EFFECTS OF AERONAUTICAL CHANNEL DYNAMICS ON THE PERFORMANCE OF LINK DEPENDENT ADAPTIVE RADIO (LDAR)

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ABSTRACT

This paper includes aeronautical channel dynamics in the flight simulations of the Link Dependent Adaptive Radio (LDAR) for realistic measurement of the throughput gain with the adaption of the modulation and coding parameters for aeronautical telemetry. Previously, the LDAR flight simulator used a fixed channel for different phases of the flight. This paper shows the performance of LDAR using a dynamic channel created by the customized two ray channel model considering delay spread, Doppler and other channel dynamics. The merger of such dynamic channel simulator with the LDAR flight simulator could help the telemetering community by providing reliable simulation results before test flights.

INTRODUCTION

Wireless technology is developing continuously for better communication. Improved quality of communication has always been a priority in wireless telemetry. Generally, wireless telemetry uses radio channels for transmitting test article data. But radio channels are unpredictable and dynamic and poor channel conditions affect performance in several ways such as noise, multipath, and Doppler effects. Channel dynamics, especially frequency selective fading of the channel becomes a bigger issue in highly dynamic environments such as aeronautical communication where the speed of the aircraft exceed mach1 [1-3].

Dedicated telemetry links between the ground station and test article 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 of telemetry links while ensuring an acceptable level of data quality and reliability [4-6].

LDAR

The next frontier of telemetry systems is creating a self-modulating coding rate based radio which adapts to the channel condition “on the fly”. And Link Dependent Adaptive Radio (LDAR) does exactly that by choosing the best modulation scheme while analyzing the current channel condition based on the telemetry environment. This produces maximum throughput with mixed levels of link quality. Depending on the SNR or delay spread, if the communication channel quality is high between the Ground Station and Test Article then LDAR adapts to a higher data rate [4]. Conversely, having a low-quality channel (or when the error level crosses a predefined performance threshold) the adaptive system provides a feedback system which lowers the data rate during the successive communication phases. This adaptation is achieved by altering the modulation scheme or truncating the coding rate of the transmission [3-6].

The basic Link Dependent Adaptive Radio (LDAR) system model consists of a transmitter, a receiver, and a telemetry channel model. The transmitter has an encoder and a modulation which consists both Orthogonal Frequency Division Multiplexing (OFDM) and Shaped-Offset Quadrature Phase Shift Keying (SOQPSK). The receiver consists a demodulator and decoder [3-4]. 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.

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 1 shows a comprehensive set of results with two different coding schemes for various Quadrature Amplitude Modulation (QAM) sizes with Additive White Gaussian Noise (AWGN) channel.

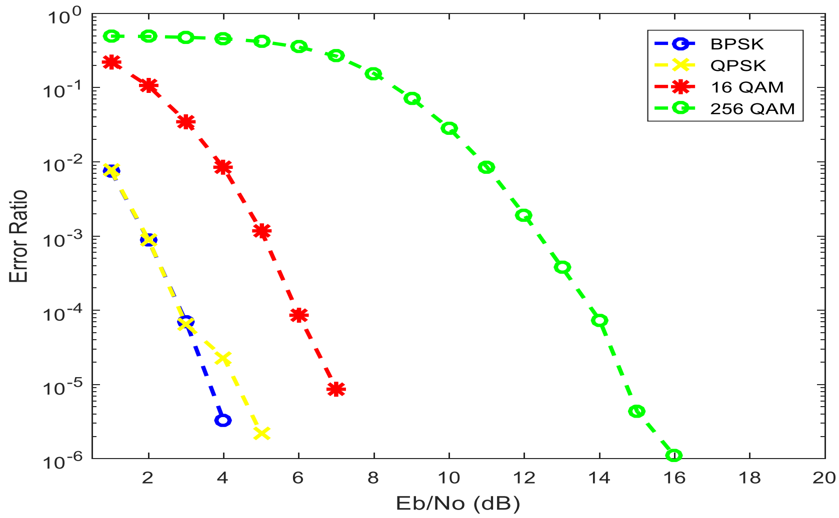


Figure 1: Error performance of variable QAM with half code rate

These curves result in the creation of LDAR tables for noisy channel. After the Error threshold is satisfied, we chose the highest possible throughput above the threshold line. A theoretical approach for Mode adaption and Transmission Table has been developed from this error performance graph of different modulation scheme.

FLIGHT SIMULATION OF LDAR

In our previous work, a flight path simulation has been developed where flight scenarios have been demonstrated to simulate the flight path for the Test Article (TA) and selects modulation schemes based on channel condition. The flight path demo had three different phases: Taxi, take off and Cruise as shown in Figure 2 below. The flight path simulator used a constant channel for different phases of the flight.

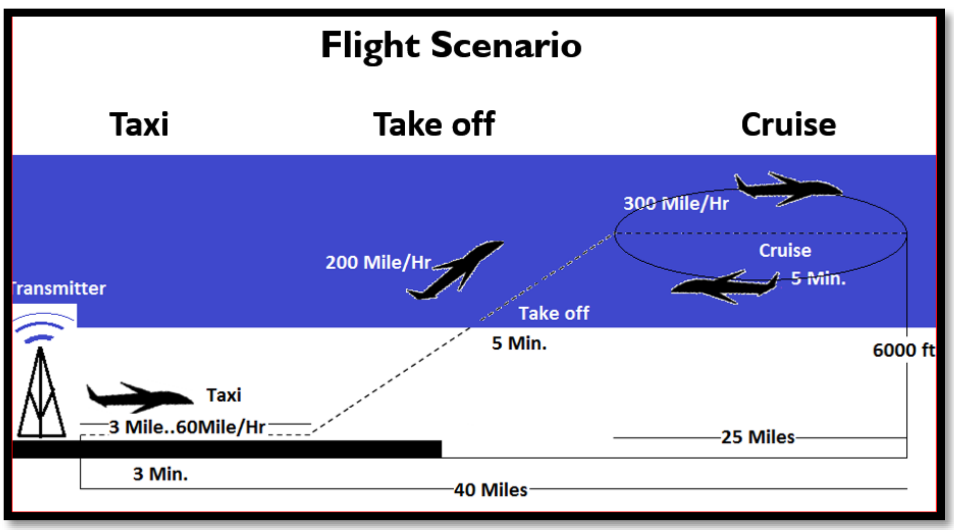
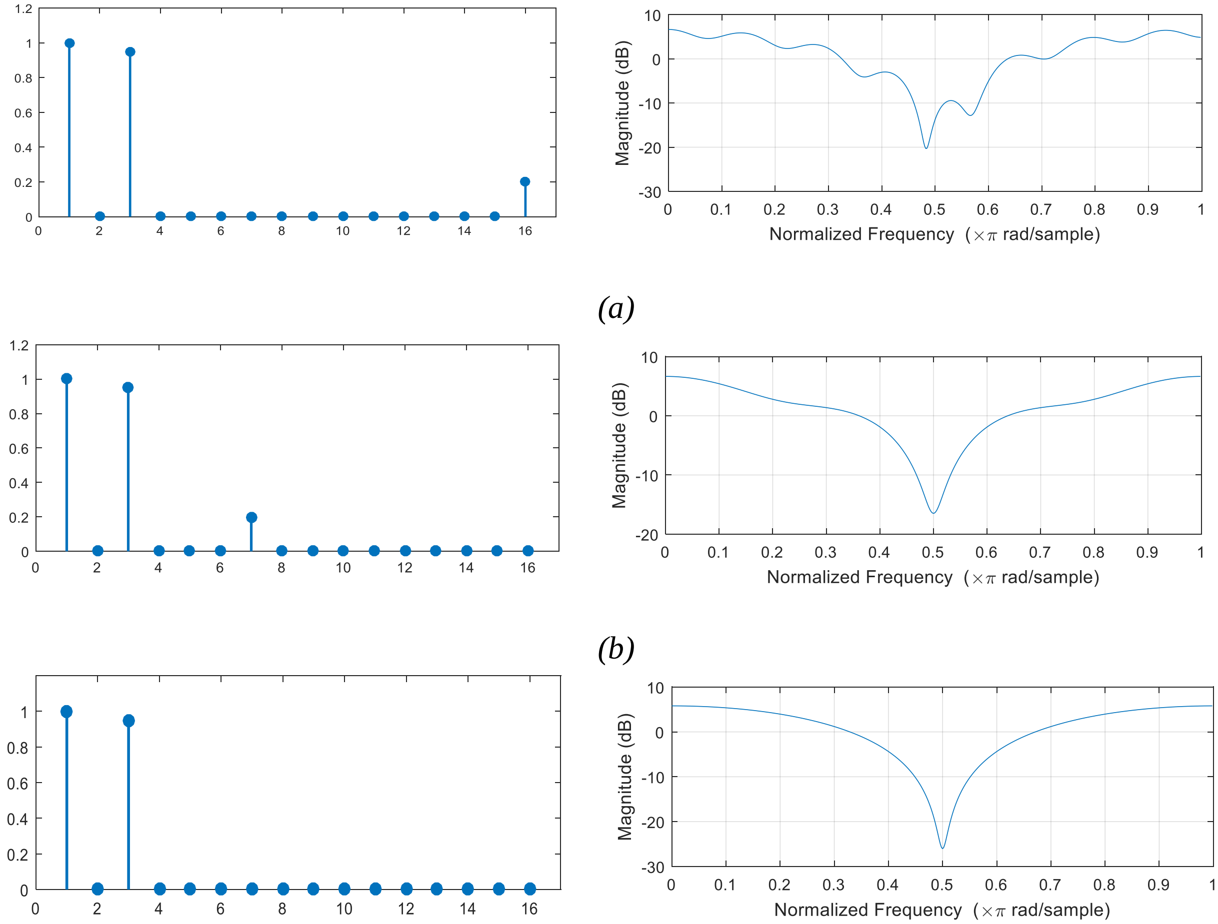


Figure 2: Flight path scenario of LDAR

The static channel impulse response and frequency response during Taxi, Take-off and Cruise has shown in figure below:



(c)

Figure 3: Impulse Response and Frequency Response of (a) Taxi Channel, (b) Take off Channel and (c) Cruise Channel

In taxi channel, there are three significant impulses where the first and second impulses denote the direct path and ground bounce respectively. One at the sixteenth tap represents the clutter perhaps from a nearby building in the test range. In the take-off channel, the first two impulses shown in the figure-3(a) are direct line of sight and reflected path respectively along with another reflecting object. And in the cruise channel, only line of sight and ground bounce is observed.

Using the Log distance path loss model, the Signal to Noise Ratio values for the entire flight path is computed. The duration of this flight simulation is 1560 seconds and sampled for each second. SNR values have been generated and stored prior to the test. Figure 4 below shows the SNR profile of the flight path for all phases including outbound and inbound.

Taxi phase lasts for 180 seconds and is 3 miles long. The path loss exponent used for taxi phase is n=4.

The exponent is assumed 4 because test article is close to the ground station and usually ground station is surrounded by other buildings and other test articles. First 180 seconds on figure 4 shows SNR values for taxi phase. The Taxi phase has a high SNR at the beginning and as the test article reaches to the end of the runway, SNR drops sharply. Takeoff phase lasts for 300 seconds and spans 12 miles. Note the rapid increase in SNR as the path loss drops with elevation. The path loss exponent considered for this phase is 2.5. This results in a smoother SNR compared to the taxi phase.

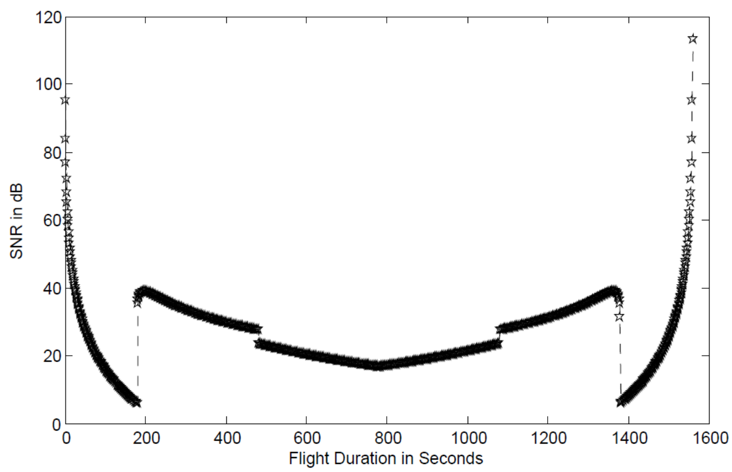


Figure 4: SNR profile of the channel for the flight path

During takeoff, the distance is increasing and SNR drops again. In the cruise phase n=2 results in smooth drop and at around 800 second, the test article starts to return to the base via the same flight path. So, the SNR profile is symmetric to the outbound path in reverse [6].

The flight is simulated with several modulation schemes such as BPSK, QPSK, 16 QAM, and 256 QAM. The Symbol Error Rate (SER) for all the modulation sizes in the flight path are shown in figure 5 below.

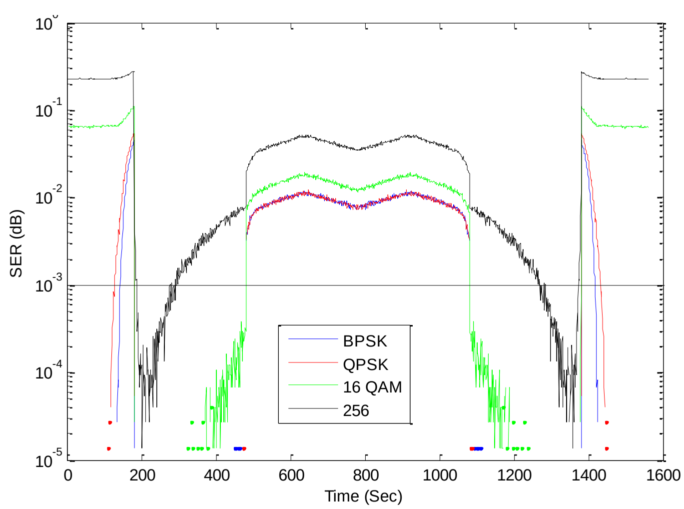


Figure 5: SER for the entire flight path with different modulation sizes

The modulation is dynamically selected by the LDAR controller given the tolerable error threshold and the previously ranked table for modes of operation. The final product is a live simulation of decision making in LDAR flight simulator. Figure below shows several snapshots of the simulator.

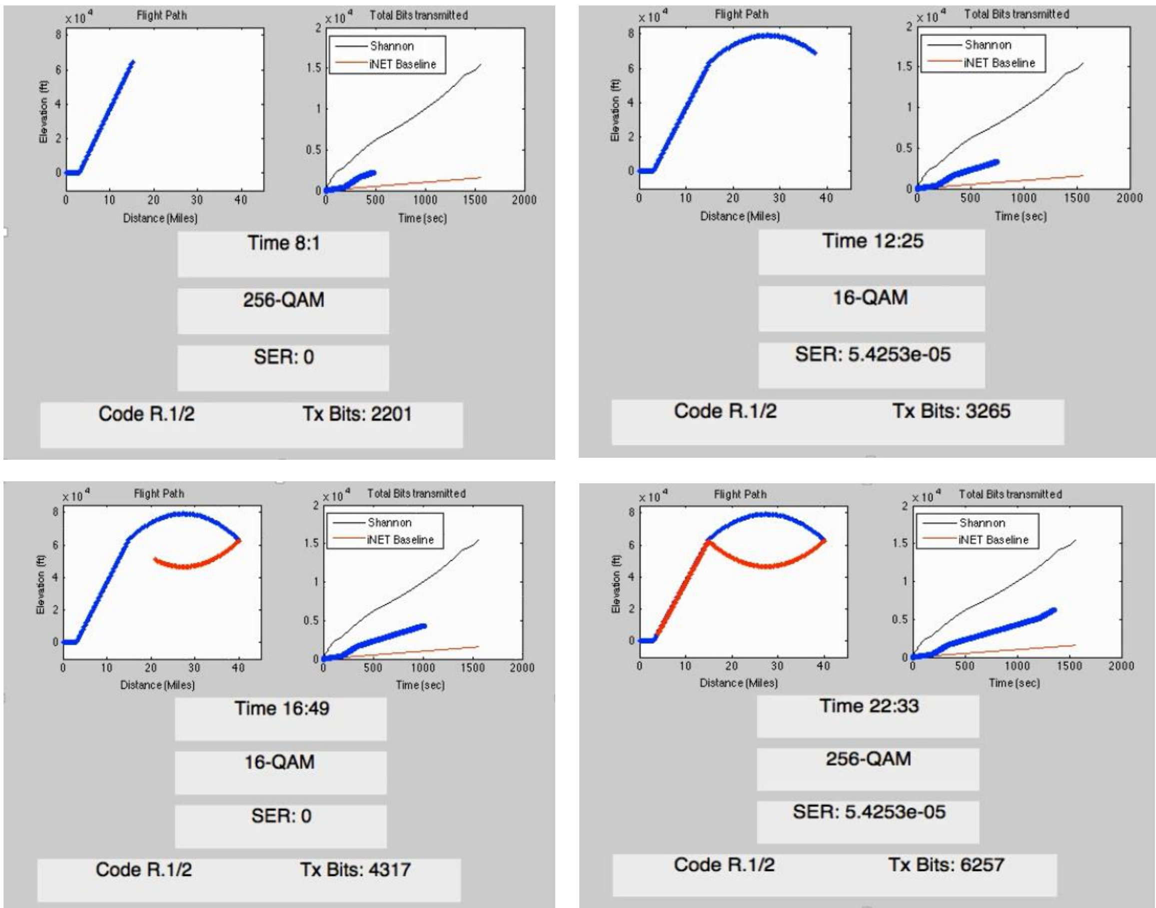


Figure 6: Snapshots of flight path simulator

The Total transmitted bits are increased by a factor of 5.5 over the iNET baseline. This is a promising result, however the channels within this simulator are static and averaged over the entire path which excludes the Doppler spread and delay spread changes during the flight [6].

The channels are selected from the results of Dr. Michael Rice's channel sounding test flights at EAFB. However, in the simulations only a snapshot of the channel is used for taxi, take off, and cruise phases without considering the delay spread and other dynamics of the aeronautical channel. We find this to be a common practice in flight simulations which could potentially result in considerable error levels in computer simulation of the test flights compared to the real flights.

The final goal of this prototype system (Link Dependent Adaptive Radio) is to ensure maximum throughput in a telemetry communication by adapting modulation scheme and error correction depending on the channel condition in real time. In a real time scenario channel is not static. Real time channel is dynamic. To increase the accuracy of this simulator, channel dynamics must be considered in this simulation. Using the two-ray ground reflection model, Doppler spread, and delay spread characteristics of such flight scenario, dynamic channels could be generated.

DYNAMIC CHANNEL SIMULATION

Dynamic channel simulation has been developed to generate dynamic channels and then to incorporate this in our LDAR flight simulation to ensure accuracy. The channel simulation process starts by identifying the number of taps from the impulse response of Dr. Rice's channel [7, 8]. Then, approximate the position of the taps and their amplitude from the impulse response graph (Tap_tau and Tap_mean). The amplitudes then normalized to the tap with highest amplitude. The other amplitudes were determined from the amount of dB decrease which normalized subtracted from the highest amplitude. Assume a bandwidth of 15 MHz thus the sampling rate is,

$$SR = \frac{1}{2 \times 15 * 10^6} = 33\, nsec$$

The next step is then to divide tap position values by sampling rate.

Effects added to the channel are: 1. The Doppler and frequency offset and 2. Delta radian per sample. Both has been described below.

The Doppler and frequency offset (Tap_fd): Given that each path or taps possesses its specific Doppler, each Doppler were added to the frequency offset between the transmitter and the receiver, which was calculated with an oscillation recovery located between ±15000 Hz, following the logic:

$$Frequency\ Offset = \cos(2\pi f_0 t)$$

$$Frequency\ Offset\ (FO) = 15000 \times 2 \times random\ input$$

$$FO\&Doppler = FO + doppler$$

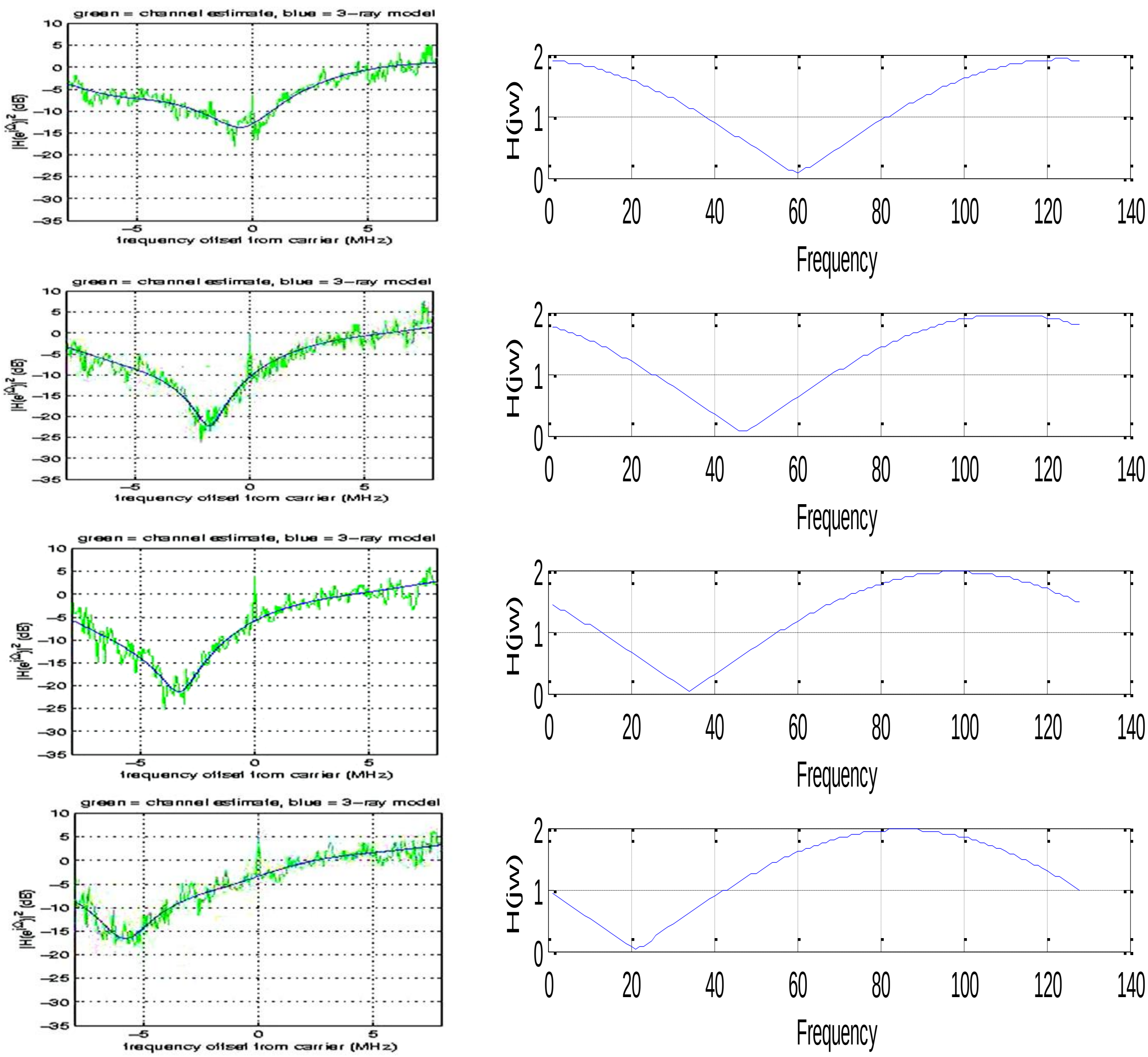
The Doppler values varied between the following values: 1000, 100, 2.

Delta radian per sample (Tap_dTH): The calculation of the angle increment per sample was performed through the following formula:

$$Tap_{dTH} = \frac{2\pi\ (Tap\_fd)}{SR}$$

After setting the channels, a convolution of the input per sample was performed using a random created input of 100000 samples.

For example, a two-ray airborne channel from Dr. Rice’s experiment. Snapshots of the frequency response of Dr. Rice’s Channel are shown below [9]. The simulated dynamic channel responses for the same channel are shown below.



(a) *(b)*

Figure 7: (a) Snapshots of the frequency response of Dr. Rice’s experiment in 2 ray airborne case; (b) Frequency response of dynamic channel simulator in 2 ray airborne case

The moving null in the frequency response of the channels are observed in figure7. The similarity of the actual and simulated dynamic channel responses are result of the inclusion on the simulated channel dynamics at the presense of two strong rayleigh paths. In addition, The four graphs illustrate that the doppler effect over time through the manifestation of the Nulls which are happening at different frequencies as the Dr. Rice’s channel would behave.

NEXT STEP

Next step in this work is to incorporate the dynamic channel simulator into LDAR flight simulation and compare the throughput gain that is computed with the static and dynamic channels in the simulator. Now that the behavior of the channel with flight dynamics are simulated, the inclusion of this channel simulator in the LDAR simulator will provide more realistic set of results in a dynamic aeronautical environment. These dynamics could be critical in any modeling of aeronautical telemetry and provide support for testing new communications payloads in simulation prior to test flight. The impact of creating accurate simulation results with this dynaic channel simulator reaches beyond LDAR and will help the telemetry community to improve the accuracy of computer simulation in the design and pre-test stages.

ACKNOWLEDGEMENT

This work is funded by a grant from International Foundation for Telemetering (IFT). Author and other WiNetS laboratory members in the School of Engineering at Morgan State University thank IFT for their support of this research.

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