LINK DEPENDENT ADAPTIVE RADIO – DESIGN FOR iNET

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ABSTRACT

This paper focuses on the design of a simple Time Division Multiple Access (TDMA) signaling structure for the Link Dependent Adaptive Radio (LDAR) prototype wireless radio communication system to meet the timing requirements of the iNET standard. Built for aeronautical telemetry, LDAR adapts its modulation and coding scheme based on the channel condition in real time. In this paper, a simple protocol for transmission of Command Message and Data Message between Ground Station and Test Article is discussed. This protocol includes all analysis for the continuous adaptation of modulation scheme and coding rate to maximize throughput while ensuring a minimum level of link quality. This project was a collaborative effort between Morgan State University and Georgia Tech Research Institute and is a continuation of our previously published work on LDAR.

Keywords: *Link Dependent Adaptive Radio (LDAR), TDMA, iNET, OFDM, SOQPSK*

INTRODUCTION

Spectrum scarcity has become one of the major issues in wireless communication with the dramatic increase of data demand. With the growing demand, the aeronautical spectrum is expected to be congested [1,2,4]. Also wireless telemetry uses unpredictable and dynamic radio channels for transmitting information which affect performance in several ways including Doppler effect, noise, multipath etc. Channel dynamics, specially fading of channel becomes a bigger issue in highly dynamic environments such as aeronautical communication where the speed of aircraft exceeds mach1. Higher performance in data transformation requires improved channel [4]. Dedicated links between the ground station and test article of a telemetry communication has proven to be an inefficient bandwidth utilization method. The integrated network enhanced telemetry (iNET) project – supported by Test Resource Management Centre (TRMC) – has aimed at abandoning the point to point link dedication and moving toward networked telemetry. Georgia Tech Research Institute (GTRI) and Morgan State University have undertaken a project within iNET aimed at a bandwidth efficient and adaptive system for aeronautical communication. Link Dependent Adaptive Radio (LDAR) is an effort to maximize the throughput for telemetry links while ensuring an acceptable level of data quality and reliability [3-7].

LDAR

The main concept of Link Dependent Adaptive Radio (LDAR) is to develop a wireless radio communication system that adapts its modulation system and coding rate based on the channel condition in real time in a telemetry environment. Analyzing the current channel condition in real time, LDAR selects a modulation scheme (that suits best current channel condition) which maximizes throughput while ensuring a minimum level of link quality. If the quality of channel (SNR or delay spread) is improved, a control signal informs both Ground Station and Test Article of a telemetry communication to switch to a higher data rate [4]. But if the channel quality decreases or the performance error exceed the predefined acceptable threshold, the same adaptive mechanism ensures that next transmission happens in lower data rate, either by changing the modulation scheme or by reducing the coding rate [4,5,6].

SYSTEM MODEL

A system model for this prototype system is shown in figure 1 below.

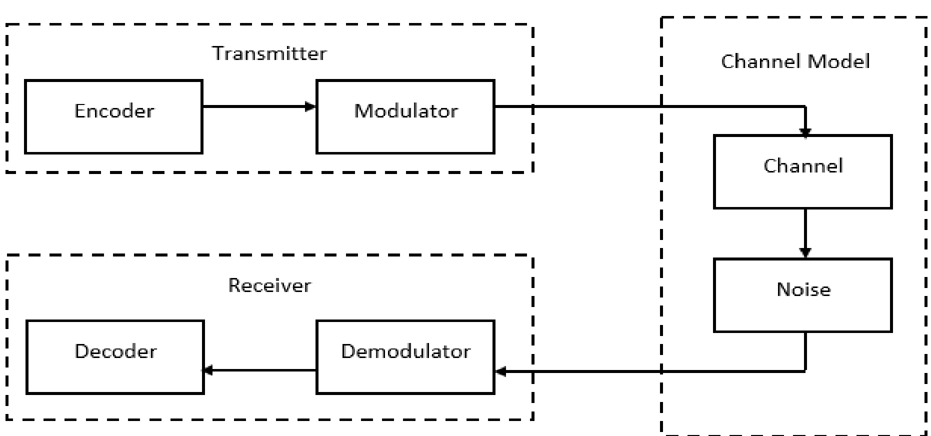

Figure 1: System Model

The system consists of a transmitter, a receiver, and a telemetry channel model. The transmitter has an encoder and a modulator which consists of Orthogonal Frequency Division Multiplexing (OFDM) and Shaped-Offset Quadrature Phase Shift Keying (SOQPSK) modulation. The receiver consists of a demodulator and decoder. The adaptation of modulation scheme and code rate takes place after the Signal to Noise Ratio (SNR) or delay spread is computed. Based on the predetermined table, LDAR decides on the next set of parameters for transmission.

CHANNEL PARAMETERS ADAPTATION

To make optimum decision for parameter selection or for mode adaption depending on channel quality, different code rate and modulation has been tested previously. Figure 2 shows a comprehensive set of results with two different coding schemes and all the Quadrature Amplitude Modulation (QAM) sizes under study of Additive White Gaussian Noise (AWGN) channel [6].

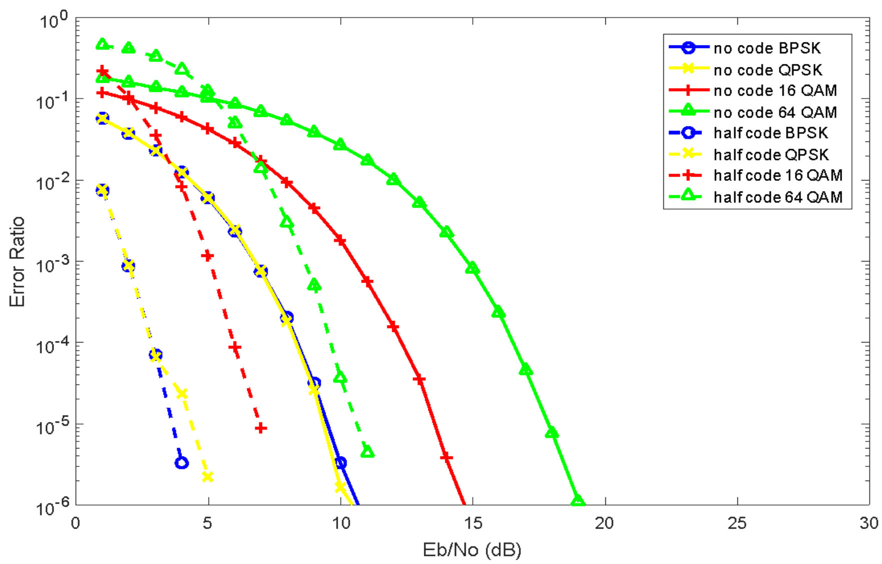

Figure 2: Error performance of AWGN channel with variable QAM and code rate

These curves result in creation of LDAR tables for noisy channel. After the Error threshold is satisfied, we chose the highest possible throughput above the threshold line. In our previous work, only OFDM-QAM modulation with different code rate were considered for LDAR and the above graph reflects those results. However, in iNET standard, two types of modulation are considered, SOQPSK and OFDM-QAM. Later, Both OFDM and SOQPSK modulation were incorporated in this project. A theoretical approach for Mode adaption and Transmission Table has been developed to be followed throughout the project. OFDM modulation incorporates QPSK, 16-QAM and 64-QAM modulation schemes with different Forward Error Correction (FEC) coding rates. Figure 3 shows the order of modulation schemes for LDAR with respect to the accepted delay spread and SNR of the channel. Table 1 shows different Modulation schemes with different coding rates which results in various values for throughput.

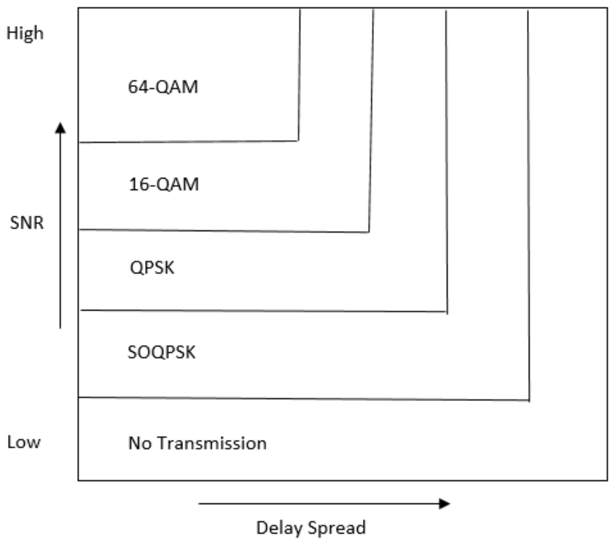

Figure 3: Link Dependent Adaption

Mode	Modulation	Code Rate, R	Data/symbol
1	SOQPSK	0.33	0.333
2	SOQPSK	0.50	0.500
3	SOQPSK	0.88	0.875
4	SOQPSK	1.00	1.000
5	QPSK	0.33	0.667
6	QPSK	0.50	1.000
7	QPSK	0.88	1.750
8	QPSK	1.00	2.000
9	16QAM	0.33	1.333
10	16QAM	0.50	2.000
11	16QAM	0.88	3.500
12	16QAM	1.00	4.000
13	64QAM	0.33	2.000
14	64QAM	0.50	3.000
15	64QAM	0.88	5.250
16	64QAM	1.00	6.000

Table 1: Different Transmission choices

In the next section, the two major Modulation schemes in iNET standard are introduced.

MODULATION SCHEMES

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 and has been shown to prove a good foundation for adaptable spectrally efficient modulation. OFDM divides spectrum into several sub-carriers. By dividing the bandwidth into smaller channel, 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, 24 or 64 [8].

In i^{th} block of OFDM, a set of N QAM symbols are transmitted over N sub-carriers and these frequency components are converted into time samples by performing FFT. After parallel to serial conversion, a cyclic redundancy of length v is added as a prefix and the signal is then serially transmitted over a noisy multipath channel with channel response h and noise vector w.

The output of the channel can be written as,

$$y^i = h_{circ} x^i + w$$

Where, h_{circ} is an $N \times N$ circulant matrix.

SOQPSK: The Shaped Offset Quadrature Phase Shift Keying (SOQPSK) modulation scheme is defined as a continuous phase modulation (CPM) with baseband modulated signal [3]. Different versions of SOQPSK differ by their respective frequency pulse. In this project, we use SOQPSK-TG (Telemetry Group SOQPSK).

The output of the channel can be written as,

$$y_n = h * x_n + w_n = \sum_{l=0}^{L-1} x_{n-l} h_l + w_n$$

Where, x_n is a discrete time SOQPSK waveform, h_l is the multipath channel impulse response, L is the channel length and w_n is an additive white Gaussian noise [9].

In the next section, LDAR modes of operation is discussed.

LDAR MODES OF OPERATION

This section includes an update to our prior publication on the signaling of LDAR [4]. The transmission of Control Messages over Link Dependent Adaptive Radio (LDAR) depends on four different modes between Ground Station and Test Article: i) Ground Station Transmitter ii) Test Article Receiver iii) Test Article Transmitter iv) Ground Station Receiver

The diagram of LDAR Modes of Operation has shown below in figure 4.

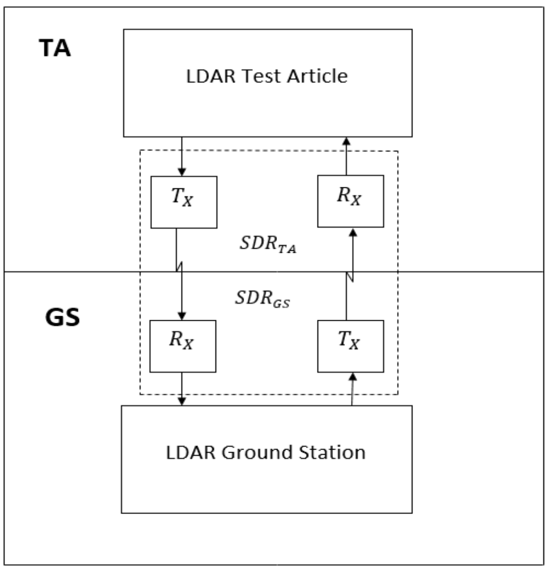

Figure 4: LDAR Modes of Operation

The process starts by sending a command message (CM) by ground station transmitter using a test sequence script through an Uplink radio channel. The receiver of the test article accepts this message to direct or command the Test Article (TA) to transmit the Data Message (DM). The initial command message includes information about the modulation scheme and coding rate on which the Data Message can be assembled. After receiving Command Message, test article receiver then decodes CM and sends the mode selection and coding rate to test article transmitter. The transmitter then processes data message according to the specification of mode and code rate. The TA transmitter conveys DM to ground station receiver through downlink radio channel.

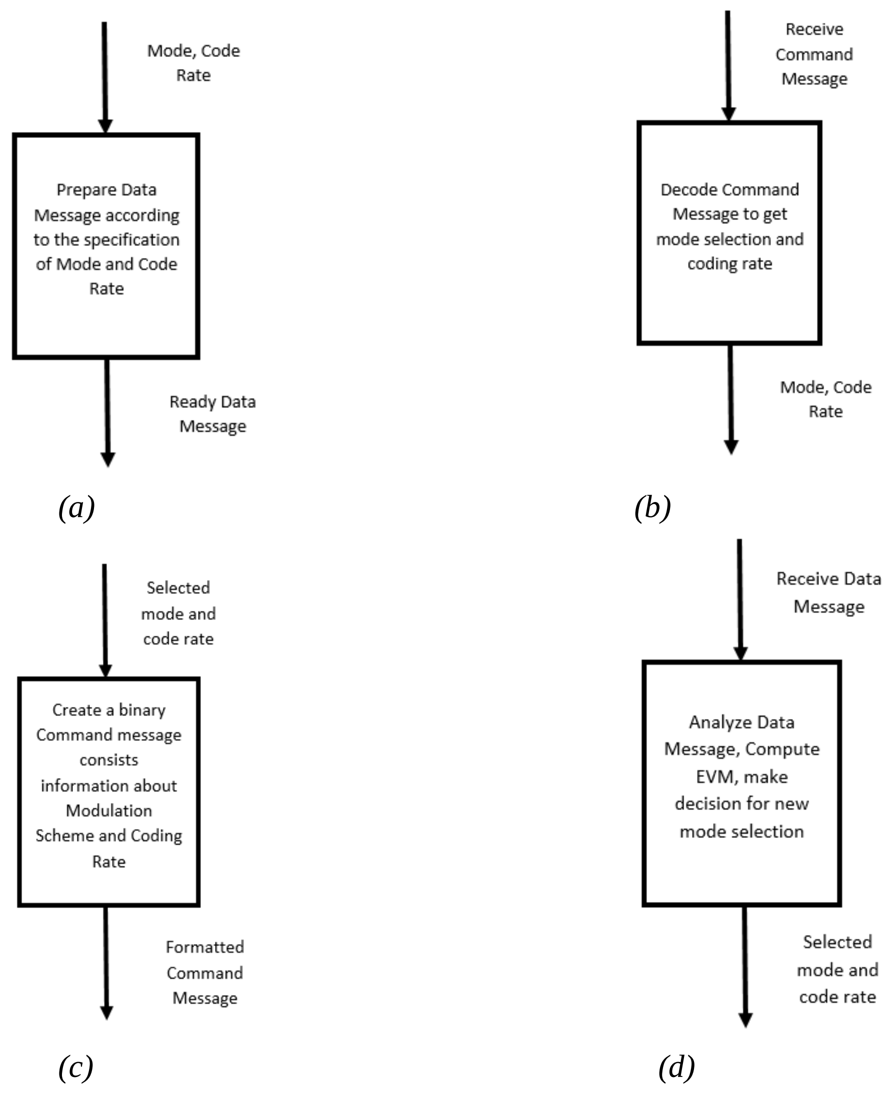

Figure 5: Modes of operation (a) Ground Station Transmitter (b) Test Article Receiver (c) Test Article Transmitter (d) Ground Station Receiver

COMMAND MESSAGE

The Command Message is the coded version of Mode Rate. This is a 32-bit message with 5 repetitions. It comprises of Mode Rate code as 16 bits and 16 bits of Frame Structure. 16-bit Mode Rate contains 8-bit data and 8-bit Cyclic Redundancy Check (CRC). 16-bit Frame Structure is also created with 8-bit data and 8-bit CRC. The 8-bit data for Mode rate includes the binary information of Modulation and Code Rate selection. And 8-bit data for Frame structure contains information for different frame structure for data packet to be sent.

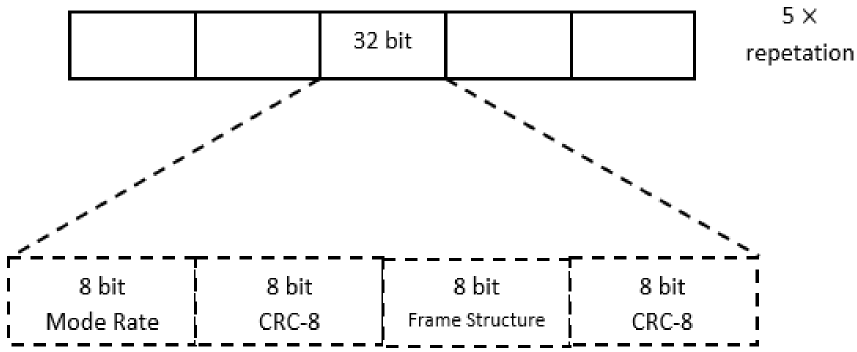

Figure 6: Command Message Structure

DATA MESSAGE

Based on the Mode Rate and variable frame structure, data message of our simulation is the 2047 PN sequence initialized as 00000000001 from polynomial $z^{11} + z^2 + z$ with a '1' appended to last bit. This Sequence is repeated multiple times to represent a complete frame. (sub-frame × framemultiplier) and truncated for the last packet as needed.

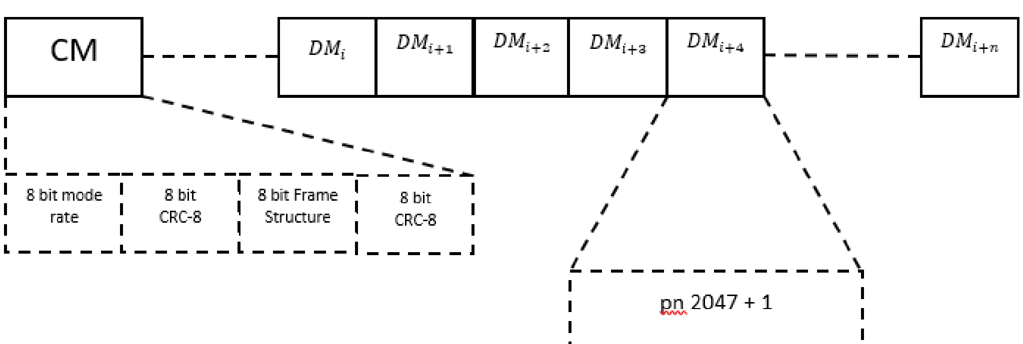

Figure 7: Data Message Structure

Table 2 and 3 show the specifications of Packet Structure and Frame Structure for command and data messages.

Mode	Modulation	bits/symbol, K	Code Rate, R	Data/symbol	Sub-Frame	Data/Sub-Frame
1	SOQPSK	1	0.33	0.333	1.4msec	2731
2	SOQPSK	1	0.50	0.500	1.4msec	4096
3	SOQPSK	1	0.88	0.875	1.4msec	7168
4	SOQPSK	1	1.00	1.000	1.4msec	8192
5	QPSK	2	0.33	0.667	1.4msec	8192
6	QPSK	2	0.50	1.000	1.4msec	12288
7	QPSK	2	0.88	1.750	1.4msec	21504
8	QPSK	2	1.00	2.000	1.4msec	24576
9	16QAM	4	0.33	1.333	1.4msec	16384
10	16QAM	4	0.50	2.000	1.4msec	24576
11	16QAM	4	0.88	3.500	1.4msec	43008
12	16QAM	4	1.00	4.000	1.4msec	49152
13	64QAM	6	0.33	2.000	1.4msec	24576
14	64QAM	6	0.50	3.000	1.4msec	36864
15	64QAM	6	0.88	5.250	1.4msec	64512
16	64QAM	6	1.00	6.000	1.4msec	73728

Table 2: Data/Packet Structure

Frame Multiple	Frame (ms)	Guardband (ms)	Frame Period (ms)
10	1.4	0.14	15.4
30	1.4	0.14	46.2
100	1.4	0.14	154
300	1.4	0.14	462
1000	1.4	0.14	1540
10	1.4	0.28	16.8
30	1.4	0.28	50.4
100	1.4	0.28	168
300	1.4	0.28	504
1000	1.4	0.28	1680
1000	1.4	0	1400

Table3: Frame Structure

TDMA STRUCTURE

The Uplink and Downlink channels have a simple Time Division Multiple Access (TDMA) structure in order to meet iNET specification [3].

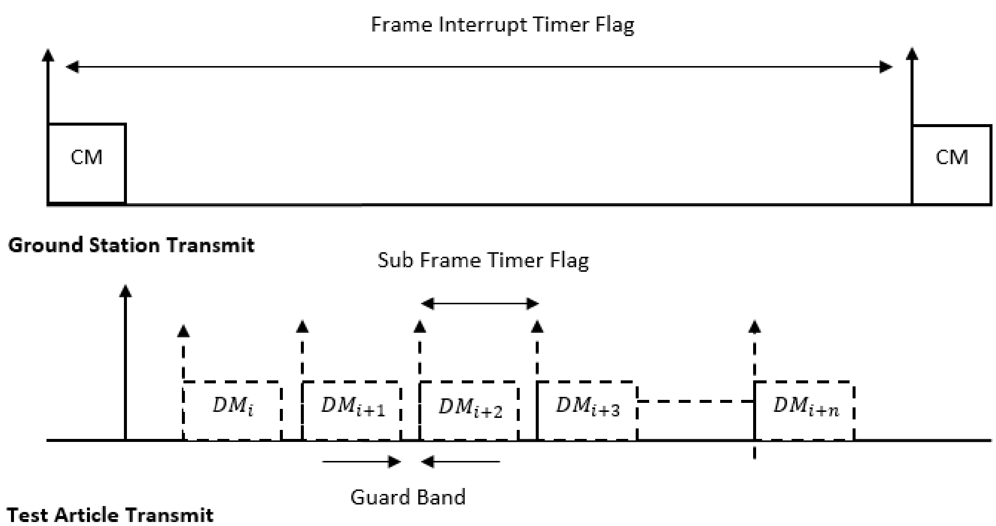

Figure 8: TDMA structure for uplink and downlink channel

DETERMINATION OF CHANNEL QUALITY

For LDAR to maximize the throughput of the telemetry link while ensuring the minimum level of reliability, the channel condition must be estimated to determine what mode and code rate needs to be selected. Georgia Tech Research Institute (GTRI) has developed a new approach of an adaptive link metrics that measures the degradation due to thermal noise and channel effects. They present the Error Vector Magnitude (EVM) for OFDM and second order Godard Dispersion ($D^{(2)}$) for SOQPSK and derived a mathematical relationship between these two metrics [9].

EVM measures the difference between the received symbols and their expected positions in the I/Q plane. EVM has no meaning for SOQPSK since there is no soft decision in the demodulation of the signal. Second Order Godard dispersion, defined as $D^{(2)} = E\,[(|y(n)|)^2 - R_2)^2]$ where $y(n)$ is the received signal and R_2 is the amplitude of the constant modulus signal, to measure the quality of a received SOQPSK signal. The mathematical relationship between EVM and Godard dispersion derived by GTRI enables to utilize a set of empirically-derived adaptation rules that incorporate both modulation schemes [9].

Using the mathematical equation provided in the mentioned paper [9], we can determine the channel condition by comparing the incoming Data message through the channel.

CONCLUSION

This paper shows the design of LDAR with a simplified iNET Time Division Multiple Access (TDMA) structure of Uplink and Downlink channel. This work maps the LDAR design into timing structure of iNET by creating command messages that governs the mode of operation with a simple TDMA structure. Its adaptation of Modulation depending on the channel condition ensures error performance is controlled by a specific command and control messaging that we showed in this paper.

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