM configurations to be tested. Four main criteria were used to assess the performance of the OFDM system, which were its tolerance to multipath delay spread, peak power clipping, channel noise and time synchronization errors.

The OFDM system was modeled using the Communications Toolbox, Signal Processing Toolbox and Simulink of MATLAB$^{\text{TM}}$, and is shown in Figure 2.1 A brief description of the model is provided below.

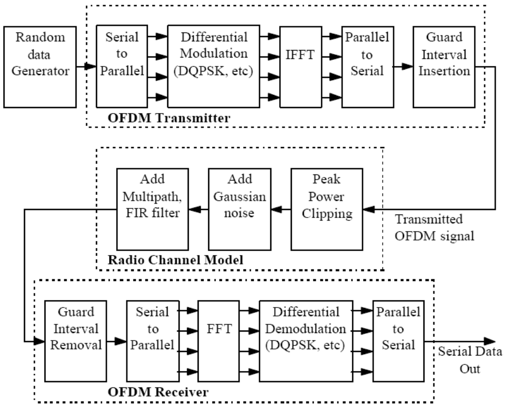


Fig2.1:OFDM Model used for simulations.

3. OFDM

3.1 Serial to Parallel Conversion

The input serial data stream is formatted into the word size required for transmission, e.g. 2 bits/word for QPSK, and shifted into a parallel format. The data is then transmitted in parallel by assigning each data word to one carrier in the transmission.

3.2 Modulation of Data

PThe data to be transmitted on each carrier is then differentially encoded with previous symbols, and then mapped into a PSK format. Since differential encoding requires an initial phase reference an extra symbol is added at the start for this purpose. The data on each symbol is then mapped to a phase angle based on the modulation method. For example, for QPSK the phase angles used are 0, 90, 180, and 270 degrees. The use of phase shift keying produces a constant amplitude signal and was chosen for its simplicity and to reduce problems with amplitude fluctuations due to fading.

3.3 Inverse Fourier Transform

After the required spectrum is worked out, an inverse Fourier transform is used to find the corresponding time waveform. The guard period is then added to the start of each symbol.

3.4 Guard Period

The guard period used was made up of two sections. Half of the guard period time is a zero amplitude transmission. The other half of the guard period is a cyclic extension of the symbol to be transmitted. This was to allow for symbol timing to be easily recovered by envelope detection. However it was found that it was not required in any of the simulations as the timing could be accurately determined position of the samples. After the guard has been added, the symbols are then converted back to a serial time waveform. This is then the base band signal for the OFDM transmission.

3.5 Channel

A channel model is then applied to the transmitted signal. The model allows for the signal to noise ratio, multipath, and peak power clipping to be controlled. The signal to noise ratio is set by adding a known amount of white noise to the transmitted signal. Multipath delay spread is then added by simulating the delay spread using an FIR filter. The length of the FIR filter represents the maximum delay spread, while the coefficient amplitude represents the reflected signal magnitude.

3.6 Receiver

The receiver basically does the reverse operation to the transmitter. The guard period is removed. The FFT of each symbol is then performed to find the original transmitted spectrum. The phase angle of each transmission carrier is then evaluated and converted back to the data word by demodulating the received phase. The data words are then combined back to the same word size as the original data.

3.7 OFDM generation

To generate OFDM successfully, the relationship between all the carriers must be carefully controlled to maintain the orthogonality of the carriers. For this reason, OFDM is generated by first choosing the spectrum required, based on the input data, and modulation scheme used. Each carrier to be produced is assigned some data to transmit. The required amplitude and phase of the carrier is then calculated based on DQPSK. The required spectrum is then converted back to its time domain signal using an Inverse Fourier Transform. In most applications, an Inverse Fast Fourier Transform (IFFT) is used. The IFFT performs the transformation very efficiently, and provides a simple way of ensuring the carrier signals produced are orthogonal.

The Fast Fourier Transform (FFT) transforms a cyclic time domain signal into its equivalent frequency spectrum. This is done by finding the equivalent waveform, generated by a sum of orthogonal sinusoidal components. The amplitude and phase of the sinusoidal components represent the frequency spectrum of the time domain signal. The IFFT performs the reverse process, transforming a spectrum (amplitude and phase of each component) into a time domain signal

3.8 Adding a Guard Period to OFDM

One of the most important properties of OFDM transmissions is its high level of robustness against multipath delay spread. This is a result of the long symbol period used, which minimizes the inter-symbol interference. The level of multipath robustness can be further increased by the addition of a guard period between transmitted symbols. The guard period allows time for multipath signals from the previous symbol to die away before the information from the current symbol is gathered. The most effective guard period to use is a cyclic extension of the symbol.

If a mirror in time, of the end of the symbol waveform is put at the start of the symbol as the guard period, this effectively extends the length of the symbol, while maintaining the orthogonality of the waveform. Using this cyclic extended symbol the samples required for performing the FFT (to decode the symbol), can be taken anywhere over the length of the symbol. This provides multipath immunity as well as symbol time synchronization tolerance.

As long as the multipath delay echoes stay within the guard period duration, there is strictly no limitation regarding the signal level of the echoes: they may even exceed the signal level of the shorter path! The signal energy from all paths just add at the input to the receiver, and since the FFT is energy conservative, the whole available power feeds the decoder. If the delay spread is longer than the guard interval then they begin to cause inter-symbol interference. However, provided the echoes are sufficiently small they do not cause significant problems. This is true most of the time as multipath echoes delayed longer than the guard period will have been reflected of very distant objects.

3.9 OFDM parameters [2]

Table 3.1 shows the configuration used for most of the simulations performed on the OFDM signal. An 800-carrier system was used, as it would allow for up to 100 users if each were allocated 8 carriers. The aim was that each user has multiple carriers so that if several carriers are lost due to frequency selective fading that the remaining carriers will allow the lost data to be recovered using forward error correction. For this reason any less than 8 carriers per user would make this method unusable. Thus 400 carriers or less was considered too small. However more carriers were not used due to the sensitivity of OFDM to frequency stability errors. The greater the number of carriers a system uses, the greater it required frequency stability.

2.1 Table

Parameter	**Value**
Carrier Modulation used	DBPSK, DQPSK, D16PSK
FFT size	1024
Number of carrier used	400
Guard Time	256 samples (25%)
Guard Period Type	Half zero signal, half a cyclic extension of the symbol

4. IMPLEMENTATION

4.1 Transmitter:

The transmitter will generate the signal that will be transmitted through the channel.

The signal or type of data to send in the transmission may be of:

a) Random data

b) Grey scale bitmap image (only the picture data is sent not the file header or colour map). This is useful for high error rate conditions.

c) Wave Sound file This reads in an 8 bit windows 3.1 wav file.

4.2 The transmission of random data

Here, random data is taken as input, which is been divided into N number of frames. Each frame consists of 30 symbols; a symbol is made up of 8 bits. In the above example 12000 bits of random data is taken, which is put into 1 frame. The useful symbol duration *T* affects the carrier spacing and coding latency. To maintain the data throughput, a longer, useful symbol duration results in increase of the number of carriers and the size of FFT (assuming the constellation is fixed). In practice, carrier offset and phase stability may affect how close two carriers can be placed. Generally, the useful symbol duration should be chosen so that the channel is stable for the duration of a symbol.

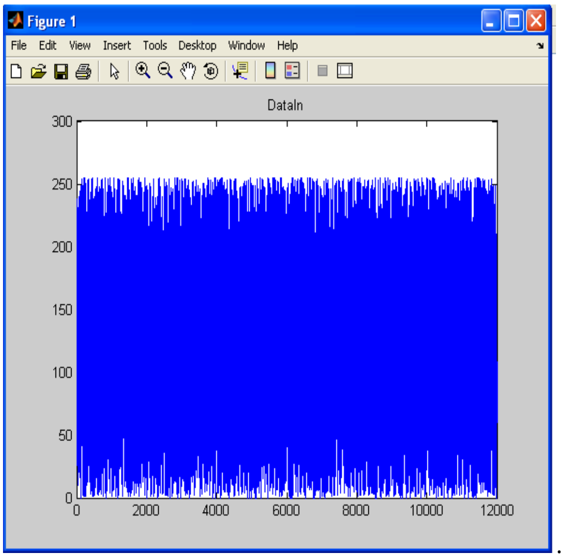


Fig 3.1: The base signal (Random signal)

The input signal is encoded using DQPSK modulation technique as shown in the figure 3.2

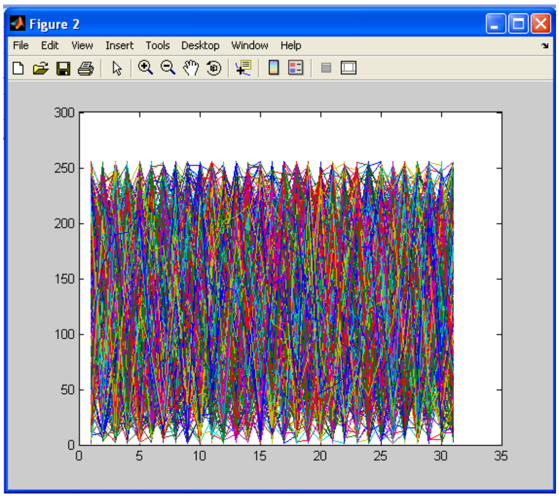


Fig3.2: DQPSK Output

The DQPSK output signal is given to IFFT, where the carriers have been placed orthogonally as shown in figure 3.3.

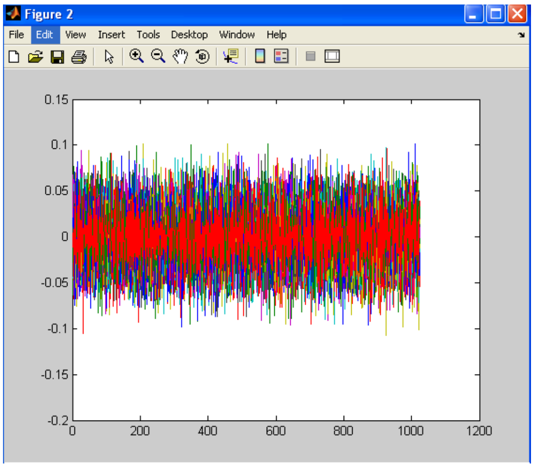


Fig3.3: IFFT Output

4.1 Orthogonality and OFDM

The use of orthogonal subcarriers would allow the subcarriers' spectra to overlap, thus increasing the spectral efficiency. As long as orthogonality is maintained, it is still possible to recover the individual subcarriers' signals despite their overlapping spectrums. If the dot product of two deterministic signals is equal to zero, these signals are said to be orthogonal to each other. Orthogonality can also be viewed from the standpoint of stochastic processes. If two random processes are uncorrelated, then they are orthogonal.

Given the random nature of signals in a communications system, this probabilistic view of orthogonality provides an intuitive understanding of the implications of orthogonality in OFDM. Later in this article, we will discuss how OFDM is implemented in practice using the discrete Fourier transform (DFT). One view of the DFT is that the transform essentially correlates its input signal with each of the sinusoidal basis functions. If the input signal has some energy at a certain frequency, there will be a peak in the correlation of the input signal and the basis sinusoid that is at that corresponding frequency. This transform is used at the OFDM transmitter to map an input signal onto a set of orthogonal subcarriers, i.e., the orthogonal basis functions of the DFT. Similarly, the transform is used again at the OFDM receiver to process the received subcarriers. The signals from the subcarriers are then combined to form an estimate of the source signal from the transmitter. The orthogonal and uncorrelated nature of the subcarriers is exploited in OFDM with powerful results. Since the basis functions of the DFT are uncorrelated, the correlation performed in the DFT for a given subcarrier only sees energy for that corresponding subcarrier. The energy from other subcarriers does not contribute because it is uncorrelated.

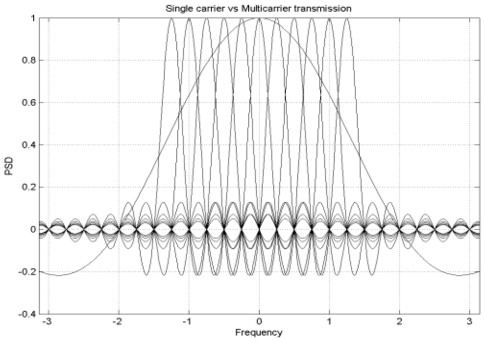


Fig3.4: Single Carrier vs Multicarrier Transmission

This separation of signal energy is the reason that the OFDM subcarriers' spectrums can overlap without causing interference [4] [5].

4.2 OFDM system

The idea behind the analog implementation of OFDM can be extended to the digital domain by using the discrete Fourier Transform (DFT) and its counterpart, the inverse discrete Fourier Transform (IDFT). These mathematical operations are widely used for transforming data between the time-domain and frequency-domain. These transforms are interesting from the OFDM perspective because they can be viewed as mapping data onto orthogonal subcarriers. For example, the IDFT is used to take in frequency-domain data and convert it to time-domain data. In order to perform that operation, the IDFT correlates the frequency-domain input data with its orthogonal basis functions, which are sinusoids at certain frequencies. This correlation is equivalent to mapping the input data onto the sinusoidal basis functions.

In practice, OFDM systems are implemented using a combination fast Fourier Transform (FFT) and inverse fast Fourier Transform (IFFT) blocks that are mathematically equivalent versions of the DFT and IDFT, respectively, but more efficient to implement. An OFDM system treats the source symbols (e.g., the QPSK or QAM symbols that would be present in a single carrier system) at the transmitter as though they are in the frequency-domain. These symbols are used as the inputs to an IFFT block that brings the signal into the time domain. The IFFT takes in N symbols at a time where N is the number of subcarriers in the system. Each of these N input symbols has a symbol period of T seconds. Recall that the basis functions for an IFFT are N orthogonal sinusoids. These sinusoids each have a different frequency and the lowest frequency is DC. Each input symbol acts like a complex weight for the corresponding sinusoidal basis function. Since the input symbols are complex, the value of the symbol determines both the amplitude and phase of the sinusoid for that subcarrier. The IFFT output is the summation of all N sinusoids [4][5].

The IFFT block provides a simple way to modulate data onto N orthogonal subcarriers. The block of N output samples from the IFFT make up a single OFDM symbol. The length of the OFDM symbol is NT where T is the IFFT input symbol period mentioned above. After some additional processing, the time-domain signal that results from the IFFT is transmitted across the channel. At the receiver, an FFT block is used to process the received signal and bring it into the frequency domain.

4.3 Guard band insertion

Guard band(null symbol) is inserted between the frames this was to allow for symbol timing to be easily recovered by envelope detection.

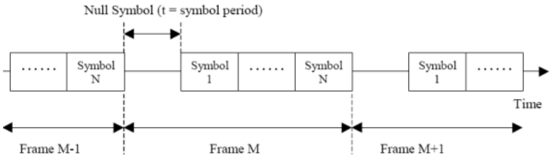


Fig3.5: Frame Structure

The base signal is inserted between the two headers for better synchronization as shown in the figure 3.5.

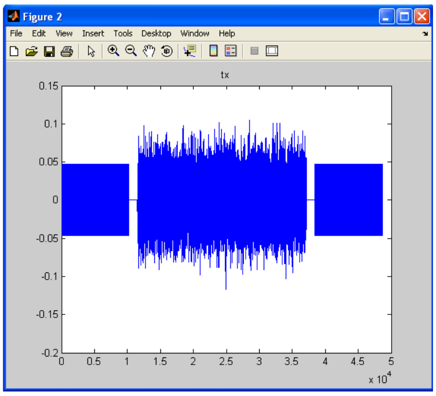


Fig 3.6: Time signal

Time signal = Header + Base signal + Header

The time signal is then transmitted to the channel.

4.4 Multipath channels and the use of cyclic prefix

Problem in most wireless systems is the presence of a multipath channel. In a multipath environment, the transmitted signal reflects off of several objects. As a result, multiple delayed versions of the transmitted signal arrive at the receiver. The multiple versions of the signal cause the received signal to be distorted. Many wired systems also have a similar problem where reflections occur due to impedance mismatches in the transmission line. A multipath channel will cause two problems for an OFDM system. The first problem is intersymbol interference. This problem occurs when the received OFDM symbol is distorted by the previously transmitted OFDM symbol. The effect is similar to the intersymbol interference that occurs in a single- carrier system. However, in such systems, the interference is typically due to several other symbols instead of just the previous symbol; the symbol period in single carrier systems is typically much shorter than the time span of the channel, whereas the typical OFDM symbol period is much longer than the time span of the channel. The second problem is unique to multicarrier systems and is called Intrasymbol Interference. It is the result of interference amongst a given OFDM symbol's own subcarriers.

4.4 Multipath Delay Spread

The received radio signal from a transmitter consists of typically a direct signal, plus reflections of object such as buildings, mountings, and other structures. The reflected signals arrive at a later time than the direct signal because of the extra path length, giving rise to a slightly different arrival time of the transmitted pulse, thus spreading the received energy. Delay spread is the time spread between the arrival of the first and last multipath signal seen by the receiver. In a digital system, the delay spread can lead to inter-symbol interference. This is due to the delayed multipath signal overlapping with the following symbols. This can cause significant errors in high bit rate systems, especially when using time division multiplexing (TDMA). Figure 3.6 shows the effect of inter-symbol interference due to delay spread on the received signal [6].

Inter-symbol interference can be minimized in several ways. One method is to reduce the symbol rate by reducing the data rate for each channel (i.e. split the bandwidth into more channels using frequency division multiplexing). Another is to use a coding scheme which is tolerant to inter-symbol interference such as CDMA.

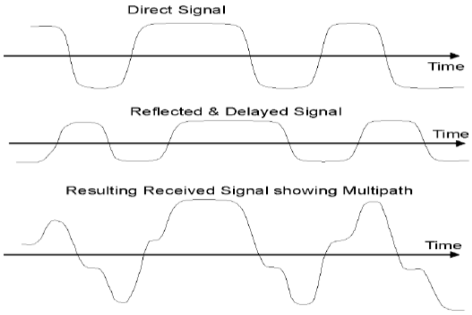


Fig 3.7: Multipath Delay Spread

4.5 Receiver

The output of the channel is given to the receiver where the guard bands are removed and FFT is performed to remove the orthogonality of the carriers. The received signal is decoded and the original data is recovered. The received data is as shown in the figure 3.7.

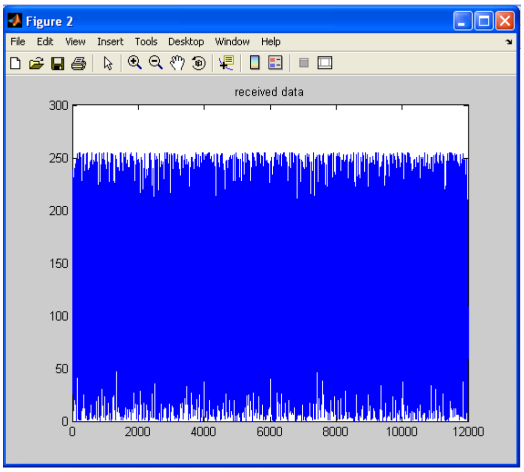


Fig 3.8: Received Data

Calculation of errors:

Calculate the BER

Finally we are going to calculate the bit error rate (BER). BER is defined as the ratio of total number of errors to the total number of data. Total number of errors is the difference between the transmitted data and the received data.

```
Errors = find(Datatx-Datarx);

NumErr = length(Errors);

NumData=size(Datarx,1)*size(Datarx,2);

BER = NumErr/NumData;
```

5. IMPROVEMENTS OVER EXISTING SIMULATIONS

. Simulation performed with DQPSK as the modulation technique for sub-carriers; DQPSK is the modulation most popularly used in modern implementations of OFDM.

. Channel model considered simulates the increasingly constrained and hostile environment in which OFDM operates today. The satisfactory performance of OFDM despite such channel conditions is proven.

. The simulation is also relevant to wired systems with multiple reflections, a situation similar to multipath in wireless systems.

6. CONCLUSION

OFDM has already found wide deployment in various applications such as WLAN [3], vehicular communications [1] [2], etc. An OFDM link has been confirmed to work by using MATLAB^{TM} simulations, and some practical tests performed on a low bandwidth baseband signal. Four main performance criteria have been tested, which are OFDM's tolerance to multipath delay spread, channel noise, peak power clipping and start time error. Several other important factors affecting the performance of OFDM have only been partly measured. These include the effect of frequency stability errors on OFDM and impulse noise effects.

Most practical systems would use forward error correction to improve the system performance. Thus more work needs to be done on studying forward error correction schemes that would be suitable for telephony applications, and data transmission.

We can find many advantages in OFDM, but there are still many complex problems to solve.

This MATLAB^{TM} simulation proves that OFDM is better suited to a multipath channel than a single carrier transmission technique such as 16-QAM.

7. ACKNOWLEDGMENTS

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