Adaptive OFDM for Aeronautical Channels

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ABSTRACT

Previous work modeled the cruise phase of an aeronautical channel and showed how the channel varied as a function of height, distance, and speed. What was apparent from that analysis was that the ``cruise" channel was remarkable stable and varied slowly and predictably over time. The steady state channel reflected a 2-ray multipath model which exhibits deep nulls in the spectrum which affects serial tone modems significantly. Further the application of parallel tone modulation improves performance except for that portion of the band which was degraded by the null. This points to the use of Adaptive OFDM (AOFDM) structure wherein tones are only sent in portions of the band which are strong and not areas where the signal is weak. This work develops a method for capturing a profile of the Signal to Distortion Ratio (SDR) for each tone for each frame and over time. It also develops a method for converting the SDR per tone to estimate the optimum QAM modulation scheme for each tone for application in Link Dependent Adaptive Radio (LDAR).

Key words: *OFDM,Adaptive OFDM, Link Dependent Adaptive Radio (LDAR), Signal-to-Distortion Ratio (SDR) OFDM (AOFDM)*

1. INTRODUCTION

The iNET projects at Wireless Network Security (WiNetS) Lab at Morgan State University have been carried out to develop an aeronautical LDAR system that adapts to the radio channel conditions. Adaptation mechanisms such as Signal-to-Noise Ratio (SNR) or delay spread are measured in real time to select a data rate for the communicating entities that improves the bandwidth efficiency while keeping the quality and reliability of the channel. An adaptive OFDM scheme (AOFDM) is an ideal candidate as it selects the optimum modulation scheme for each tone in the OFDM symbol.

2. LINK DEPENDENT ADAPTIVE RADIO

One of the goals of the iNET project is to develop aeronautical radio channel system model which adapts to different channel conditions and select coding rates according to real time measurements. This model is known as Link Dependent Adaptive Radio (LDAR). LDAR uses different modulations schemes based on real time channel conditions. Parameters such as SNR, SDR, and Delay spread measurements between the TAs and GSs are used to accommodate the best data rate [0]. Error measurements can be also be compared to a threshold value to achieve the link adaptation.

Basically LDAR consists of transmitter, the wireless channel model, and receiver. The transmitter has an encoder and various modulation schemes. The adaptation of modulation scheme and code rate takes place after the Signal to Noise Ratio (SNR), Signal to Distortion Ratio (SDR) or delay spread is computed. Based on the predetermined table, LDAR decides on the next set of parameters for transmission. This paper proposed an AOFDM scheme that maximizes the modulation scheme for each of the OFDM tones.

2.1 AOFDM/LDAR Model

To maximize the throughput of the aeronautical communication channel, OFDM system model shown in Figure 1 is implemented.

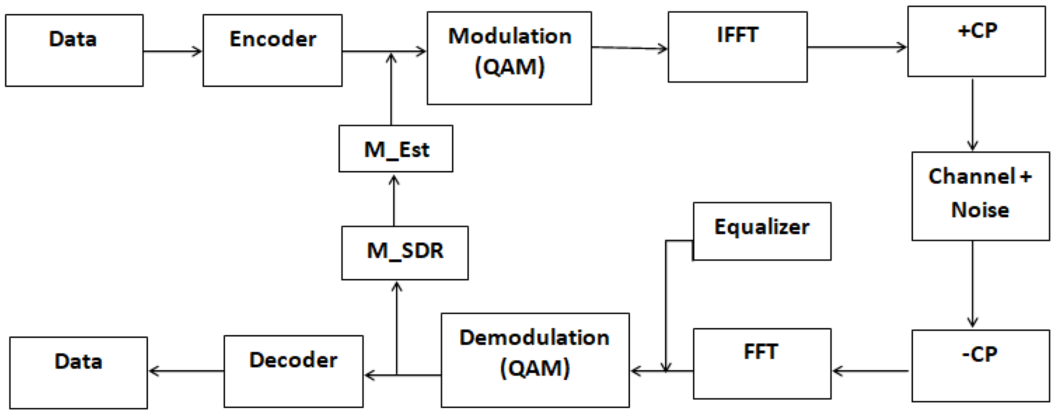


Figure 1: AOFDM Block Diagram

The data bit stream in the OFDM system is sent out by the source is expanded by the encoder by adding redundant bits. In this work, coding techniques are not applied. Different modulation schemes are applied on the encoded data bit steam. The modulations schemes in this work include particularly use QAM. The output of the modulation symbols are mapped into consecutive blocks through a serial-to-parallel converter before sending out to the Inverse Fast Fourier Transform (IFFT) processor. Cyclic Prefix is applied before the data is transmitted into the radio channel.

At the receiver, the opposite operations of the transmitter are applied on the received data. The receiver tries to get the original data which is affected by different effects on the radio channel such as noise. The cyclic prefix will be removed from the data received from the radio channel. A Fast Fourier Transform (FFT) is applied to convert the modulated data into the frequency domain. Then the modulated data will pass through the demodulation block and the decoder. The decoded symbols are then converted into binary stream of data as output.

Previous works on LDAR implemented variable coding rate OFDM for aeronautical channel [2]. A LabView simulation of LDAR was also developed as a test bed [3]. A test flight scenario for the cruise phase was also simulated for a 2-ray ground reflection model which is based on position, velocity, and direction of the TA [4]. This model includes Doppler shift and delay spread for each path of the channel [5]. The ultimate goal of these simulations was to improve the accuracy of the flight simulation in the design and pre-test stage.

2.2 Discrete Multi-Tone (DMT) Modulation Channel Model

The term discrete multi-tone modulation (DMT) denotes OFDM-based communication systems that adapts the transmission to the channel conditions individually for each sub-carrier. DMT is similar to Orthogonal Frequency Division Multiplexing (OFDM), with the difference that DMT carries different numbers of bits on different sub-channels. This signaling scheme leads to a better usage of the channel capacity. A DMT system transmits data in parallel over several narrowband channels. The sub-channels carry a different number of bits depending on their measured SDR which include additive noise and channel distortion effects.. This is an Adaptive OFDM (AOFDM) system,

Shannon's noisy channel coding theorem states that the highest error free bit rate, R, a discrete memoryless channel can reach is bounded by the channel capacity, C. Gaussian noise is the worst kind of additive noise for a discrete memoryless channel.

In an AOFDM system, a high-speed binary serial input data sequence is divided into N parallel lower-speed binary streams. For each stream indexed by n, where $n = 0,1,...,N-1$, every M number of bits are grouped together and mapped onto complex values $C_n = A_n + jB_n$ according to a quadrature amplitude modulation (QAM) constellation mapping consisting of 2M states. Usually, the IFFT is used in the DMT transmitter to efficiently modulate the complex values C_n onto N different subcarrier frequencies, which, as a result, are mutually orthogonal.

In order to achieve a real-valued, baseband AODFM transmission sequence consisting of N subcarriers, a 2N-point IFFT is needed. For the 2N inputs of the IFFT, indexed by $n = 0,1,...,2N-1$, the first half are assigned the values C_n and the second half have to be assigned the complex conjugate values of C_n, following the Hermitian symmetry property [6].

3. SIGNAL-T0-DISTORTION RATIO (SDR) AOFDM

One of the popular specifications for quantifying ADC dynamic performance is (signal-to noise-and-distortion ratio). There are a number of ways to quantify the distortion and noise of an ADC. To maximize the Signal-to-Distortion Ratio (SDR) of the OFDM system, FFT analysis is the commonly used technique.

In conventional OFDM system, at the transmitter, the bit stream is parsed into $\frac{M}{2}$ sub-channels. The parsing allocates a suitable number of bits into each sub-channel based on SNR. Afterwards, the sub-channel bit streams are QAM-encoded, resulting in $\frac{M}{2}$ complex symbols. In this paper, SDR measurements are used to adapt the allocation.

3.1 Signal-to-Distortion Ratio (SDR) for AOFDM

Let $E[|x_i|^2] = \sigma^2$, be the power of the input signal and $\hat{x}_i$ is the signal after clipping, the SDR is given as

$$SDR = \frac{E[|x_i|^2]}{E[|\hat{x}_i - x_i|^2]}$$

For X-the time domain signal, n-sub-carriers with data$d_0, d_1, \ldots, d_{n-1}$could be detected at the receiver.The data sequence is extracted from the noisy version of X with an error as low as possible. We have to design

$$|x_k - d_k| < \varepsilon d_{min}, \forall i = 0,1,2, \ldots, n-1$$

When d_{min} is the minimum distance among constellation points in the chosen constellation for the data symbols. Note that only if $0 < \varepsilon < 0.5$ is satisfied that data symbol d_k may be recovered from x_k without ambiguity. The value $|x_k - d_k|\ for\ k = 0,1,2, \ldots, n-1$represents in-band distortion on the k^{th} data symbol, d_k.

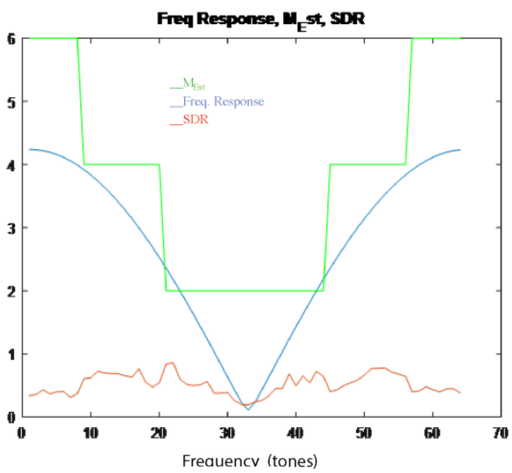
The adaptation mechanism takes place after the Signal to Distortion Ratio (SDR) is computed. Based on the predetermined table, LDAR decides on the next set of parameters for transmission. As can be seen from Figure 1, at the receiver SDR measurement per sub-channels of theAOFDM (M_SDR) are used to estimate the suitable number of bits per symbol of the corresponding sub-channel (M_{Est}).

Once M_{Est} values are determined at the receiver, these values are used as a feedback to the transmitter to schedule the adaptive transmission using suitable M-QAM modulation schemes (M_{est}) which determined the M for the MQAM for each tone.. This is repeated over successive transmissions making it an adaptive OFDM.

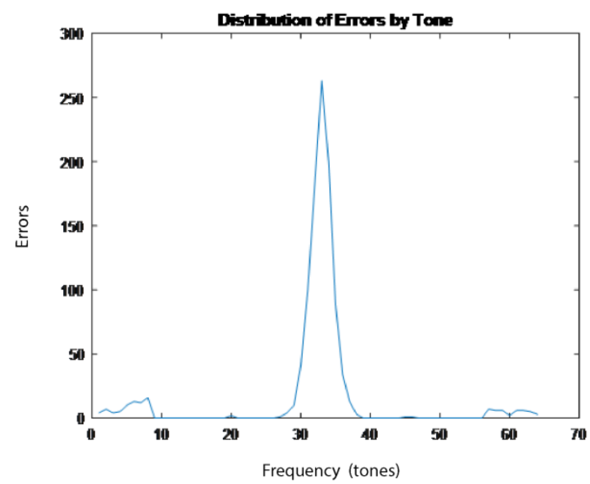
3.2 Results

In this paper a two-ray channel model for AOFDM is simulated in MATLAB. To simplify, the AOFDM used ideal equalizer and no coding mechanisms were in place. SNR values are varied from 8-33dB to measure SDR values and select QAM sizes per tone of the DMT. (Note that SDR computations were incomplete and experimental values of M_{est} were used instead.) Three scenarios (Figure 2-4) with Strong, Medium, and Weak signal levels are selected. Each scenario is accompanied by three plots: the first plot shows frequency response, SDR and M_{Est}, the second plot shows the measured symbol error rate over the frequency tones, and the third plot corresponds to 3D (mesh) visualization of the errors in frequency and time.

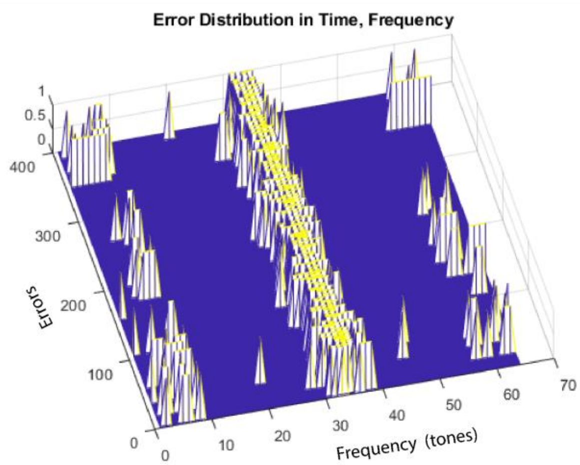
Scenario I: Strong signal considered (SNR=33dB)



(a)



(b)

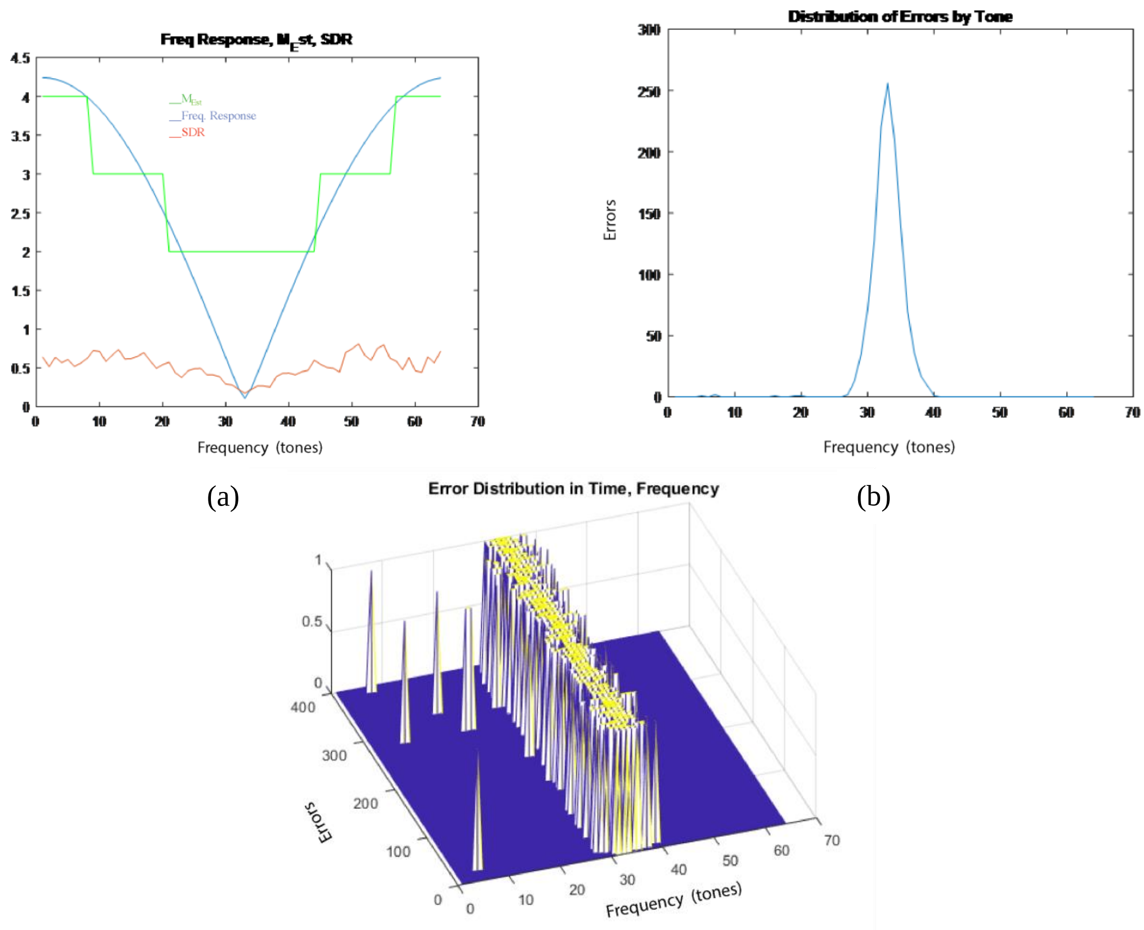


(c)

Figure 2: Strong Signal (a) Tones,SDR, M_Est (b) tones vs Errors in time (c) Tones vs Errors Mesh

This scenario represents a good channel (33dB SNR) overall but with a severe 2 path fade in the channel. Note that in the good portion of the curve a 64QAM and 16QAM modulation is achieved with a manageable error rate. Note also that in the region of the null, even a 4QAM signal is not viable, the performance overall has an average of almost 4 bits per tone. This compares well to SOQPSK which provides only 1 bit per symbol.

Scenario II: Medium Strength signal considered (SNR=20dB)



(a) (b)

(c)

Figure 3: Medium Signal (a) Tones,SDR, M_Est (b) tones vs Errors in time (c) Tones vs Errors Mesh

This case is a moderately good channel (20dB SNR), but with a 2 path null. This channel supports 16QAM, 8QAM and 4QAM modulation with an average of almost 3 bits per tone even as the middle tones are unusable.

Scenario III: Weak Signal considered (SNR=8dB)

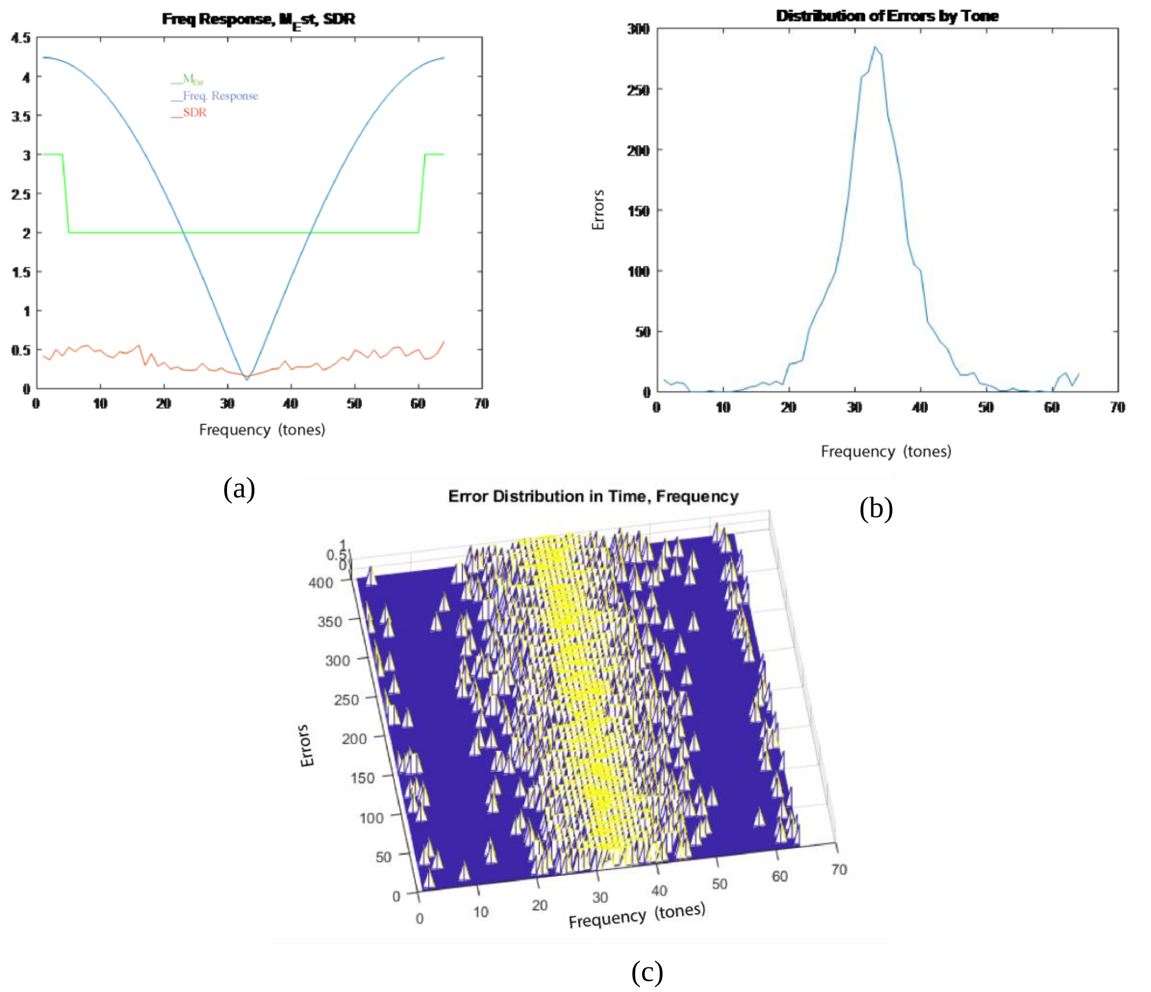


Figure 4: Weak Signal (a) Tones,SDR, M_Est (b) tones vs Errors in time (c) Tones vs Errors Mesh

This case is a poor channel with just 8dB SNR and a 2 path null in the channel. Even this case works well with 8QAM in the strong areas and 4 QAM elsewhere with an average of 2 bits per tone delivered.

The above results demonstrate that AOFDM works for aeronautical channels and offers better data rate than a serial single tone modulation schemes such as QPSK by adapting different QAM sizes for the different tones based on SDR measurements. Note that this approach would compliment error coding well. Because only good areas of the channel are used, the system avoids the huge error conditions expected in the null area and produces a manageable error rate for the others for typical coders. OFDM tones in high error regions would be blanked and avoided at the receiver.

4. CONCLUSIONS AND FUTURE WORK

This paper introduces a design of an adaptive OFDM modulation scheme for use with LDAR for aeronautical channels. The AOFDM scheme presented operates on severely degraded 2 ray paths that are the norm in steady state flight. This approach shows promise for future development and application in the telemetry environment. Future work will focus on estimation of SDR for M_{est} calculation, the addition of a real equalizer, and coding.

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