# LINK DEPENDENT ADAAPTIVE RADIO PERFORMANCE ON DYNAMIC CHANNEL

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## ABSTRACT

This paper includes analysis of aeronautical channel dynamics in flight simulations of the Link Dependent Adaptive Radio (LDAR). LDAR system includes realistic measurement of the throughput gain with the adaptation of the modulation and coding parameters for telemetry applications. To increase the accuracy, channel dynamics have been incorporated in the simulation. Dynamic channel simulator is developed by the customized two ray ground reflection channel model including Doppler shift, delay spread, and other channel dynamics. This paper shows the comparison of the performance of LDAR using both static and dynamic channel. The impact of creating accurate simulation results with this dynamic 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.

## INTRODUCTION

A Wireless communication setup consists of three major components: Transmitter, Receiver and the Channel. The transmitter contains the information about data/message being transmitted and the modulation/coding technique of data transmission. The receiver contains the technique of effective data receiving and demodulation/decoding of the data to produce an accurate output. Channel is the non-deterministic and non-configurable component of the system [4]. Wireless telemetry uses radio channels for transmitting information. Radio communications in wireless channel is challenging because of multipath frequency selective fading and various man-made and natural interference. These issues are exacerbated by the dynamics of the high speed aeronautical environment [5].

The performance of the transmitter and receiver can be controlled by configuring according to its specification needed for the system. But channels are unpredictable and dynamic. Improved channel quality ensures higher performance. On the other hand, poor channel conditions affect performance in several ways such as noise, multipath and Doppler. 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 [1,2].

# LINK DEPENDENT ADAPTIVE RADIO

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 [4]. LDAR chooses the best modulation scheme while analyzing the current channel condition based on the channel environment. This produces maximum throughput with mixed levels of link quality. As the performance of channel changes, the modulation and coding rate for transmission will change accordingly. 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 [1,2,4]. Conversely, having a low-quality channel (or when the error level crosses a predefined performance threshold) the adaptive system provides a feedback 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 [1-4].

In a previous work, a flight path simulator 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 [6,7]. The flight path demo of LDAR has three different phases: Taxi, take off and Cruise as shown in Figure 1 below.

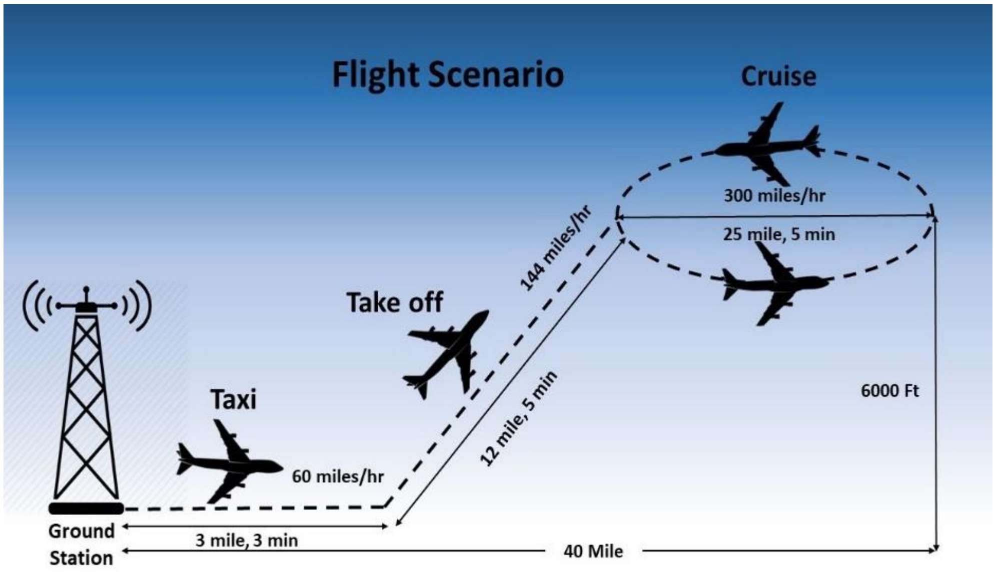


*Figure 1: Flight path scenario of LDAR*

Symbol error rate (SER) plays a vital role in the mode selection of LDAR. To dynamically adapt the modulation scheme and coding rate depending on the channel performance, a threshold parameter is necessary which holds the direct relation with the channel performance. SER is one of the parameter that has the direct relationship with the channel performance. If we set an error threshold at certain margin on the channel performance, transmitter can pick up the modulation scheme to operate below the selected threshold error rate [4,5].

Figure 2 shows the Symbol Error Rate (SER) for all the modulation schemes such as BPSK, QPSK, 16 QAM and 256 QAM with no coding over the same flight path. The threshold shown here is $10^{-4}$ and LDAR would select the highest throughput scheme (shown in black) below that threshold. The channel selected here is static and excludes Doppler effects, delay spread, multipath fading etc.

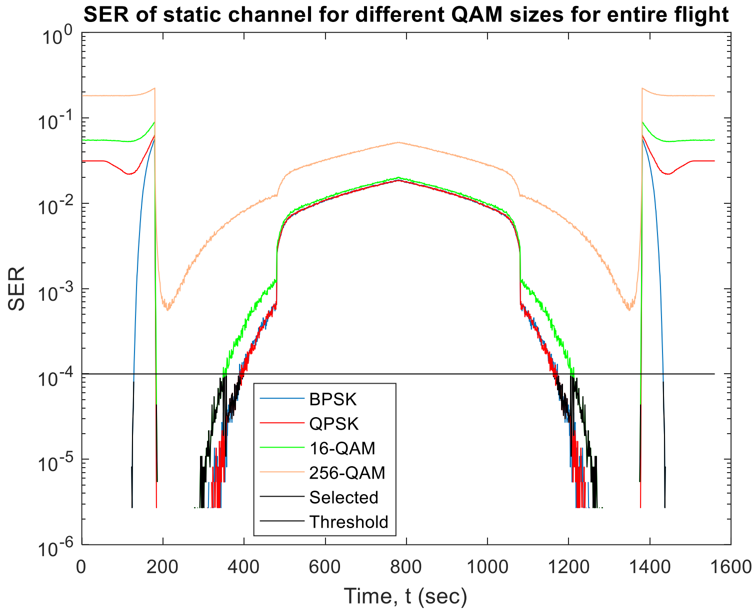


*Figure 2: SER profile of the entire flight path with different modulation sizes*

In a real-time scenario, the channel is not static. The real time channel is dynamic which includes effect of delay spread and Doppler shifts for each path. To increase the accuracy of this simulator, channel dynamics must be considered in this simulation.This paper shows the incorporation of channel dynamics to the LDAR system simulation to observe and analyze its effect.

## DYNAMIC CHANNEL SIMULATOR

Using the two-ray ground reflection model, Doppler shift, and delay spread characteristics of any flight scenario, dynamic channels could be generated. The channel simulation process starts by identifying the number of taps from the impulse response of Dr. Rice's channel [8]. One then approximates the position of the taps and their amplitude from the impulse response. The amplitudes are then normalized to the tap with highest amplitude. The other amplitudes are determined from the amount of decrease which is normalized and subtracted from the highest amplitude [5].

For our given flight path scenario, the Doppler and phase shift of the flight path (in the cruise state) can be computed for each second of the flight duration using two ray ground reflection model. Figure 3 shows the aeronautical two ray channel model for Doppler and phase shift calculation for LDAR flight path scenario.

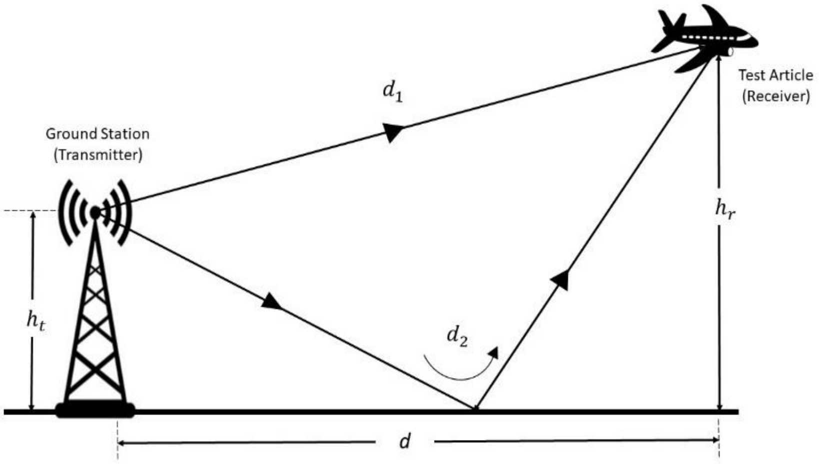


*Figure 3: Aeronautical channel model for any flight path*

Knowing the speed and position of the test article, one can easily compute the distance and height of the test article from the ground station as a function of speed and climbing angle for each second,

$$\text{distance, } d(t) = d(t-1) + \cos(\theta(t) * \nu(t)) \tag{1}$$

$$\text{height, } h(t) = h(t-1) + \sin(\theta(t) * \nu(t)) \tag{2}$$

Where, $\theta(t)$ = climbing angle of the test article at time t
$\nu(t)$ = speed of the test article at time t

Using the *method of images*from Rappaport [3], which is demonstrated in figure 4, the path difference Δ, between the line of sight and ground reflection can be expressed as,

$$\Delta = d'' - d' = \sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2} \tag{3}$$

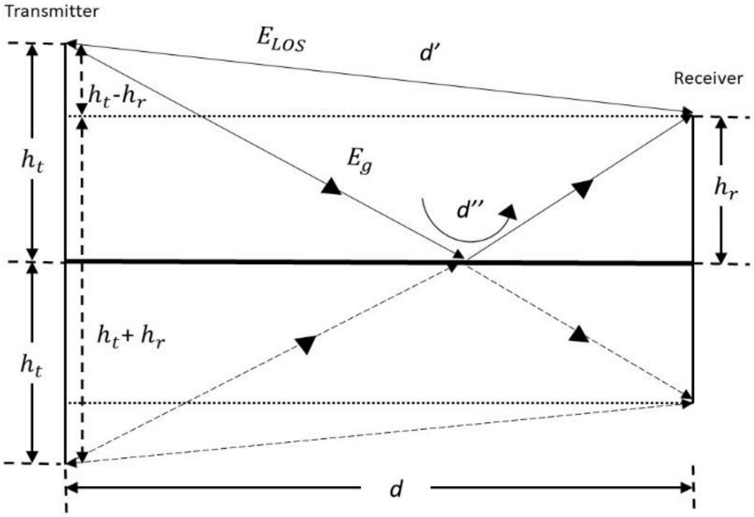


*Figure 4: The 'method of images' to find the path difference between the line of sight and the ground station*

Using equation (1), (2) and (3) we can now calculate the path difference, delta, Δ. Once the path difference is known, the phase difference $\theta_{\Delta}$and time delay $\tau_d$, between the arrival of two components can be computed by the following relation,

$$\theta_{\Delta} = \frac{2\pi\Delta}{\lambda} = \frac{\Delta w_c}{c} \tag{4}$$

Using the two ray model, the phase difference in the two tones of the impulse response of a channel can be calculated. Then the phase difference from one between the direct path and the reflected path can also be modelled.

Modelling of the impulse response with delay and phase shift per tap is shown in figure 5 below.

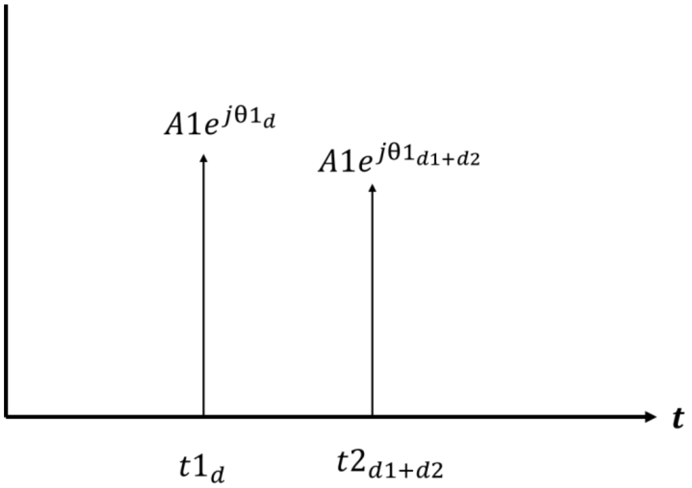


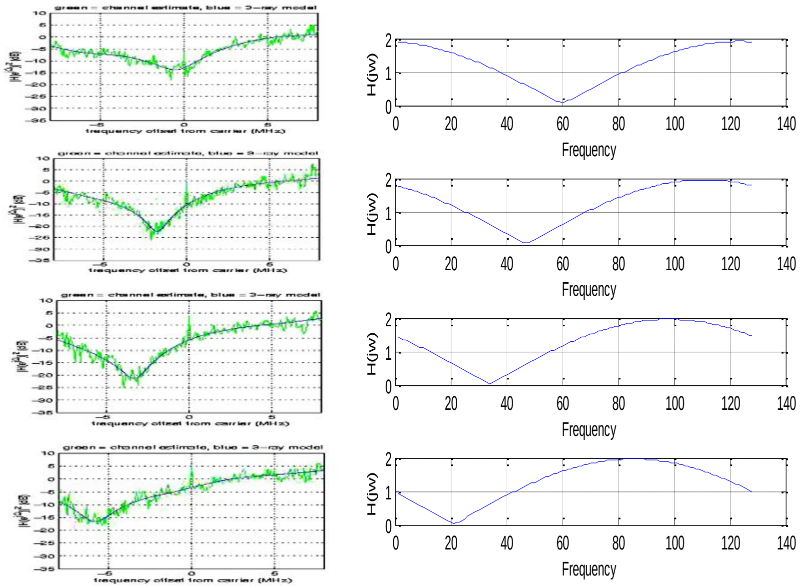
*Figure 5: Channel Impulse Response*

Figure 5 shows, at each time $t$, each path arrives after a delay $\Delta t$, which is a function of the distances for the direct path $d$ and the reflected path $d1 + d2$, and each path arrives at an amplitude $A1$ and $A2$ at phases $\theta1$ and $\theta2$. We normalized these such that the direct path has an amplitude of 1 and a zero phase and the reflected path has an amplitude $A2$ and a phase $\theta2 - \theta1$. The calculation of the angle increment per tap was performed using equation (4). [5].

Dynamic channel simulation has been developed to generate channel dynamics and then to incorporate this in our LDAR flight simulation to ensure accuracy.

A sample channel has been simulated to visualize the effect of the null movement of the channel. For example, let's consider a two-ray airborne channel from Dr. Rice's experiment. Snapshots of the frequency response of Dr. Rice's Channel are shown below in figure 6 [8]. Also, the simulated dynamic channel responses for the same channel are shown below in the same figure for comparison of null movement. [2]

The moving null in the frequency response of the channels are observed in figure 6.



*(a)* *(b)*

*Figure 6: (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*

## EFFECTS OF CHANNEL DYNAMICS ON LDAR

The effects of channel dynamics on LDAR using the dynamic channel simulator for the entire flight path has been analyzed. The Symbol Error Rate performance for 16 QAM with no coding has shown below in figure 7 with the comparison of static channel.

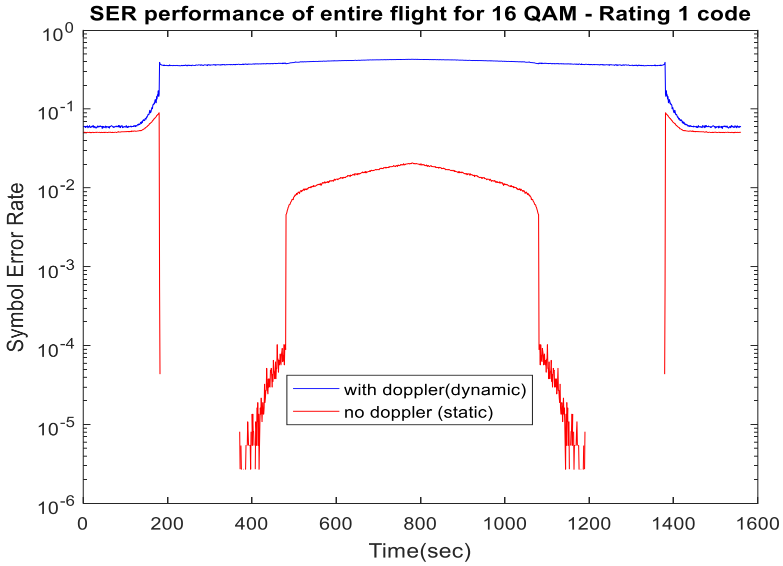


*Figure 7: SER performance of the entire flight path for 16 QAM*

The effect of the dynamic channel simulator on LDAR is dramatic. The error rate with added dynamics of the aeronautical channel is close to 50 percent. Reduction of the Doppler values and analyze the effect of the reduced Doppler on LDAR will help to understand the effects of SER performance better.

As the Doppler calculation and frequency shift calculation directly depends on the speed and angle of the aircraft (text article), a small change or reduction of the speed or the angle of the test article will also change or reduce the frequency shift per sample per second. But the speed and the angle of the aircraft is constant according to the specification of the flight path scenario shown in figure 1.

Doppler calculation is also directly dependent on carrier frequency, which is assumed to be 1.5 GHz to match the exact specification of Dr. Rice's channel. To reduce Doppler, we reduced carrier frequency from 1.5 GHz to 1.5 MHz while calculating the Doppler values for the specific flight path scenario. Along with the new reduced Doppler values, size of the modulation scheme has also been reduced for better understanding the dynamic effects thus, simulated 4 QAM with no coding [5].

Figure 8 shows the comparison of SER performance of the entire flight for 4 QAM with no coding for both dynamic and static channel. It shows that with the reduced dynamic phase changes there is an acceptable error perofrmance for dynamic channel to proceed further. In the taxi and take-off phase of the flight, the error performance of the dynamic channel is comparabe to the static channel. But in cruise phase, the error performance is quite similar.

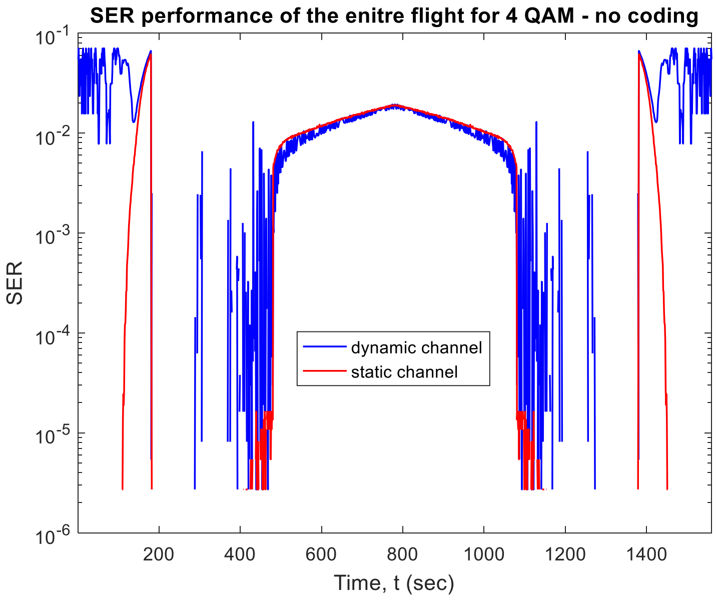


*Figure 8: SER performance of the entire flight for 4 QAM no coding*

Next, we generated the SER peformance for dynamic channel of the enitre flight with different QAM to analyze the error performance below and above the error thresahold, shown below in figure 9.

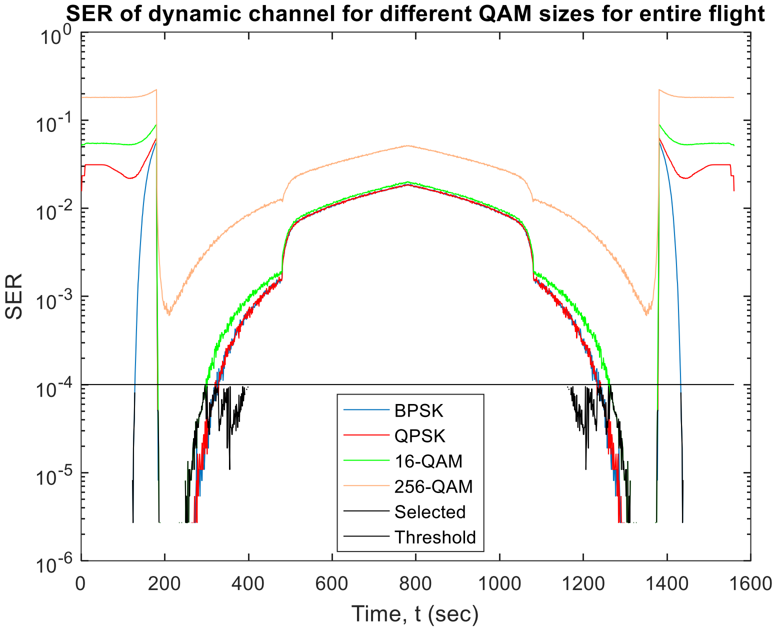


*Figure 9: SER performance of dynamic channel for different modulation scheme for entire flight*

The SER profile with different modulation schemes is really important for adaptation for the radio to chose the best modualtion for transmission to ensure maximum throughput with an acceptable error threshold, which is the core purpose of Link Dependent Adaptve Radio. With the added dynamics, the modulation scheme selectionfor transmission in the taxi phase, looks quite similar to the modulation selection of the static channel. But, a difference selection of modulation in take-off and cruise phase is prominent.

After computing the SER profile of both dynamic and static channels,this data was incorporated into the flight simulator to analyze the total transmitted bits of both channels through the entire flight.Figure 10 shows the total transmitted bits of the entire flight, adapting different modulation scheme for different phases by choosing the best SER compared to the SER threshold. Figure 10 also shows the iNET baseline fro transmitted bits for better comparison.

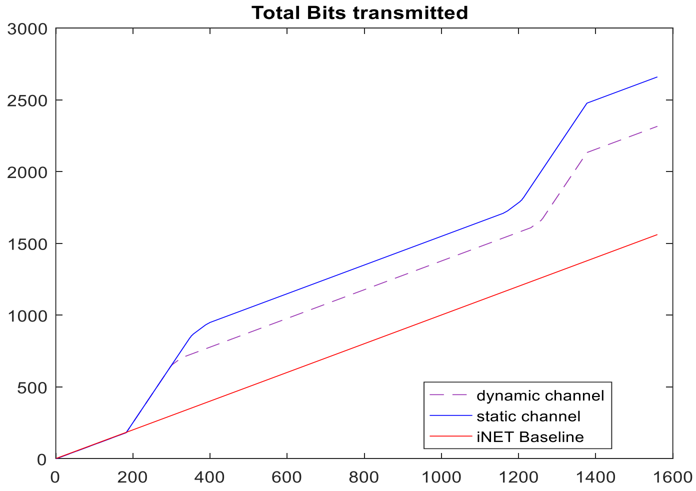


*Figure 10: Total transmitted bits*

Figure 10 shows that for the dynamic channel, LDAR takes a longer time to switch to higher data rates than the static channel. Althought the total tranismmited data of dynamic channel is somewhat lower than the static channel, it is still above the iNET baseline.

## ANALYSIS

From the results above, it is shown that the dynamic phase changes at 1.5GHz, particularly for OFDM system, dramatically affects performance. But after decreasing the carrier frequency, the phase shift effect on LDAR has better throughput with an acceptable error performance. Which means the higher carrier frequency has higher effect than the lower frequency on LDAR in terms of dynamicity. The reason behind it is the absence of frequency offset compensation in our system. If a Phase Lock Loop (PLL) has been used for the frequency offset, that would eliminate the higher error with higher carrier frequency [5]. In this section, different coding rate has been applied along with different modulation scheme, to analyze the effects of coding rate on the dynamic channel. Figure 11 shows the total transmitted bits of the system with different coding for both dynamic and static channel.

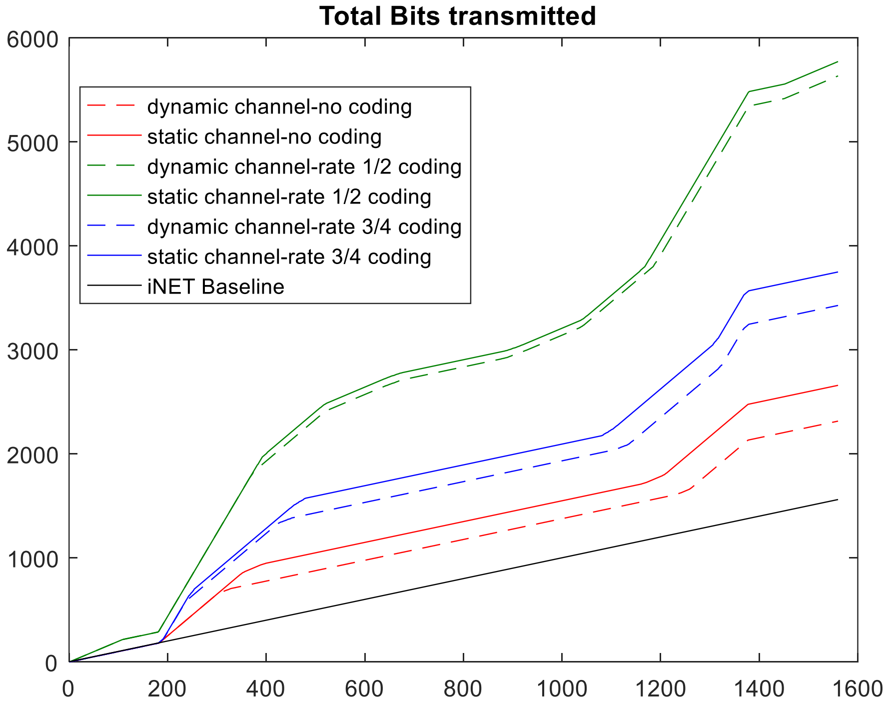


*Figure 11: Total Transmitted bits with coding*

It shows that adding code rate improves the error performance but the error performance is always worse than the static channel. It also shows that with half coding rate, the system constantly switches to one modulation scheme to another depending on the acceptable error threshold in different phases of the flight [5].

## CONCLUSION

In this project we have succesfully incorporated the aeronautical channel dynamics in LDAR system and has analyzed its effect. These effects demonstrate, behavior of real channels where frequency nulls in the spectrum “walk” across the spectrum as the test article moves. The error performance of the dynamic channel was compared to the static channel model. Our work indicates that a differential Doppler between the two paths represents a major 'dynamic' feature of the channel that has been ignored in most prior work on aeronautical channel. For OFDM this effect is significant and should be considered in any aeronautical OFDM, especially the equalizer. Note that our other 2018 ITC paper [9] provides and analysis of the dynamics of the channel over the range of flight paths and points to the use of an Adaptive Orthogonal Frequency Division Modulation scheme as a way to resolve these channel degradations.

The inclusion of dynamic channel simulator in the LDAR simulator provides 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.

## ACKNOWLEDGEMENT

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