

Application of AOFDM on simulated test flight scenario

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ABSTRACT

This paper presents the test results of an Adaptive Orthogonal Frequency Division Multiplexing (AOFDM) modulation system on virtual flight path scenario of a Link Dependent Adaptive Radio system. This work also compares its results with fixed rate OFDM with the same Signal to Noise Ratio (SNR). The AOFDM system identifies the distortion of the individual OFDM tones and adjusts the modulation to optimize the performance of each tone. Such a design demonstrates significant improvement of spectrum efficiency and error performance for different test flight scenarios.

INTRODUCTION

As a part of the iNET project, the Wireless, Network and Security (WiNetS) Lab at Morgan State University has explored the operational structure of an Adaptive Orthogonal Frequency Division Multiplexing (AOFDM) scheme and also later implemented AOFDM for various aeronautical channels. Previously our work has proven AOFDM to be an ideal candidate for telemetry channels with an adaptive and optimal modulation scheme for each tone in the Orthogonal Frequency Division Multiplexing (OFDM) symbol [1]. Our previous work on implementation of AOFDM indicated that the cruise channel varied slowly and predictably over time which shows the channel as remarkably stable. In addition, the steady state channel of AOFDM presented a 2-ray multipath model and shows deep null in the channel spectrum, that negatively affects serial tone modems significantly with the introduction of noise and severe phase distortion. Additional work demonstrated enhanced performance over a wide range of signal-to-noise ratios (SNR) [1-2]. Following up our previous work, this paper shows refinements to the AOFDM scheme in a simulation setting and additional test results over a simulated test flight scenario.

AOFDM STRUCTURE

The AOFDM system model has been developed to maximize the throughput of the aeronautical channel for telemetry applications. This application exhibits the need for enhanced data throughput for a down link channel and the presence of a minimal up link. The overall structure of the AOFDM model is presented in Figure 1 [2]. The most important design factor of the model structure is the introduction of a back channel which communicates the information of the adaptive M(order) Quadrature Amplitude Modulation (MQAM) for each tone with a system for adaptation.

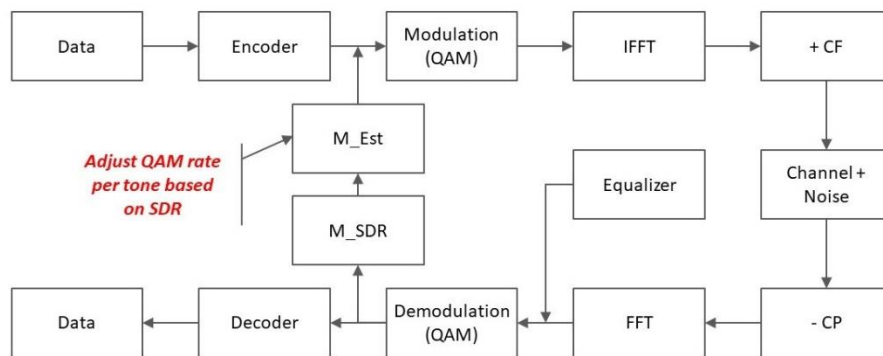


Figure 1: AOFDM Block Diagram

This system is comprised of a traditional OFDM modulation and demodulation structure, an aeronautical channel simulation, an adaptive equalizer, and a feedback channel with information to adapt the modulation structure M in an MQAM scheme. The channel simulation incorporated two approximately equal paths with the addition of noise and a Doppler of approximately 40 Hz. The adaptive equalizer used a simple gradient equalized for amplitude and phase separately based on the estimated error at the receiver. The feedback channel shown in Figure 1 is the key to this scheme. It develops an estimate of the best M value for subsequent MQAM frames based on a measurement of signal to distortion ratio (SDR) at the receiver, where the changes are constrained to increment or decrement the M value over a range of $M = 2,4,8,16,32,64$.

EXPERIMENT SETUP

In our previous study, we have made a pre-emptive assumption that we know the state of the channel Signal to Distortion Ratio (SDR), which needed to be measured [1]. As a part of our second study, we did estimate the SDR [2, 4]. Setting up the simulation environment, we have

set the Channel as a 2-ray model with 25 dB null, which is a typical steady-state aeronautical channel. Next, we introduced a 40Hz phase shift into the channel, with symbol rate of 4 microseconds. Compared to the 40Hz doppler shift, the symbol rate is relatively small and the channel is semi-stationary. The 40 Hz doppler is twice the amount we would observe for a Mach 1 Test-article, when the Test-article is perfectly aligned with the direction of base station presenting the worst-case scenario. At this stage, we introduced an Adaptive Gradient Equalizer for each tone – with 100 frames of training. The Equalizer can adapt with a particular amplitude and phase of the error associated with the channel [2].

In this paper we proceeded to test this AOFDM scheme over a simulated test flight developed for a typical aeronautical application based on the work in [3]. This testing included all of the channel, noise, and Doppler conditions as above, and provided performance results over a wide array of channel condition as the test article traveled toward the horizon and returned.

The MQAM’s estimated values for the experiment were 64, 32, 16, 8, 4 and 2 QAM. The rate and structure of the QAM was designed to increase or decrease, in order to adjust the average error rate around 10^{-4} . This adjustment was made considering the measured distortion and the threshold. The entropy of M-changes for each tone was measured for the back channel. Next, we measured the data throughput during each test: 6 bits per tone for 64 QAM, 5 bits per tone for 32 QAM, 4 bits per tone for 16 QAM, 3 bits per tone for 8 QAM and 2 bits per tone for 4 QAM. Considering the Signal to Noise Ratio (SNR) of our channel, these data throughputs compared well with Shannon Limit [2].

This design also added the feature to send zero data on severely degraded tones and where the M values were set to 2. This had a considerable impact on the overall performance as it avoided the unnecessary introduction of errors and simplified the job of error correction or detection to be considered later.

Table 1 below shows the thresholds of the SDR used to determine when to increment or decrement the M values shown in the table [2].

QAM	SNR lower	SNR Upper
64	<25dB	
32	<21dB	>25dB
16	<17dB	>21dB
8	<15db	>17dB
4		>15dB

Table 1: MQAM Lookup Table

TEST RESULTS

The testing consisted of two independent runs of the system with our flight simulation. The first case used the AOFDM structure described below and the second case operated with a fixed structure with 4QAM where we get results comparable to a simple QPSK modulation scheme. As described in [3] our flight simulation simulates 6 states which are taxi, takeoff, cruise and a return with cruise, landing and taxi. The emphasis of this test was the cruise phase of the flight as would be the case for a telemetry application. The most significant feature of the test is the variation of the SNR of the channel during the cruise phase. For both the AOFDM and the Fixed OFDM runs data was captured for the SNR, Data throughput, Bit errors and Bit Error Rate (BER) versus time as well as a measure of the net throughput and errors. These are shown in figure 2 and 3 below.

CASE 1: AOFDM Test Flight

The performance of the test flight for the AOFDM scheme is captured over approximately 1600 frames of AOFDM as shown in Figure 2 below.

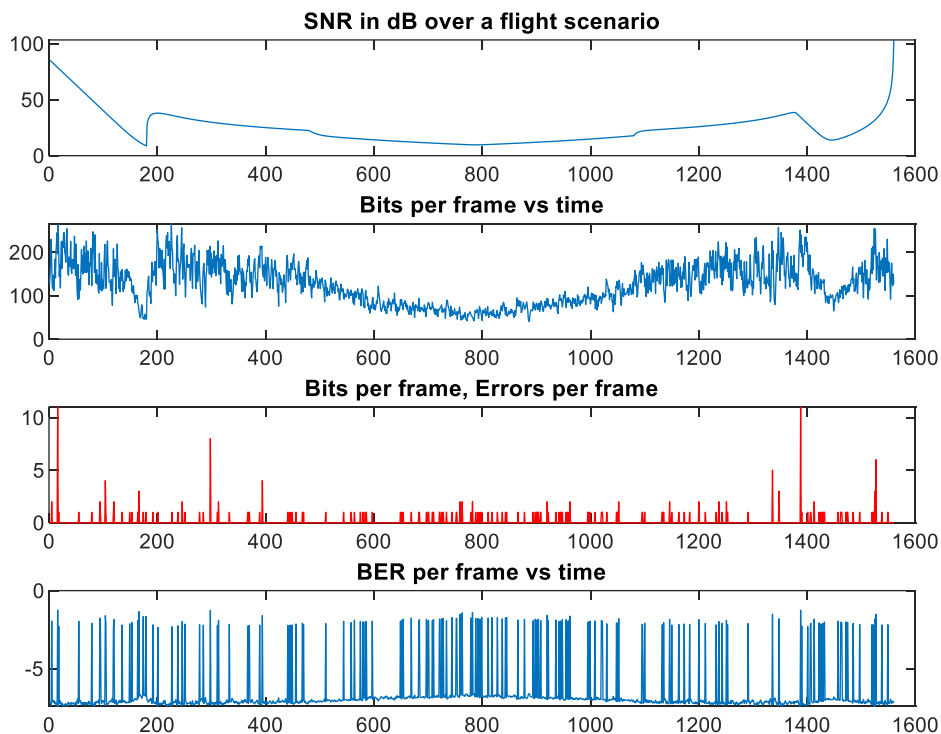


Figure 2: Performance Results for AOFDM Test Flight

The SNR for this flight varied from about 40 dB at the beginning of the cruise phase (frame 200) to about 9dB SNR at the furthest range of the flight (frame 800). The total data transmitted was 195,903 bits and the total errors were 226 yielding a BER of .0012. Note that the total bits/frame in Figure 2, tracks with the SNR from more than 200 bits per frame on the better channels (~frame 200) to about 50 bits/frame on the poor channels (~frame 800). Most of the frames were error free while most of the error were in clumps of 1 or 2 errors per frame. Most significantly, the BER on the worst channel (~frame 800) was comparable to the BER on the better channels. This points to a robustness over the range of conditions that is desirable.

CASE 2: Fixed Rate (M=4) Channel

The performance of the test flight for the fixed Rate (M=4) scheme is captured over approximately 1600 frames of OFDM as shown in Figure 3 below.

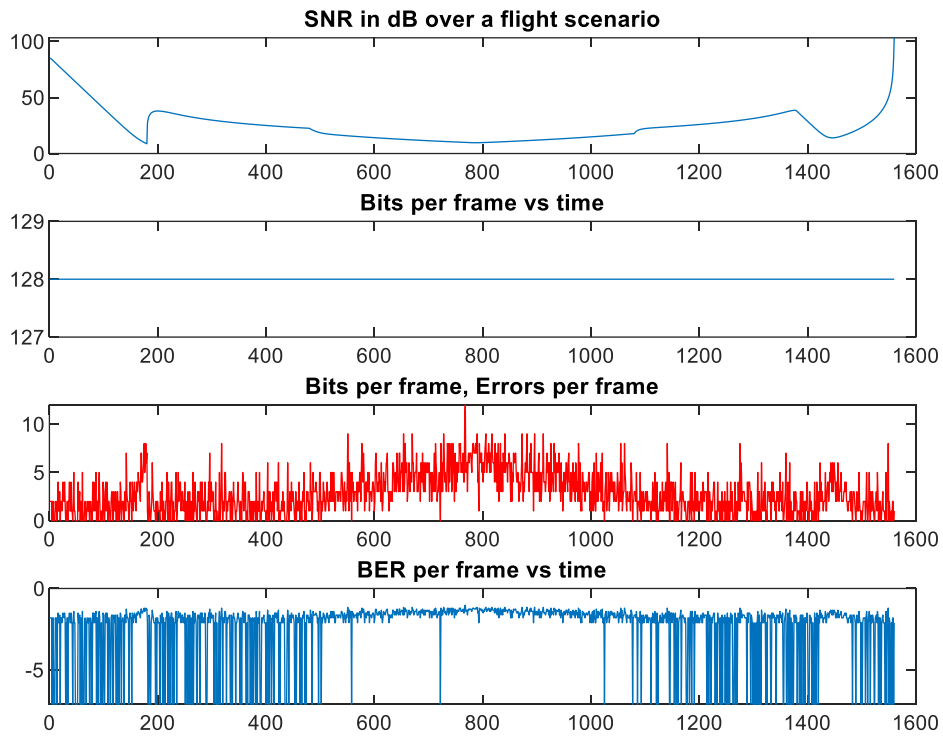


Figure 3. Performance Results for Fixed Rate (M=4) Test Flight

Our second test was performed with the same flight simulator and channels. In this case we fixed the modulation of the OFDM at M=4 or QPSK. The SNR range was identical to Case 1 as were all the other channel conditions. The overall throughput of the channel was about 204,800 while then total errors were about 4096 with a BER of 0.02 or 2 percent. So, while the overall

throughput of the fixed scheme was comparable to the variable scheme, the error rate made the data almost unusable. It should be noted that a serial tone modem such as QPSK or SOQPSK might have better error performance than shown here with the addition of adaptive equalization and Error Correction. But this is a challenging channel for such schemes as with deep nulls in the spectrum and the rapid transition in phase shift. More comparisons will make this apparent.

CONCLUSION

This paper summarized our work to date in the design and testing of an Adaptive OFDM scheme for application with aeronautical telemetry. We have supported our assertion that this AOFDM scheme is near optimum for the kinds of channels experiences in this application. The results show that our scheme is feasible showing how to adapt the modulation of an OFDM MQAM structure, and with demonstration of performance over a flight simulation over a broad range of test conditions, and with comparison to a fixed rate $M=4$ scheme. These results are promising and suggest that this system be further developed with prototype hardware testing in a real aeronautical test flight.

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