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Implementation of Error Control and Correction in Frequency Domain: An OFDM Approach

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***Abstract* – In this paper, we have introduced error-correcting and coding techniques for the binary data that can be derived from the real-number and complex-number fields, infrequency domain. We have implemented our proposed system utilizing digital signal processing methods in order to be operated by the normally available standard programmable digital signal processors. This paper also explains the application of OFDM in our system, operating over a Gaussian, Rician and Rayleigh fading channel with the help of MATLAB simulation. In the course of working with our proposed system and its corresponding simulations, we compared the results obtained by the Bit Error Rates (BER) under variable conditions with other efficient systems using various plots, graphs and diagrams.**

***Index Terms*– AWGN-Additive White Gaussian Noise, OFDM-Orthogonal Frequency Division Multiplexing, LBC-Linear Block Codes and QAM-Quadrature Amplitude Modulation**

I. INTRODUCTION

THE concept of OFDM was well introduced in the early 90's. Over constant research and proper studies through the subject, this innovative concept nowadays has become a part of our modern communication systems due to its vast advantages. Thus came the need for this multiplexing technique for large amount of data especially the real numbers and sparse signal processing that includes data bits range up to Gigabits and Terabits.

The paper begins with a discussion of transforming real data into frequency domain by using signal processing techniques (FFT and IFFT) and encoding it by various source codes at the baseband. The use of Orthogonal Frequency Division Multiplexing (OFDM) technique adds to a new concept in the progress of our research. We make use of this technique here because of the fact that the multiplexing used in this concept requires a Fourier transform of the samples which we have implemented at the baseband itself. Thus there is less complexity in the OFDM block that used FFT and IFFT. Other advantages include better noise immunity, proper guard band and efficient use of the available bandwidth. While working on real numbers we must ensure that the channel shall handle higher amount of data with high speed and shall have low noise in the reception which eventually points us to use this OFDM scheme.

II. OUR PROPOSED SYSTEM

From the Fig. 1, we can conclude the proposed structure or gist of the initial approach of our system. It shows an encoder system which is fed with the Z-transformed bits of the real number sequences that makes us possible working in frequency domain. The 'q' is the modulation technique and the 'e' is the error introduced in our system. In the decoder section the coded bits are estimated, demodulated and detected as the Z-transformed bits. The final binary sequence is calculated using latest DSP processors that introduce high accuracy and low transient response for quick calculations.

The Z-transform method is introduced in our work to implement our proposed system under various stability conditions. As we all know that in frequency domain, the Z-transform becomes very handy in determining stable and causal systems and also implementing data in them efficiently. Thus our improvisation with this method will prove fruitful in working with unstable and non- linear systems too.

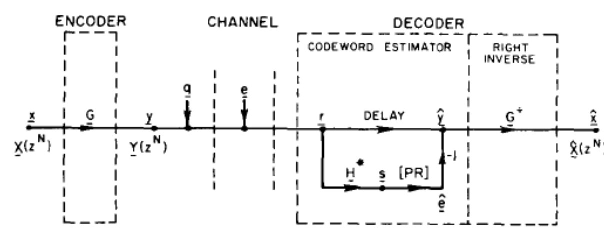

Fig. 1: Block diagram of our system

III. THE OFDM SYSTEM

Transformed data in frequency domain when passed through the channel are always prone to noises in any communication channel. We can't avoid the noise but to reduce it to a minimum level. The main purpose in our paper is not only to pass the data through the channel but also efficiently decode it through the receiver. Hence it is our utmost importance to include efficient algorithms, codes and appropriate robust techniques that ensures less noise and minimum utilization channel bandwidth throughout the system.

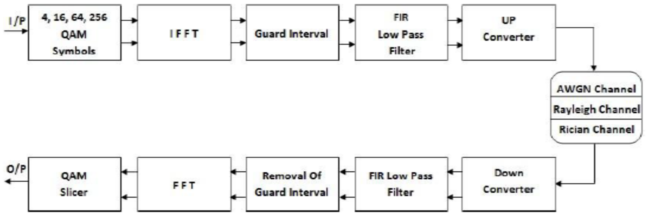

Fig. 2: Block diagram of proposed OFDM system

The purpose behind this OFDM approach in band pass section of our system is to conserve the amount of bandwidth and power which are the main constraints in transmissions of large bits over the channel.

The above is the complete block diagram of our proposed system for an OFDM system. The Z - transformed bits from baseband system are then mapped with QPSK or QAM modulation techniques. Furthermore the mapped symbols are transformed into frequency domain using Inverse Fast Fourier Transform (IFFT) method. By using the low pass filter we surpass the low frequency signals that are less affected by noise and contain the main lobe in frequency domain. As the signals found to be very low in the order of -100dB, we decided to increase its gain by up converter systems that include class A amplifiers. Apparently in our paper we have experimented to transmit data in range of 3.1 GHz to 10.6 GHz and it proved satisfactory results. For ultra wide band uses, the bandwidth is kept up to 4.125 MHz between the signals. The transmitter emits signals ranging from 1W to 10W for a SNR in the AWGN channel assuming to be 20dB.

The receiver section is exactly opposite of the transmitter section which deals with the noise affected signals. At the output we observe the bits to have errors that can be dealt while decoding with the error correcting codes. In order to improve the robustness of the system with respect to multipath effects, the standard exploits frequency diversity through band hopping while demanding a settling time of 10 ns. The output power level of transceivers has been limited to -41.3 dB/MHz by us as per FCC norms, so as not to interfere with existing wireless systems.

IV. MODULATION AND CODING SCHEMES

A. Why convolutional coding?

The use of convolutional coding as error control codes is far better than LBC codes theoretically as well as practically. Convolutional coding provides a better authentication and bit immunity especially in channel affected by fading and noise. As we know in Convolutional coding, the bit size of code word is rather increased by shift registers, hence we can make use of this forward error 0involving millions of bits per second. From the Fig. 3, one can verify that convolutional codes provide better immunity to the bit error rate (BER) at very low E_b/N_0 ratios compared to the other linear codes as stated. Therefore we can work with large number of bits as required in our system corresponding to very little changes in SNR values.

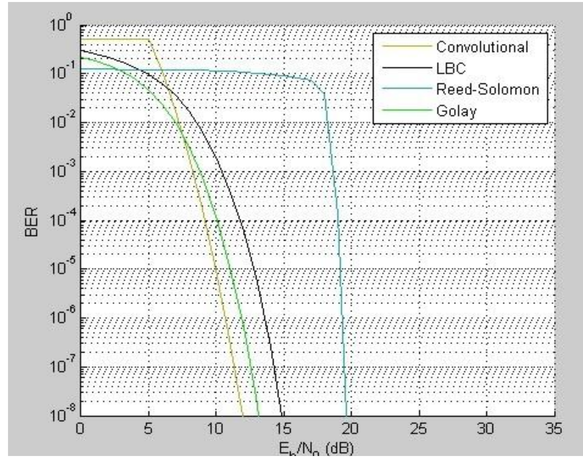

Fig. 3: E_b/N_0vs BER plot of various coding schemes

According to the system model, the binary bits are convolutional encoded and are passed through a QAM block for modulation. Each code bits are represented by a separate symbol in QAM and passed on to the IFFT block. Every bit is worked upon for Fourier transform by an M-ary IFFT and thus we transform it into frequency domain.

B. Importance of QAM in our system

The bit error efficiency of the QAM modulation also depends on the amount of symbols used to represent the data bits. The length of bits determines the appropriate type of QAM modulation that can be used which is basically of the N-ary QAM where 'N' is the number of symbols per message. From the fig 4.below we see that as the value of 'N', which is of the order of 2, decreases, the best is the efficiency of bit error rate at higher SNR.

Although our system deals with real numbers that consists of large binary bits which adds up to several redundant bits due to convolutional coding. Hence our aim should be to deal with those bits using a 16-ary QAM and scatter them separately and evenly over the spectrum. The QAM serves the right purpose in OFDM system as it sparsely modulates each bits that are in quadrature angles with each other.

From the Fig. 5, below we can see that though QAM gives a poor error rate at high SNR in comparison to other modulation schemes, it proves a better provision in our system. The reason behind the selection is the fact that we are receiving a comparatively low attenuated signal at the receiver due to various fading occurring in surrounding.

Also by using the QAM modulation it is possible to transmit the bits in orthogonal positions which is practically not compatible with other keying and multiplexing methods. The Fig. 6 shows the theoretical performance of the QAM modulation in a surrounding where Rayleigh and Rician fading takes place.

Thus it is our utmost need to increase the signal power that may increase the energy per bit i.e., E_b thus increasing the SNR giving rise to more errors. So following the Fig. 3 to Fig. 5, we can conclude that the QAM signal gives more immunity to error rates at high SNR.

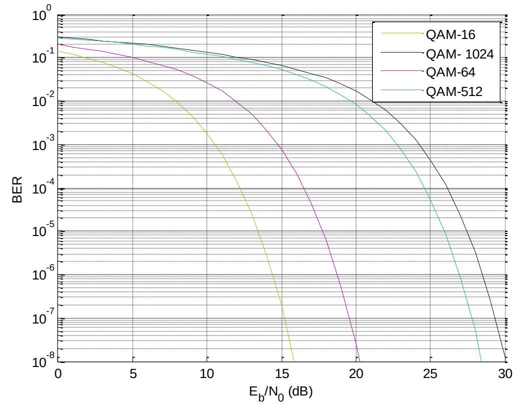

Fig. 4: Comparison of various QAM in AWGN channel

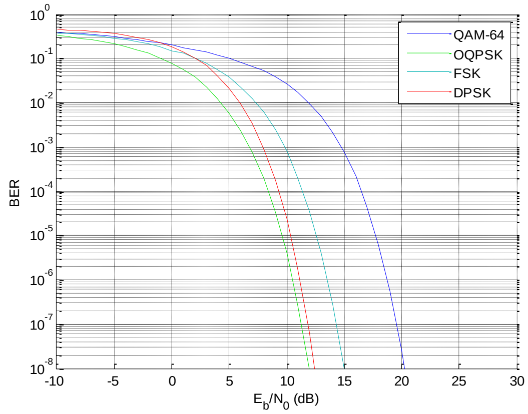

Fig. 5: SNR vs BER graph of different keying schemes

Though it shows that QAM is much suitable for Rician faded channels too and our system is designed for higher authentication of bits and errors which practically shows that the bits are less affected by the Rician fading and we can still recover the bits although at low attenuation and high fading.

V. SIMULATION AND RESULTS

The band pass block diagram of the system stated above has been verified using MATLAB® simulation. We created a simulation model using the default blocks embedded in the software and observed the results and the graphical displays of the output under various circumstances and situations. In our paper we have implemented our proposed system using convolutional coding and 16-ary QAM that ultimately helps in our further progress of OFDM techniques over the fading and noisy channels.

A. Transmitter section

It is seen from Fig. 6 above that at centre frequency around 160 Hz, the band reaches the minimum level. The dots indicate the encoded binary data which is separated from the noise data around the centre. This proves that by performing IFFT we can improve the immunity of the error rate as it doesn't allow the data bits to be mixed with the noise. Also each bit is orthogonal to each other thus improving the crosstalk problem between the bits as we know the

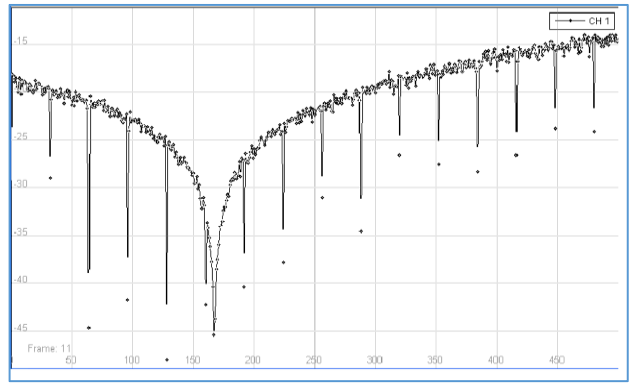

Fig. 6: OFDM sub-band spectrum using convolution codes

autocorrelation between any two orthogonal signals is zero.

From Fig. 7, we see that each bit represents a separate symbol in the plot. The symbols are scatters all around the phase and quadrature of the signal. In the IFFT block every symbol shown above goes through the process. Also it's difficult to detect the exact symbol from pile of bits, which shows better authenticity in OFDM channels. Referring to the magnitude spectrum in Fig. 8 we conclude that a certain OFDM signal will appear as a noisy single for normal receiver hence it increases security against hacking and theft.

B. Effect due to noisy and fading channel

The AWGN is the most common type of noise that occurs in communication channel. The noisy channel introduces errors and bit scrambling that causes problems in proper decoding and reception of the signal. Noise and bandwidth are the two most important constraints in any communication channel and one of our sole intentions of reducing AWGN is using OFDM in frequency domain.

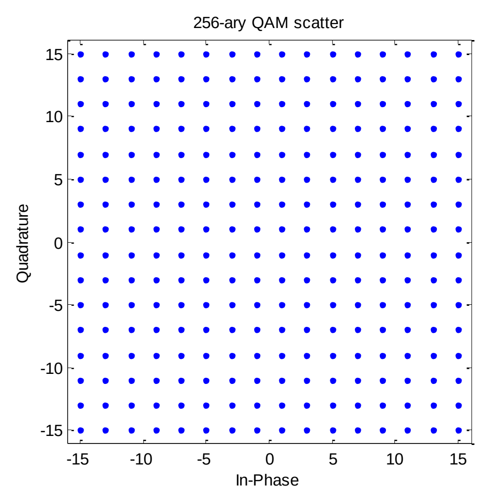

Fig. 7: Scatter plot of the 256-ary QAM constellation

In our system we can see from the plot in fig. 9 that the coded bits constellate orthogonally with each other while the noisy bits are gathered in-phase with the signal thus distinctly segregating the noisy bits with the proper coded symbols. A noise of SNR ranging upto 20dB is provided in the channel and we observe satisfactory results in our simulations.

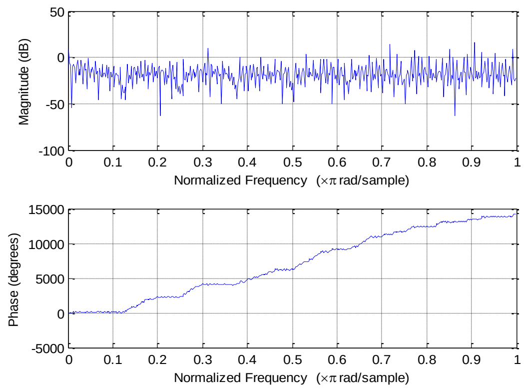

Fig. 8: Magnitude and phase response of transmitted OFDM signal

Rayleigh fading occurs due to improper weather conditions, stray noises or any extra-terrestrial sources that scatters the path of signals. Due to Rayleigh fading, the amount of bits is reduced and the orientation of the bits changes. But still it's observed in Fig. 10 that the orthogonal property is retained throughout although we have affected the signal through a Doppler frequency of 100Hz for scattering effect.

In rician fading, the signal arrives at the receiver by several different paths exhibiting multipath interference and at least one of the paths is changing. Rician fading occurs when one of the paths, typically a line of sight signal, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution.

From the Fig. 11, we can observe that the paths of the constellated symbols are almost distinct with each other in-phase as well as in quadrature. This indicates that, no two symbols correlates or interferes with each other which does not affect the travelling path of the symbols although there are multipath fading occurring in the channel.

The bits are seen to be modulated by the QAM carrier. Each bit is orthogonal to each other and thus reception can only be done by RAKE receiver that uses correlation and most probable bits principle for decoding. All the noisy bits are collected at the origin or in the carrier itself, while the useful data are untouched due to efficient IFFT algorithms.

Comparing the above Fig. 8 with the Fig. 12, we observe that the received signal had undergone severe attenuation and noise. Thus it is required to use a low pass amplifier for proper reading and reception of the signal at satisfactory energy levels.

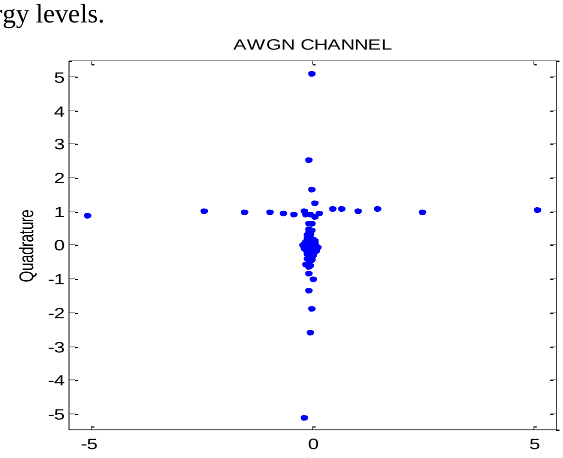

Fig. 9: Scatter plot of the signal in AWGN channel

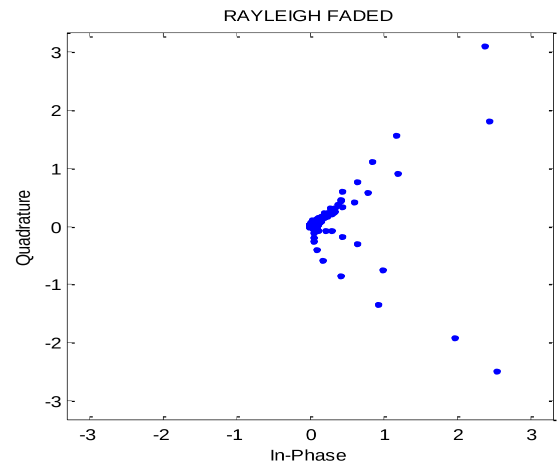

Fig. 10: Scatter plot of the Rayleigh faded signal

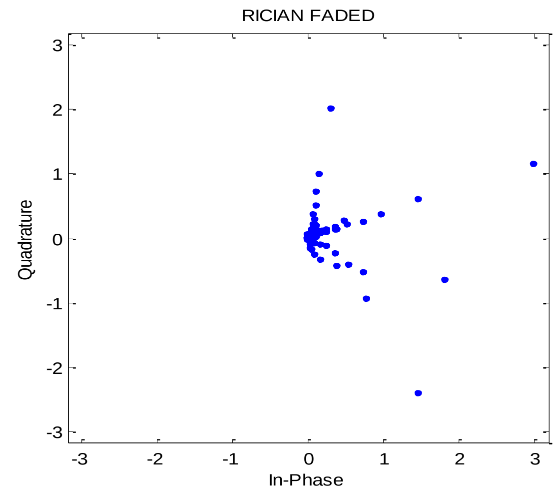

Fig. 11 Scatter plot of the Rician faded signal

C. Receiver section

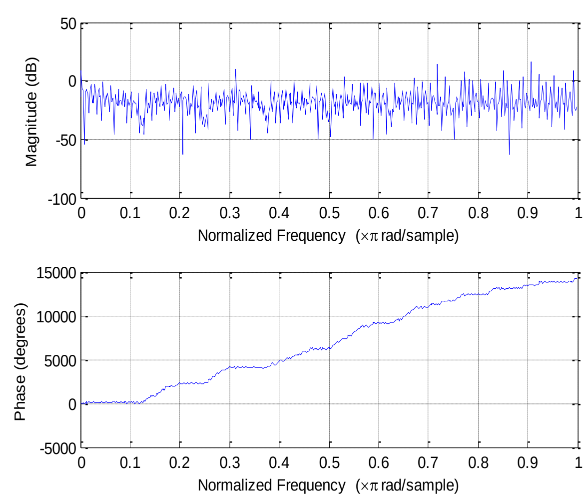

Fig. 12: Received OFDM signal frequency spectrum

VI. CONCLUSIONS AND FUTURE SCOPE

A. *Advantages of our system*

- Efficient use of allocated bandwidth as we are working in frequency domain by use of Z- transforms, DFT and FFT in Digital Signal Processing.
- Low noise and interference as we are dealing with AWGN channel which normally has an equal amplitude in frequency spectrum.
- By the use of signal processing we can implement large bits of data using latest TMS39025X DSP processors that are cheap, compact, accurate and faster to operate and function.
- Less interference, jamming and crosstalk due the use of RAKE receivers and AWGN signals. This provides security and authentication amongst the users.
- The method can be implemented for higher and complex codes like LDPC codes, Turbo codes, BCH and Reed-Solomon codes.
- Due to OFDM technology large number of bits and real numbers of values in millions can be transferred fast and correct over a long range of distance.

B. *Disadvantages of our system*

Although there are advantages of implementing this method for error control and detection but there are some demerits that can be processed further in future.

- Convolution method between signals containing millions of bits makes the process slow and complicated.
- The method can be sometimes complex as it involves array arithmetic for large data.

C. *Applications and future scope*

- DTH (Direct to home) services in television which involves precise decoding of the picture and sound signals.
- 4G and higher generation cellular services containing high data rates and quick response speed with extra precision and authentication.
- Military services.
- Transport and communication services like telemetry and telephony which are normally unstable.
- Dealing with real time data from space in determining strange astronomical behaviours and geo-physical applications.

VII. CONCLUSION

Coding for error correction over the real and complex numbers is feasible in frequency domain and the codes can be implemented in standard digital signal processors using primarily linear shift-invariant structures. Many of the algebraic concepts of error correction over finite fields are directly applicable to real-number coding, but it was seen to be advantageous to also introduce the z-transform and other digital signal processing concepts to provide a unified framework for describing both convolution and block codes. Block transforms and their resulting frequency domain viewpoints were seen to be useful both for discovering and describing block codes; in addition, frequency domain concepts and digital filter bank descriptions were seen to be useful for describing convolution codes and are logical extensions of the block transform descriptions.

OFDM is extremely well suited for wireless communication in environments where multipath is a major source of distortion such as that found in typical WLAN deployments. The combination of multiple narrow subcarriers with interleaving and error correction coding allows OFDM to perform well in multipath while the guard interval gives the receiver an extremely simple method for eliminating ISI. These built in waveform features allow for the design of reliable, high-rate digital wireless communications systems without the complexity that would be required by conventional single carrier systems.

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