VARIABLE RATE OFDM PERFORMANCE ON AERONAUTICAL CHANNELS

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Abstract

This paper shows the design and testing of a test bed at Morgan State University as part of the development of a Link Dependent Adaptive Radio (LDAR). It shows the integration of variable rate QAM/OFDM modulation and a variable rate Punctured Convolutional Coder. It also shows a dynamic aeronautical channel simulator developed to capture the dynamics of these channels. Performance results are show for combinations of modulation, coding and channel variations that provide motivation for the potential of the LDAR system.

Key Words : iNET, LDAR, OFDM, QAM, Coding, Channels

Introduction

The INET project was launched by both Director of the Central Test and Evaluation Investment Program (CTEIP) with the primary objective of advancing networking and telemetry technology. The proposed system aims to increase and enhance data transfer and communication between aircraft and ground stations and between the aircraft themselves over an aeronautical channel. For the physical layer of the Telemetry Network system, the INET project plans to use a variation of the 802.11 Wireless LAN Protocol. This offers the potential for higher data rates and higher spectral efficiency in support of the increased demand for more data. This papers looks at how a link dependent adaptive radio (LDAR) (1) protocol can enhance data rates by controlling the radio link to operate at near capacity rates over a variety of conditions.

An aeronautical telemetry channel provides communication between aircraft and ground stations. The aeronautical channel offers significant and unique challenges. The channel is characterized by multipath distortion due to the interaction of the direct path, reflected path and associated clutter. These effects are exaggerated by the presence of Doppler shifts that can be as high as 15kHz. This distortion contributes to rapid changes in channel behavior which in turn leads to limitations in performance. LDAR performance will require analysis of aeronautical channels with an emphasis on tracking the dynamics of the channel, and matching these with adaptive rate structures.

Link Dependent Adaptive Radio (LDAR)

Georgia Tech Research Institute (GTRI) and Morgan State University have undertaken the LDAR program in an effort to maximize the throughput for telemetry links while ensuring an acceptable level of link quality and reliability. This includes the development and test of a prototype system that adapts its modulation scheme based on channel conditions in a telemetry environment. LDAR selects a modulation scheme that maximizes throughput while ensuring a minimum level of link quality given the current channel conditions. This is accomplished by estimating the channel and link quality to determine what mode of operation would meet the objective. Multiple parameters are adapted to maximize throughput while maintaining link quality which may include the waveform and constellation, signal bandwidth, number of subcarriers, and forward error correction schemes. When the signal is strong and the channel benign a high rate 64QAM might be possible with 6 bits/Hz spectrum efficiency, while degraded channels might operate at 4QAM with a Rate = ½ code. The key is to choose the best structure for the current channel condition.

Orthogonal Frequency Division Multiplexing (OFDM) and Coding

The technical approach to this effort is focused on the development of a high performance OFDM based modulation scheme which incorporates 4/16/64 QAM modulation and variable rate Convolutional coding (2) at rates 1, 3/4 and 1/2. This provides transmission options over a range of 6 to 1 in the choice of rate. This approach also includes a simple equalizer required for QAM operation. Orthogonal Frequency Division Multiplexing (OFDM) is a combination of modulation and multiplexing. It is a powerful modulation technique that increases bandwidth efficiency and reduces the multipath effect. By dividing the bandwidth into smaller channels, narrowband channels are created from a wide band environment. These narrowband subcarriers experience flat fading. When multipath occurs selected tones are faded but the data can be recovered using error correcting codes. OFDM also incorporates a cyclic prefix to remove inter-symbol interference and to maintain orthogonality in the presence of multipath.
Forward Error Correction (FEC) is a method by which errors can be controlled during data transmission. Convolution codes are error correcting codes that are used to add redundant information to the user's message, and then use this redundant information to correct errors at the receiver. In interleaving, symbols of the coded sequence are either transmitted a number of times or permutated using interleaving techniques to overcome burst error on the channel.

Methodology

The LDAR test configurations consist of an OFDM test bed which incorporates variability in Code Rate and in M-ary QAM modulation. It also includes an aeronautical channel simulation that can be configured to simulate channel dynamics. The coding selected here follows the IEEE 802.11a Convolutional coding with puncturing. In this case puncture rates 1, 3/4, and 1/2 provide test options. The OFDM & M-ary QAM operation can be configured with M=64, 16, 4. Overall this provides for a combination of nine (9) possible rate configurations which provide options for enhanced spectral efficiency. Others have shown (2) a mapping of channel distortions can be related to spectrum efficiency as illustrated in figure 1.

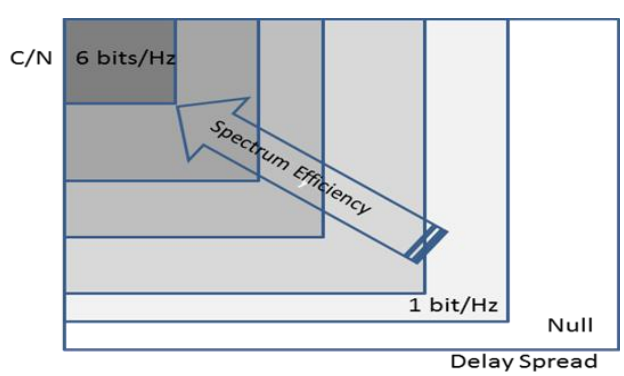

Figure 1: Mapping of Spectrum Efficiency versus Channel Distortion

Figure 1 shows notionally that regions of spectrum efficiency can be quantified and used to adapt the link structure to a configuration that matches the capacity of the channel. The test bed elements are shown below in figure 2. Each element is described below.

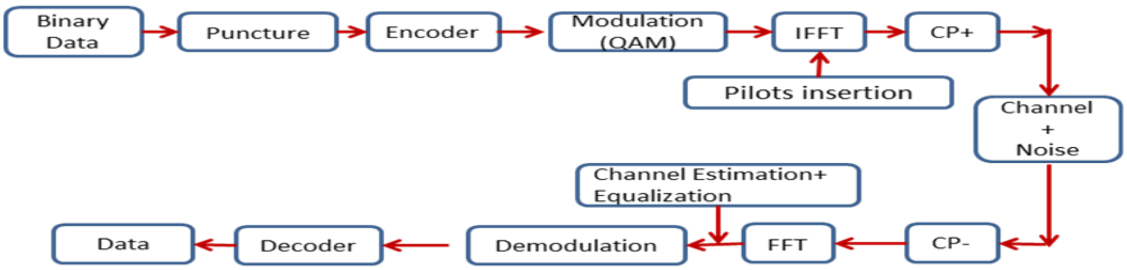

Figure 2: LDAR Test Bed

By varying the QAM rate and the coding rate the data bits/symbol can be varied from 1 bit/symbol to 6 bits per symbol in uniform steps as shown in table 1.

Table 1: Variable Rate Structure for LDAR Test Bed

QAM Bits/Symbol	Code Rate	Data Bits/Symbol
2	1/2	1
2	3/4	1.5
2	1	2
4	1/2	2
4	3/4	3
6	1/2	3
4	1	4
6	3/4	4.5
6	1	6

OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is a powerful modulation technique that increases bandwidth efficiency and helps to mitigate inter-symbol-interference (ISI) and inter-channel interference (ICI). OFDM is a technique to combat frequency selective fading. The basic idea of OFDM is to divide spectrum into several sub-carriers. By dividing the bandwidth into smaller channels, narrowband channels are created from a wide-band environment. These narrowband subcarriers experience flat fading, which is an important characteristic for the aeronautical multipath problem. Each narrow band subcarrier supports an M-ary Quadrature Amplitude Modulation scheme with M=4,16, or 64. This can provide 2, 4, or 6 bits per data symbol that can be adapted to the channel.

Cyclic Prefix

Convolution encoding causes parts of adjacent OFDM symbols to overlap causing the independently transmitted symbols to interfere with each other. This effect can be mitigated by introducing a guard-interval, referred to us as a cyclic prefix, between the symbols. OFDM system is used to increase the symbol duration and reducing ISI.

Aeronautical Channel

The aeronautical radio telemetry channel is a complex wireless connection between an aircraft and a base station. Such channels are complicated by the multipath distortion and the Doppler related to high speed aircraft. This channel can be modeled as the convolution of an input signal with a channel impulse with N_tap paths or taps as:

$$Output = \sum_{i=1}^{N\_taps} G_i\, Input(t - T_i)\, e^{j2\pi(f_0 + f_{di})t}$$

Where Gi are the complex path gains, Ti are the relative path delays, fo is the radio frequency offset, and fdi are the individual Doppler shifts for each path.

The typical airborne connection can be represented as a 2 ray model with just the direct path and a reflected path. Such a channel has been captured by Rice (4). Our model for this channel is a fixed G1 for the direct path and a Rician G2 for the reflected path. A comparison to the Rice data is shown below on the left and the simulation on the right.

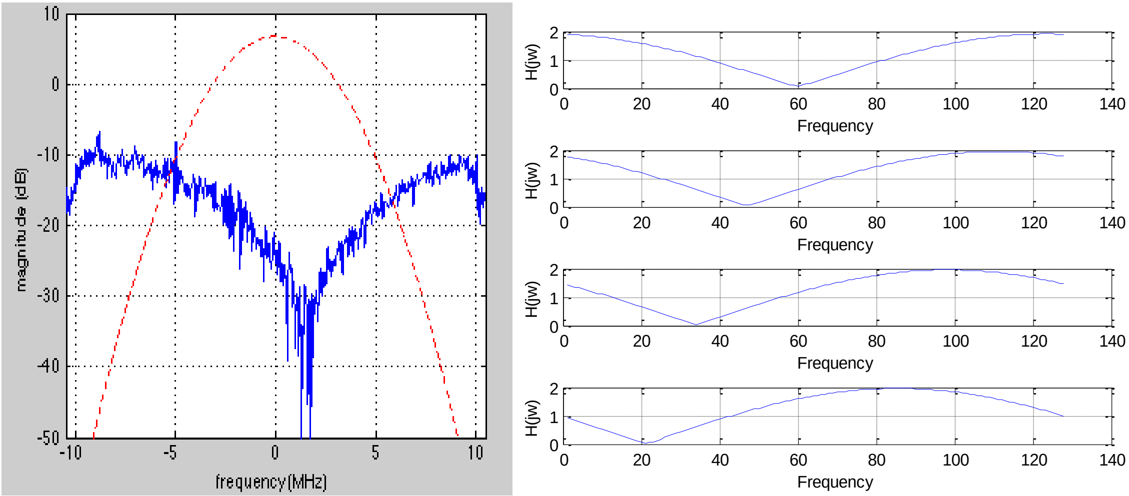

Figure 3: Airborne Channels – Rice (left) vs. Simulation (right)

The simulation is captured at four snapshots which shows the migration of the null in the channel which is related to the differential in Doppler shift from the directed and reflected path. These differences are on the order of 0.1Hz to 10Hz.Such dynamics may be important to determine the stationarity of the aeronautical channel for LDAR applications.

Another example is the Rice channel for the Taxi Runway scenario which shows 4 distinct paths including 2 clutter paths. The Rice data is shown on the right and our 4 tap model is shown on the left in figure 4. Figure 5 shows the dynamic frequency response which includes additional dips due to the clutter and the variable Doppler effects.

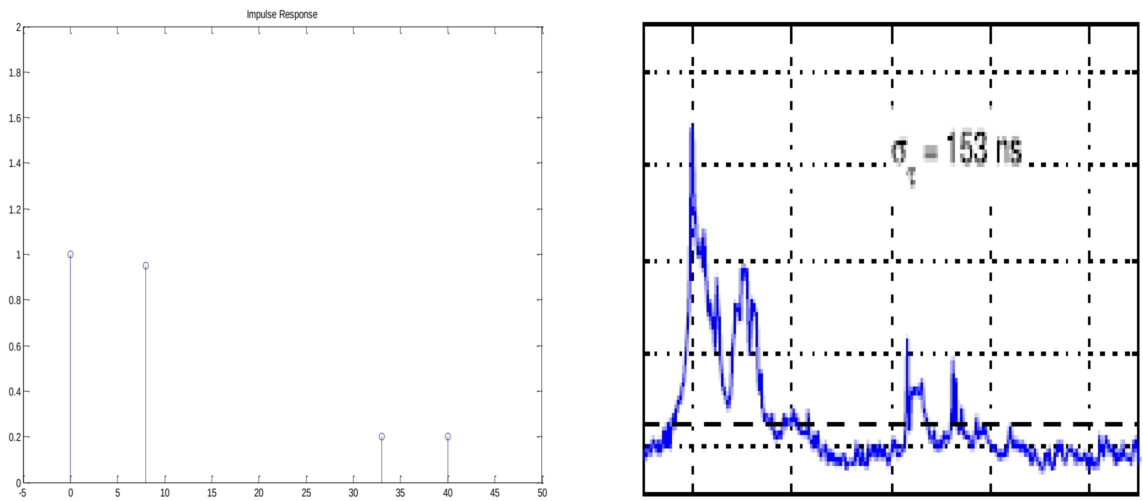

Figure 4: Impulse responses: simulated (left), Rice (right)

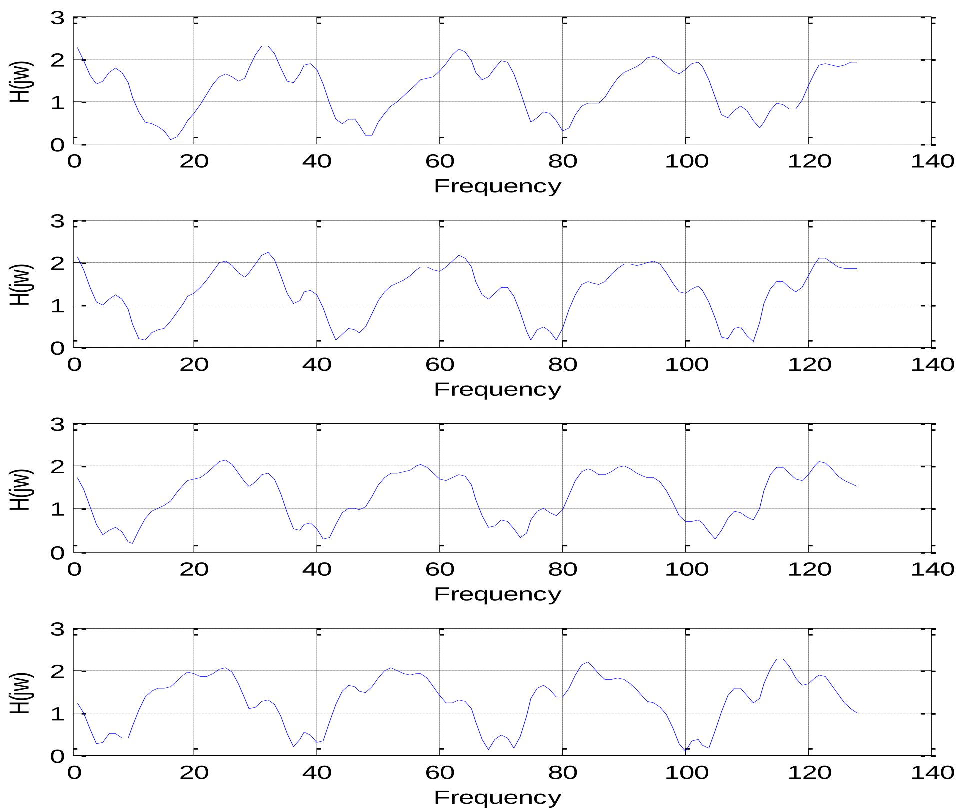

Figure 5: Runway Taxi with Clutter Frequency response

Seven channels have been adapted from Rice's data to provide a variety of channels for our test bed. These provide some variability for showing how channels may vary in time.

Convolution Coding

A punctured variable rate convolution coding (3) provides forward error correction to allow multiple code rates suited to the channel. The schematic of the Convolution coding applied in this work is shown in Figure 6. The Number of inputs bits, (k), is 1 and the number of outputs bits (n) is 2. These blocks are called the shift registers. Number of registers (K) is 7. This is also called the constraint length. U is the information sequence U=(u_1 u_2 u_3 ….) entering the encoder. Then the input is an impulse, the response to the system are generator polynomials (g1 g2). Only one bit from the input can go to the first register at a time and output corresponding to it is obtained in the output terminal. When the next bit comes, the previous bit shifts by one and another set of outputs are obtained in output terminal. This process continues until all the bits are ended in output. The generator polynomial is [g1=171, g2= 133] here[3]. After combining g1 and g2, the generator matrix called the G-matrix is produced. Encoded data (V) is achieved by convolving U and G matrix. This briefly explains how the Convolution code works. After encoding, the data is sent to the channel. As mentioned earlier, code rate is the ratio of input and output. Thus, a code rate of R=k/n = ½ will mean that only half of the input bits are transmitted through channel.

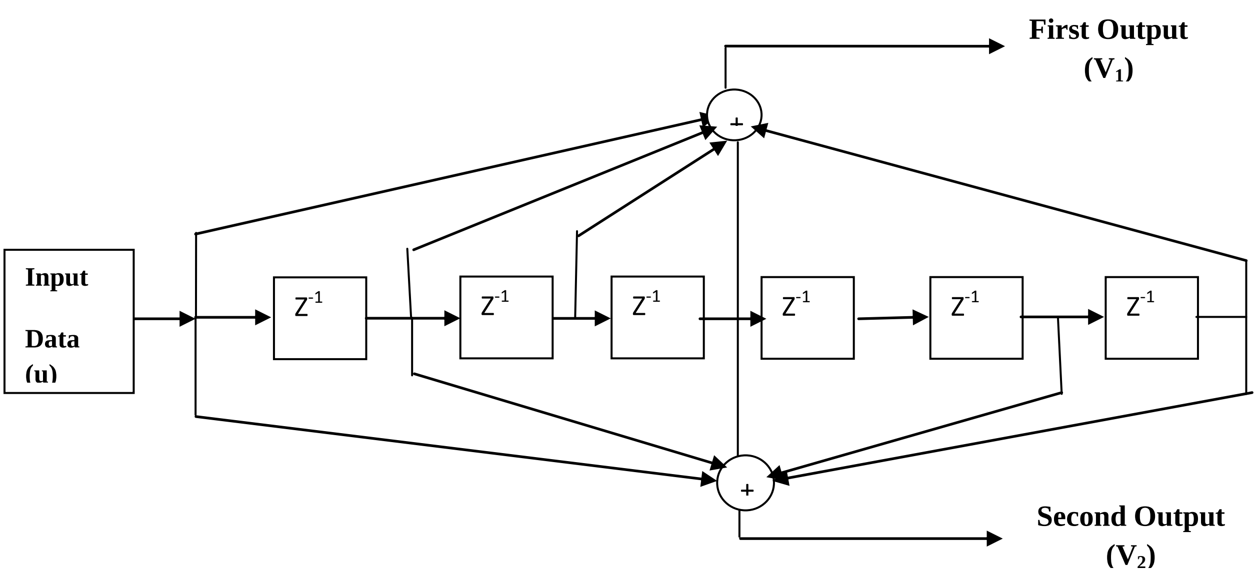

Figure 6: Schematic of Convolution coding for K=7

Results and Discussion

This LDAR test bed can produce many combinations of test configurations. A few of our preliminary tests are shown below. Figure 7a show a calibration of our system by comparing OFDM QAM at various rates to the theoretical values. Variances for the 256QAM are due to the lack of Gray Coding. Figure 7b shows the performance of the punctured Convolutional code with rates 1, 3/4,1/2.

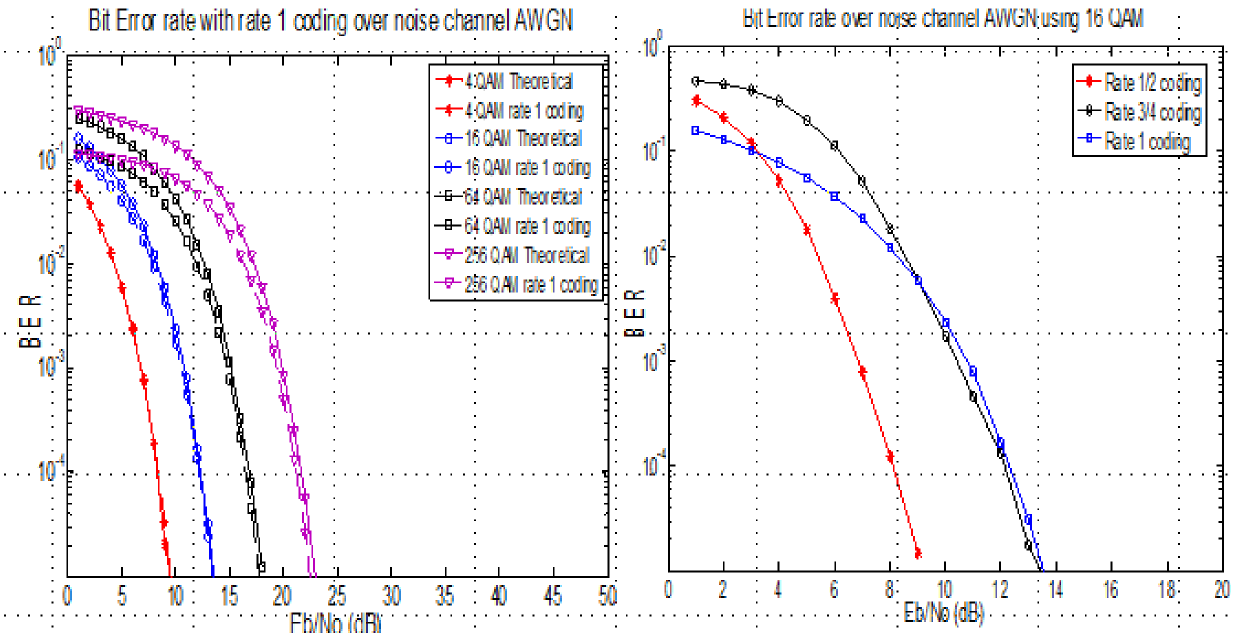

Figure 7a Theoretical BER Vs Simulation 7b with Variable Coding

Figure 8a below shows the performance of QPSK, 16QAM and 64QAM for an AWGN channel with and without rate= 1/2. This chart shows how the coding provides improvement in error performance on the order of 5dB coding gain. Figure 8b shows the performance of QPSK over seven (7) difference Rice channels. It can be seen here that the performance is severely degraded on three of these channels where the cyclic prefix length was not sufficiently long.

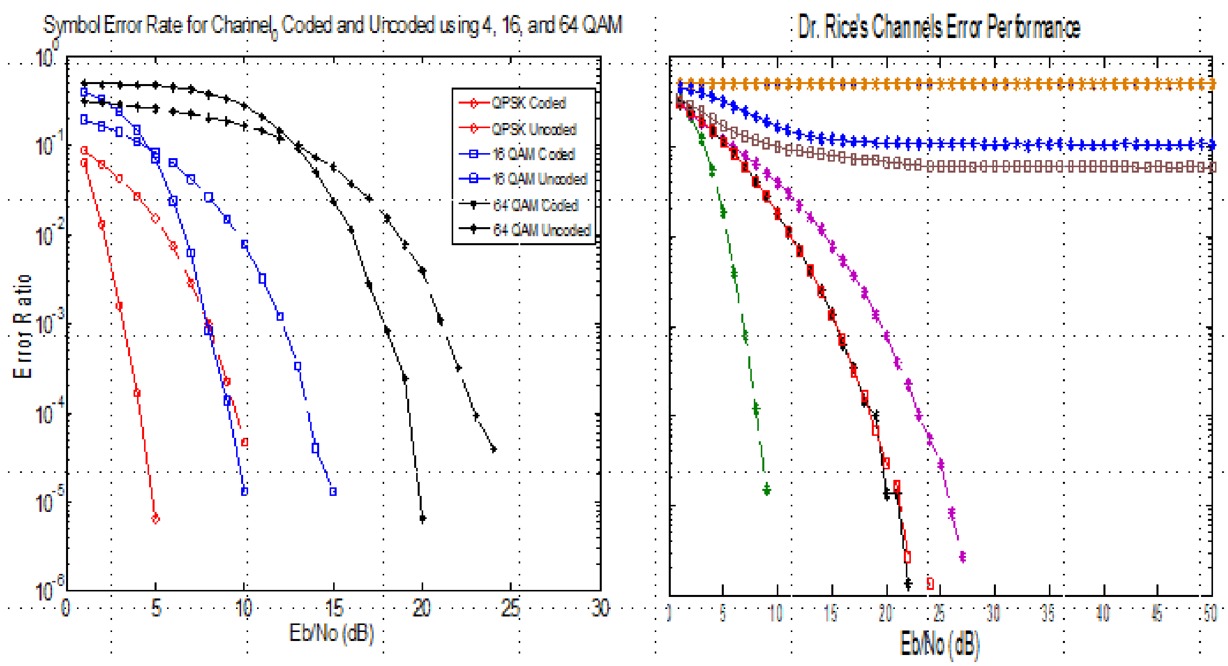

Figure 8: Error Performance with and without Coding (8a:left), Performance on Rice Channels (8b: right)

Conclusion

The paper presents the design and test results from MSU's LDAR test bed. A variable rate system has been developed with varies both M-ary QAM rate and Convolutional code rate to provide nine possible rate configurations. An aeronautical channel simulation has also been developed to simulate captured Rice channels and to provide the dynamics of these channels. These combinations of data rates and channels can now be tested to provide insight into the methods needed to predict and adapt transmission modes suited to the mix of channels expected in aeronautical telemetry applications.

Acknowledgements

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