DESIGN AND IMPLEMENTATION OF A WIDEBAND RADIO USING SDR FOR AVIONIC APPLICATIONS

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Abstract

This paper presents the design and implementation of a Wideband Radio (WBR) in a Software Defined Radio (SDR) multi-system avionic architecture able to send and receive channel data in real time, via Air-to-Ground (A/G) link or satellite link, from/to an Aircraft (A/C) and a Ground Station (GS). The implemented WBR is characterized by sharing resources with other avionic systems, having a single piece of reprogrammable hardware, facilitating In-Flight Connectivity (IFC) services, and drone evolution asking for a rapid transition towards a modernization of the Communications, Navigation and Surveillance (CNS) standards in future systems as Next Generation Data Communication of the NextGen program[1]. The main challenges of this work are: to minimize the size, weight, power and cost (SWap-C) requirements of avionic equipments implementing a flexible solution over SDR; and to establish a suitable robust communication link using Adaptive Coding Modulation (ACM) with bit error rate (BER) better than 10^{-5}. Results in laboratory using a channel simulator to emulate real conditions demonstrate the feasibility of the system as well as provide some performance metrics.

Introduction

The purpose of integrating different avionic systems in order to increase system flexibility and to achieve SWap-C requirements is what aerospace industry has pursued for years. In fact, Boeing and Airbus have recognized that the approach known as Service Oriented Avionics (SOA) architecture would be an important asset of tomorrow's Air Traffic Management (ATM) systems [1]. As we know, the goal of the SOA architecture is to be able to deliver critical flight related data such as flight management, flight control and cockpit Human Machine Interface (HMI) as well as non-critical passenger data such as IFC services. There are still many challenges to overcome regarding safety certification and accreditation of SOA systems. In fact, [2] published an in-depth study of the issues that must be examined for certification of this architectural style. When designing a highly integrated modular system, considerations such as memory partitioning, data integrity, error handling, and resource sufficiency are among the many other requirements that must be addressed [2]. Nevertheless, as SOA matures and the growing demand for CNS modernization continues, SOA and modular architectures could very well be the answer for the evolution of avionic communication systems. To this end, we propose an architecture based on SDR as a flexible and modular multi-avionic communication system. The proposed WBR architecture is to provide these avionic communication data and to enable robust satellite link via relay station such as Satellite Communication (SatCom), for example.

The WBR is implemented on Nutaq's PicoSDR™ platform. The performance analysis was conducted on the channel emulator RT Logic T400CS which can emulate RF real life conditions to evaluate the performances of the radio.

The paper is organized as follows. First, the background and the motivation behind the development of the WBR system is presented. Then, the features of the Wideband Radio and the algorithms used are introduced. Afterward, the implementation of the WBR system is explored in details. The subsequent section presents the results of the performance analysis obtained in laboratory with the channel emulator. Finally, the conclusion of the work is presented.

[1] Next Generation Air Transportation System is an Air Traffic Control Modernization program led by the Federal Aviation Administration (FAA) in United States of America (USA).

Background

From its beginning, air passenger transport has not only evolved in terms of A/C, but also in terms of avionic applications and services offered on board, so the In-Flight Entertainment (IFE) has appeared on commercial A/C vocabulary. For example, in 1921, the first in-flight movie was shown on an Aeromarine Airways flight (Table 1), giving way to a series of value services added to commercial flights through the years and continuing to this day.

Table 1. Evolution of In-Flight Entertainment

Year	IFE
1921	The first in-flight movie (Aeromarine Airways)
1932	The first in-flight television called “media event” (Western Air Express)
1937	The first recorded A/G radiotelephone service on a scheduled flight (Northwestern Airlines)
1963	The first pneumatic headset used on board (AVID Airline Products)
1971	Programmes and movies using 8mm film cassettes
1975	Atari video games were introduced on-board flights (Braniff International Airways)
1982	The moving-map system information (ASINC, Inc.)
1985	The first audio player system based Tape Cassette technology
1991	LCD monitors in first class seat backs
1996	The Atlanta Olympic Games was the first live television broadcast on flight (Delta Airlines)

Between the 40s and 60s, the IFE industry was oriented to the development of ergonomic and mechanical systems for passenger comfort and in the 90s the IFE was a priority in design of A/C cabins [3]. In the following years, IFE has been expanded to include IFC services as: Infotainment, Office (in-flight), Telemedicine, Flight security and Logistic & maintenance. This began in 2000 with the release of Connexion by Boeing (CBB). The hardware for CBB have meant installing a team of 1,000 pounds (450 kg), which added more drag, weight and fuel consumption, which was tolerable only for large A/C. However, by 2006, the company announced it was closing down its connection operation. Since the shuttering of CBB, several new providers have emerged to deliver in-flight broadband to airlines, proposing a wide range of services offering solutions based on SatCom (in Ku and Ka band) or A/G connectivity (using 850MHz, 2.4 GHz and 3GHz band).

However, the technology is far from being available on all A/C and the diversity of communications services offered to passengers and airlines are limited due to different factors such as coverage, transmission/reception delay, connection costs, quality of service, channel capacity, etc. In the other hand, the constant evolution in CNS systems and the implementation of new aviation standards such as NextGen and Single European Sky ATM Research (SESAR) in Europe are forcing aviation companies (in order to complying with regulations in different airspaces) to constant changes in equipment, which means buying new equipments and communication systems, installing new antennas on the A/C, etc. In fact, the modernization of the on-board communication systems has to be flexible so that the integration of new avionic applications and standards required for the A/C will not imply the continuous installation of new equipment, but rather the modification of the existing one [4].

Therefore, the implementation of a WBR in a SDR is presented as a solution to face this constant equipment replacement. This platform allows us to reconfigure different protocols and communication standards without the need to purchase new equipment, reducing SWap-C requirements and allowing us to implement a multi-system avionic architecture able to send and receive channel data in real time, via A/G link or using a satellite link, from/to an A/C and a GS. This new feature and capability are well aligned with the aviation manufacturer needs where the avionic equipment are installed for a long term taking into account certification process and equipment cost.

The WBR using SDR for avionic applications is a part of the AVIO-505 project, which establishes new design methods and digital signal processing techniques for robust and efficient universal CNS equipment in the fields of aeronautics and aerospace. This system is also integrated with other modular avionic systems on a single SDR platform, such as Automatic Dependent Surveillance - Broadcast (ADS-B), Distance Measuring Equipment (DME) and Mode S Transponder.

Features and Algorithms of WBR

This section presents the algorithms and key features of the proposed SDR Wideband Radio. First, it starts by introducing its communication link capabilities. Then, the algorithm used for the SNR (Signal-to-Noise Ratio) estimation will be discussed. Following that, the main feature of the WBR will be presented, which is the on-the-fly Adaptive Coding and Modulation.

Communication Links Capabilities

The Wideband Radio is able to establish a robust bidirectional communication link such as Air-to-Space (A/S), Air-to-Air (A/A) and A/G as illustrated in Figure 1. Data communication for the A/S link is done via SatCom system.

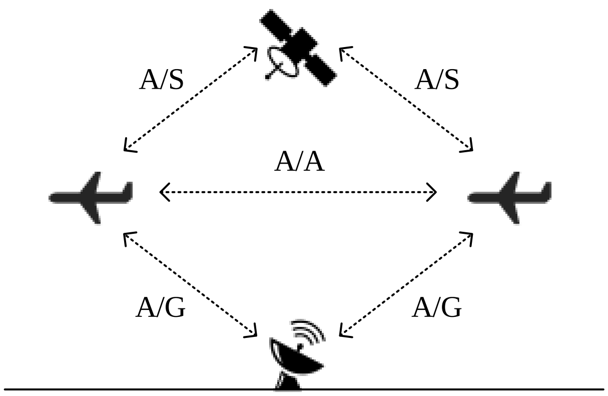

Figure 1. Potential data communication links

This ability to establish different communication links is very suitable for cognitive radio applications [5]. In fact, an A/C equipped with a WBR system can be represented as a node and other A/Cs in its vicinity, can also be represented as such, provided they are also equipped with this system. Thus, a network known as Airborne Network (AN) can be created where each A/C can communicate with each other to send and receive data such as flight related data or to enhance IFC services [6]. Each node has a limited coverage area and by establishing a network, its range can be further extended. Furthermore, A/G link performances will always be better than satellite-based communication and less expensive to operate. With the support of an AN, it is possible to extend ground-based communication for A/C that are, otherwise, unreachable due to the distance between the A/C and the GS which is especially true for intercontinental flights [6]. Moreover, it is particularly useful for IFC services where latency is an important factor to consider in order to deliver a satisfying user experience.

Signal-to-Noise Ratio (SNR) Estimation

Any wireless signal is subject to the propagation effects of its environment such as time-varying fading and scattering. Hence, the Channel State Information (CSI) estimation becomes the integral part of any system using ACM algorithm. The implemented WBR system uses a SNR estimator based on Non-Data Aided (NDA) approach called Second and Fourth Order Moments (M2M4). Additionally, this type of estimator does not require a carrier phase recovery [7]. The implemented SNR estimator is heavily based on [7].

Assuming we have a stochastic process, the signal and noise are zero-mean, and the I and Q components of the noise are independent, M2M4 can then be simplified as per equation (1) and (2).

$$M_2 = S + N \qquad (1)$$

$$M_4 = k_a S^2 + 4SN + k_w N^2 \qquad (2)$$

where k_a and k_w are the kurtosis of the signal and noise respectively. Knowing that M_4 is a second degree equation and by solving S and N, the following can be obtained:

$$\hat{S} = \frac{M_2(k_w - 2) \pm \sqrt{(4 - k_a k_w)M_2^2 + M_4(k_a + k_w - 4)}}{k_a + k_w - 4} \qquad (3)$$

$$\hat{N} = M_2 - \hat{S} \qquad (4)$$

Then, the estimated SNR can be computed with the ratio of $\hat{S}$ and $\hat{N}$.

Adaptive Coding and Modulation (ACM)

To ensure a robust communication link and a good Quality of Service (QoS), an ACM scheme is implemented to adapt to different environmental conditions in order to maximize the throughput.

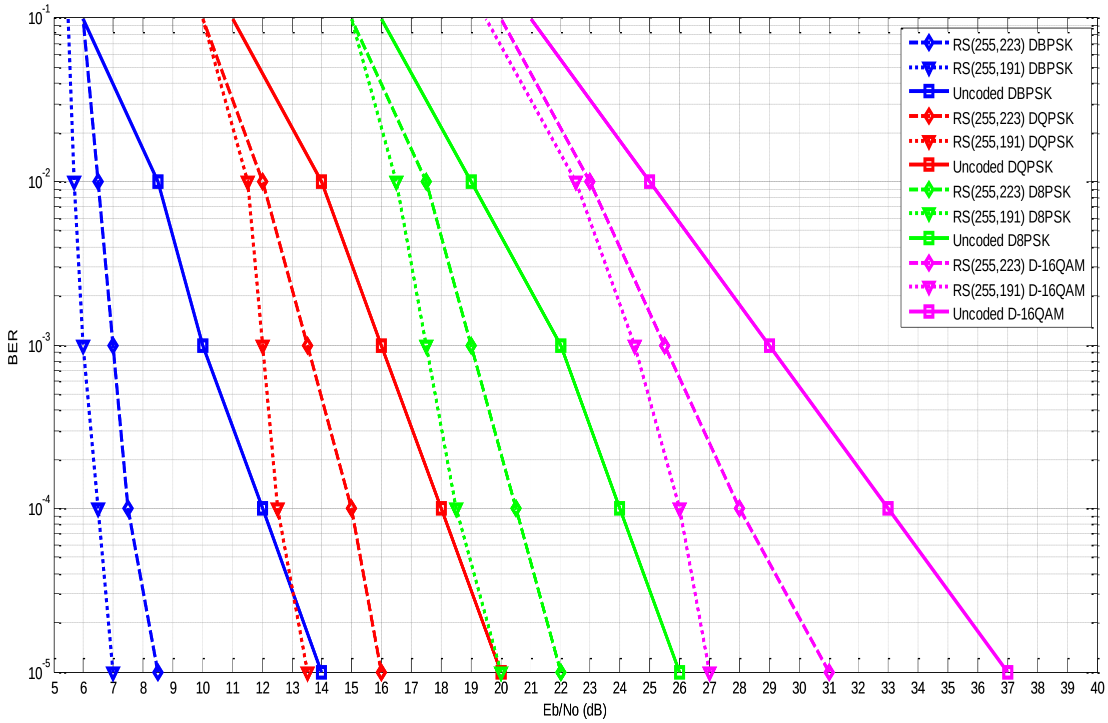

Figure 2. Measured BER of the implemented WBR system

The ACM algorithm will try to maintain a BER better than 10^{-5} by changing the modulation and coding rate according to the channel estimation. A tradeoff between robustness and data rate must be made in order to maximize the throughput while satisfying the BER requirement. The WBR uses packetized data and thus, another mechanism is added to reinforce the ACM algorithm in the event of a heavy packet loss over a short period of time by switching to a more robust configuration. This is helpful against interferences, for example, as SNR estimation may not be as reliable in this case. The BER curves obtained with Nutaq's PicoSDR™ platform are represented in Figure 2 and Figure 3 illustrates the ACM's switching scheme.

The implemented WBR system supports differentially encoded M-ary PSK and QAM modulations such as BPSK, QPSK, 8-PSK and 16-QAM. Differentially encoded modulations are well suited for SDR due to its low complexity as it does not require carrier synchronization. However, it comes at a cost of requiring a higher E_b/N_o to maintain the same BER compared to its non-differentially encoded counterpart.

Furthermore, a Reed-Solomon coding is employed for error correction which is widely used in satellite communication. They are also very efficient for correcting burst errors which is very common in fading channels. Its relatively low computational complexity and the limited resources of the SDR platform with an embedded processor are reasons why Reed-Solomon coding was picked over a more complex coding such as Low Density Parity Check (LDPC). The Reed-Solomon coding is denoted as RS(n,k) where n and k represent the symbol code word and the data symbol respectively. By adding *t* parity symbols to the data, it can correct up to *t*/2 symbols. The WBR system has two Reed-Solomon codes which are RS(255,223) and RS(255, 191) that can correct up to 16 and 32 symbols respectively. The implemented Wideband Radio offers 8 possible Modulation and Coding (MODCOD) combinations and is summarized in Table 2.

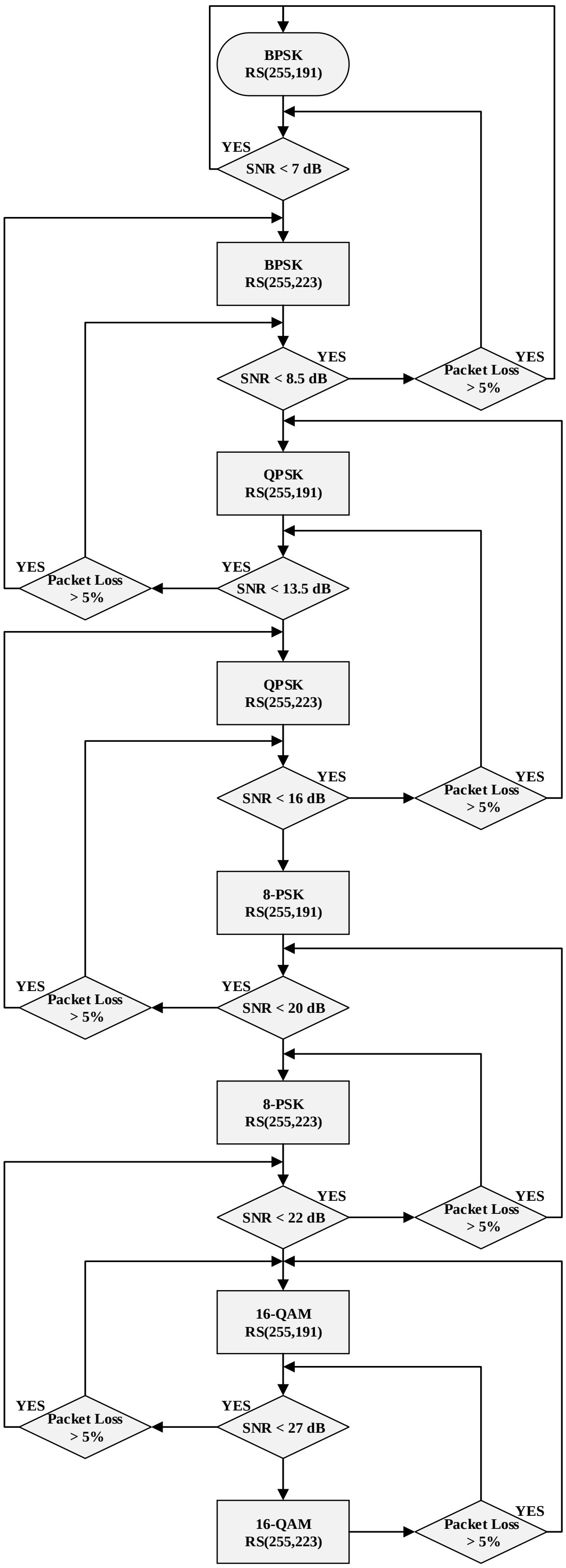

Figure 3. ACM's switching scheme

Table 2. WBR's MODCOD combinations

Modulation	RS Code	Effective Symbol Rate (bit/symbol)
BPSK	RS(255,191)	0.75
	RS(255,223)	0.88
QPSK	RS(255,191)	1.50
	RS(255,223)	1.75
8-PSK	RS(255,191)	2.25
	RS(255,223)	2.62
16-QAM	RS(255,191)	3.00
	RS(255,223)	3.50

System Implementation

This section is divided into two subsections. The SDR platform is presented in first subsection followed by the design and implementation of the WBR system in the second subsection.

SDR Platform

The SDR used for this project is the PicoSDR™ from Nutaq which is a powerful prototyping platform for designing and implementing next generation wireless communication systems. This platform is equipped with a Radio420X FPGA Mezzanine Card (FMC), a multimode RF transceiver module which is built around the Lime Microsystems LMS6002D chipset. Furthermore, this transceiver has a selectable bandwidth (1.5MHz-28MHz) which makes it suitable for narrowband or wideband applications such as the WBR. This SDR supports 2 channels and it also comes with two 12 bit ADC and two 12 bits DAC that can run up to 40MS/s. The PicoSDR™ is based on a Virtex-6 FPGA and it also has an embedded processor (Intel i7 Gen2 CPU) and an embedded operating system (OS) which eliminates the need to connect to an external PC computer.

Design and Implementation

The design of the radio is developed with GNU Radio, an open source software widely used in digital signal processing (DSP) for SDR. The WBR system can be separated into 2 parts; the transmitter and the receiver which are represented in Figure 4 and Figure 5.

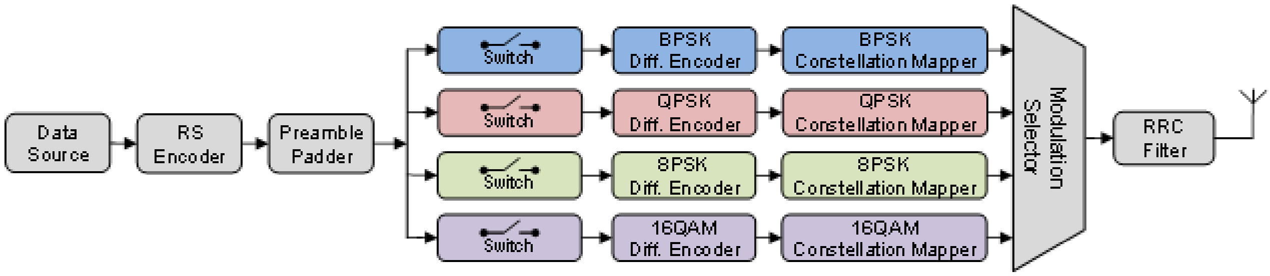

Figure 4. Transmitter of the WBR system

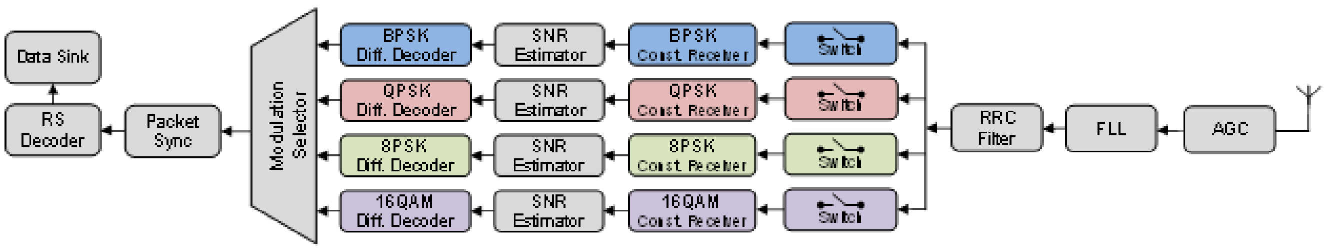

Figure 5. Receiver of the WBR system

In the transmitter (TX), the data is first encoded with the Reed-Solomon encoder by adding parity bits, then a preamble is added at the beginning of the payload to form a packet. It is then connected to the adaptive modulation blocks which comprises of constellation mappers and differential encoders that can also encode the data in gray code format. At the end of the chain, a root-raised cosine filter for pulse shaping is performed.

At the receiver (RX) side, the signal is converted to baseband. An Automatic Gain Control (AGC) is employed to control the signal's amplitude and to avoid saturating the ADC. Furthermore, a Frequency Locked Loop (FLL) based on [8] is added to help reduce the frequency offset by placing a filter in the upper band and another one in the lower band. The bandwidth of these filters is determined by the roll-off factor of the RRC filter. Due to the computational complexity of the FLL and the limited CPU resources of the embedded processor of the PicoSDR™, the AGC and the FLL are implemented in the FPGA. Then, another RRC filter is added in the receiver chain. The RRC filters of the transmitter and receiver are cascaded to obtain a raised cosine filter. Additionally, it also eliminates the intersymbol interferences (ISI) created by the transmitter's RRC filter. The signal is then demodulated with the appropriate demodulator and the SNR is estimated for the ACM algorithm described in Figure 3. Subsequently, it will seek the preamble for packet synchronization and the preamble is removed afterward. Finally, the Reed-Solomon decoder will correct errors and will remove the padded parity to obtain the payload data.

Experimental Results

Laboratory results were obtained using RT Logic's T400CS channel simulator with Agi's Systems Tool Kit (STK) as the modelling software. Channel modeling data computed with STK such as additive white Gaussian noise (AWGN), Doppler effect, fading and delays are transmitted to the channel simulator through TCP/IP to emulate these conditions. The TX and RX of the PicoSDR™ are connected directly to the channel simulator to create a Hardware-in-the-Loop (HIL) simulation at 2.4 GHz. Furthermore, a specific scenario was created on STK to emulate an A/G link as illustrated in Figure 6 and Figure 7.

Figure 6. 2D view of the emulated scenario

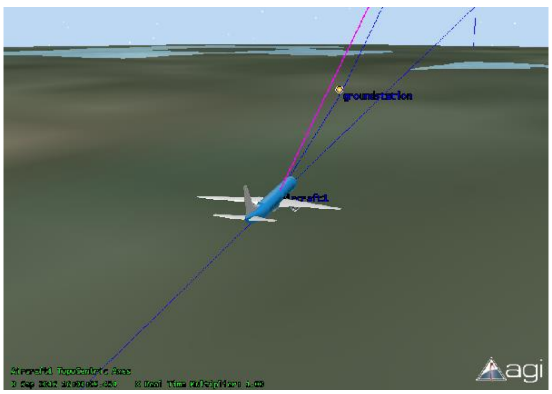

Figure 7. 3D view of A/G link

The aircraft travels in a straight trajectory above the ground station in the A/G link scenario and the environment model provided by STK are described in Figure 8 to Figure 10. The AWGN is set to -118 dBm/Hz for this scenario. Additionally, the computed effect of the Doppler, delay and gain are as expected when the A/C approaches the ground station.

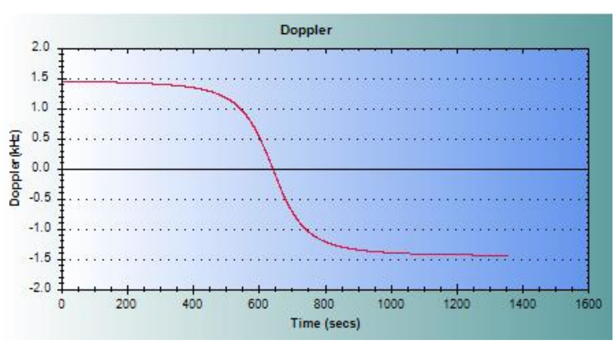

Figure 8. Doppler effect versus time of A/G link

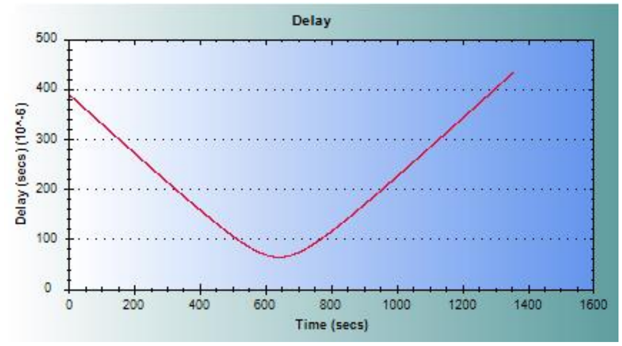

Figure 9. Delay versus time of A/G link

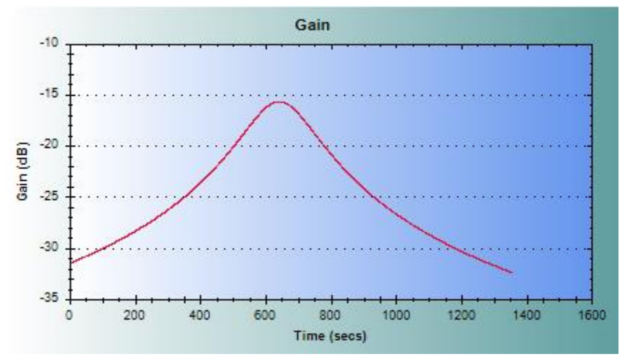

Figure 10. Gain versus time of A/G link

Using the created scenario (22.5 min), the result of the ACM algorithm is illustrated in Figure 11. As seen in that figure, the WBR switches to a faster MODCOD as the signal's strength gets stronger and it switches to a more robust MODCOD as the SNR decreases (see Figure 10). In Figure 12, the ACM that it tries to maintain a BER of 10^{-5} or better by switching configuration accordingly.

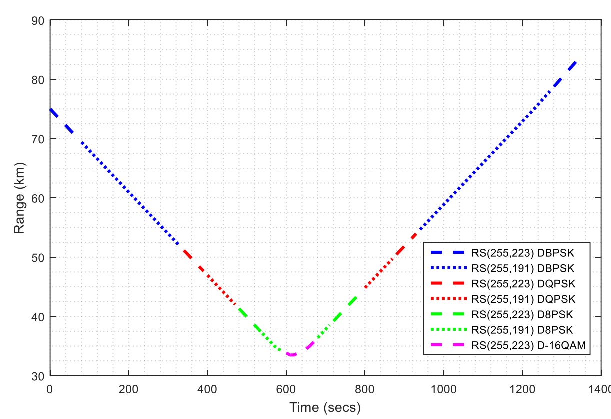

Figure 11. Result of ACM for the A/G scenario

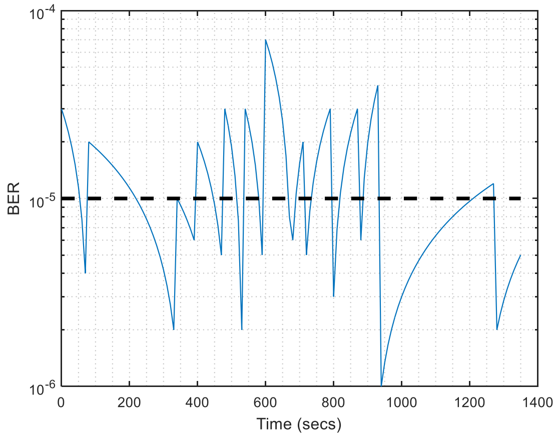

Figure 12. BER evolution over time

Conclusion

The implementation of the Wideband Radio on a SDR platform and its performances have been presented. This early prototype was used to perform laboratory tests which provided important insights on areas to improve such as better channel estimation and ACM algorithm. Moreover, more optimizations are needed to reduce CPU resources if the proposed WBR is to be integrated in a multiple modular avionic communication systems using a single SDR platform. Preparations for planned flight testing in real scenarios are underway to test the WBR system in a real environment and to demonstrate its capabilities.

As the aviation industry continues to modernize through the NextGen program and that there is a growing trend towards new approaches such as SOA, the WBR system remains a great solution to investigate for future avionic communication needs.

References

[1] EUROCONTROL and the U.S. Federal Aviation Administration (FAA), Nov. 2007, “Action Plan 17: Future Communications Study”, Final Conclusions and Recommendations Report.

[2] Brown, Andy, Jane Flenn, Catherine Menon, Oct. 2010, “Issues and considerations for a modular safety certification approach in a Service-Oriented Architecture”, Manchester, UK, 5th IET International Conference on System Safety.

[3] Norman White, John, 1994, “History of Inflight Entertainment”, New York, USA, Airline Passenger Experience Association (APEX), http://c.ymcdn.com/sites/connect.apex.aero/resource/resmgr/IFE-Resources_docs/History_of_IFE_version_2_JNW.pdf

[4] Zambrano, Joe, Omar Yeste, René Jr. Landry, Sept. 2013, “Reconfigurable Software Defined Wide-band Radio for SatCom in Aeronautical Applications”, Montreal, Canada, SAE 2013 Aero Tech Congress & Conference.

[5] Jacob, Ponnu, Rajendra Prasad Sirigina, A. S. Madhukumar, Vinod Achutavarrier Prasad, May 2016, “Cognitive Radio for Aeronautical Communications : A Survey”, IEEE Access (Volume: 4).

[6] Zambrano, Joe, Eric Zhang, Omar Yeste-Ojeda, René Jr. Landry and Victor Gheorghian, Sept. 2016, “Development and Implementation of a New Architecture for Robust Satellite Data Unit with Software Defined Radio for Airborne Network”, Sacramento, U.S.A, Digital Avionics Systems Conference (DASC).

[7] Pauluzzi, David R., Norman C. Beaulieu, August 2002, “A comparison of SNR estimation techniques for the AWGN channel”, IEEE Transactions on Communications, Vol.48, No.10, pp.1681-1691.

[8] Harris, Fred, Elettra Venosa, Xiaofei Chen, Chris Dick, Sept. 2012, “Band edge filters perform non data-aided carrier and timing synchronization of software defined radio QAM receivers”, Taipei, Taiwan, 15th International Symposium on Wireless Personal Multimedia Communications (WPMC).

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