Multispectral Image Transmission Using a Software Defined Radio Platform

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***Abstract*— Remote sensing satellites have restrictions for data storage and transmission over bandlimited channels. The advancement of sensor technologies with higher resolutions, such as sensors Multispectral and Hyperspectral had caused the demand of more storage resources on the onboard and bit rate for transmission in real-time, mainly because of the high volumes of data collected by satellite imaging systems.Therefore the communication system for transmission must has the highest efficiency. In this paper are developed simulations and tests for transmission of multispectral images collected for CBERS-2B satellite. Different systems were implemented following spacial recommendations for space data systems. The communication systems were implemented in Software-defined Radio(SDR) platform, where radio functions are developed in software codes interfaced with RF hardware. Simulations and tests perfomed have shown consistency compared to theorical results for each communication system implemented. Therefore the SDR platform represents an interesting tool to test different ideas for communication systems that can be implemented in a real remote sensing satellite.**

***Index Terms*— Image transmission, multispectral image, software-defined radio.**

I. Introduction

Satellites are the main remote sensing platforms that can provide information on a continuous basis of vast areas on the Earth's surface day and night contributing to various fields of application [1],[2]. In recent years, the remote sensing community has seen a steady shift to Multispectral and hyperspectral sensors, which are characterized by hundreds of fine resolution co-registered spectral bands. It has represented restrictions for satellite communication system where the bandwidth and the power of transmission are restrict resources [1],[2],[3],[4]. Among the examples of satellites which collect multispectral images and one of them is the CBERS-2B, the third remote sensing satellite of the CBERS (China-Brazil Earth Satellite Resource) program. Actually, CBERS-2B has a high resolution Charge Couple Device (CCD) camera with five spectral bands.

To providing solutions for technical issues for space applications, The Consultative Committee for Space Data System (CCSDS) was foundeted in 1982 composing an international forum for the development of space data systems. It has been established a variety of standards to guide the design of different systems for space missions [5].

In this work, a communication system for multispectral images is designed using a software defined radio platform.In this Tecnhnology some or all of the physical layer functions of a communication system are software defined instead of specialized circuits allowing the development o different communication systems in the same hardware platform [6][7].

In Section II, the concepts of a satellite communication system is presented. The subject of Section III is the Software Defined Radio platform used in this work. Section IV is devoted to simulation results obtained using the Gnu Radio toolkit. The implementation on SDR platform and its results are posted in Section V. Concluding this work, the final comments are presented in Section VI.

II. Satellite Communication System

Considering the CCSDS standards, in the case of image transmission, to assist an efficient design, in 2005, CCSDS proposes a standard to image compression presented in [8]. Furthermore, for a general communication system adopted by a space mission, there are some recommendations about Forward Error Correction (FEC) codes [9] and modulations techniques [10]. These recommendations are summarized in block diagram in Figure 1 that presents a complete communication system for image transmission in satellite systems.

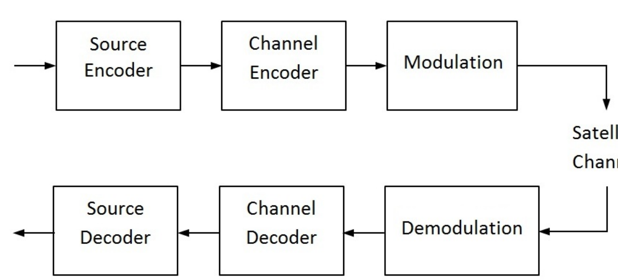

Fig. 1. Block diagram for Satellite Communication System.

A. Image Compression

Digital image data compression consists of reducing the number of bits needed to represent a given image for purpose to facilitate the storage and transmission of the data [11].

Scientific images colleted by remote sensing platform are preferably transmitted to ground station in lossless compression form to preserve the quality of image[2]. In lossless compression the number of the bits to represent an image is reduced in such a way that perfect reconstruction of the source compressed is possible [11].

The CCSDS-IDC is an image compression recommendation suitable for space applications, which was established in 2005. The algorithm adopted in the recommendation consists of a twodimensional discrete wavelet transform of the image, followed by progressive bit-plane coding of the transformed data. Therefore a discrete wavelet transform (DWT) module performs the decomposition of image data and the bit-plane encoder (BPE) encodes the transformed data [8][12]. The algorithm can provide both lossless and lossy compression, and allows a user to directly control the compressed data volume or the fidelity with which the wavelet-transformed data can be reconstructed [8].

B. Channel Coding

Error control coding consists in the incorporation of redundancy into the transmitted image ensuring high reliability over noisy satellite channels [4]. These codes introduce redundancy by adding parity symbols to the message data with a mapping of k source symbols to n code symbols resulting in a rate given to $R = k/n$. With fixed information rates, this redundancy results in increaed bandwidth and lower energy per trasmitted symbol [13].

The basic Forward Error correction (FEC) techniques used in satellite communication systems can be classified in convolutional codes and block codes. Convolutional coding with soft decision Viterbi decoding is the standard technique defined in [9]. This encoder can be constructed from its generating matrix $G(D) = [gij(D)], i = 1, 2, ..., K, j = 1, 2, ..., n$. Where K is the constraint length of the code. $K - 1 = m$ is the number of the memory elements of the encoder. The code ($R = 1/2$,$K = 7$) with generating matrix in octal $G = [171, 133] = [g1(D), g2(D)]$, corresponds to polynomials $g1(D) = 1 + D + D2 + D3 + D6 = 001111001$ and $g2(D) = 1 + D2 + D3 + D5 + D6 = 001011011$, where "+" is the adder modulo 2, and "D" is a delay, a D-flip-flop, or a memory element[14].

Any convolutional encoder can be seen as a FSM (Finite State Machine) and hence described as state diagram to study its properties. The code tree and the trellis are the two types of developments of the state diagram, useful respectively in sequential decoding and Viterbi decoding [13].

The performance improvement that occurs when using an error control coding is often measured in terms of coding gain. The power of the coding gain is that it allows a communications system to either maintain a desired BER at a lower SNR than was possible without coding, or achieve a higher BER than an uncoded system could attain at a given SNR [14],[15].

C. Modulation and Demodulation

In satellite communication the constant envelop class of modulators is generally considered as the most suitable because it minimizes the effects of non-linerity amplification in the high power amplifiers. Therefore, BPSK (Binary Phase Shift Keying) and QPSK (Quadrature Phase Shift Keying) modulation methodes are widely used. For more purposes, QPSK gives the best power bandwidth compromises and energy efficiency[14]. In this technique, the binary data are converted into $2 - bit$ symbols which are then used to phase modulate the carrier as present in equation 1. Since four combinations containing $2bits$ are possible from binary alphabet (logical $1's$ and $0's$), the carrier phase can be shifted to one of four states [10],[14],[16].

$$S_m = (\sqrt{\frac{E_g}{2}} cos(\frac{2\pi(m-1)}{M}), \sqrt{\frac{E_g}{2}} sin(\frac{2\pi(m-1)}{M})) \quad (1)$$

Where $m = 1, 2, ..., M$ and $M = 4$ for QPSK.

Considering the effects of thermal noise described by AWGN (Aditional White Gaussian Noise) model, the bit error probability for QPSK is given in 2:

$$P_b = Q(\sqrt{\frac{2E_b}{N_0}}) = \frac{1}{2} erfc(\sqrt{\frac{E_b}{N_0}}) \quad (2)$$

Where complementary error function is denoted as $erfc$.

III. SOFTWARE-DEFINED RADIO (SDR)

Software-Defined Radio uses digital signal processing techniques to decoding and demodulation waveforms, allowing the development of radio functions in software. This implies that the architecture is flexible such that the radio may be configured for different communication systems [7]. Another advantage of the SDR is the rapid implementation of differents algorithms on a single piece of hardware, reducing development costs and excludind the building of the extra circuitry [17];

One of the prevalent standardized software architectures of the SDR systems is Software Communication Architecture (SCA), defined by the US government with the purpose of securing waveform portability and improving software reuse. It has been accepted as a communication standard in military services of many other countries, but also by commercial organizations. Another widespread software architecture is GNU Radio, used by a large community academic researchers. This archi. This implementation of SDR uses the toolkit software Gnu Radio in combination with Universal Software Radio Peripheral (USRP). The USRP hardware device is used to digitalize the received analog radio signal, so it can be imported into a computer. On the computer it is possible to build your own radio receiver or transmitter by the use of GNU Radio software [6],[7].

A. Universal Software Radio Peripheral (USRP)

The USRP is a low-cost SDR system developed by Ettus Research that provides the air interface to convert between the digital baseband processed in the SDR and the analog, RF domain [6],[7]. The system consists of a motherboard with FPGA, 2 pairs of DACs and ADCs, digital downconverters and upconverters with programmable interpolation rates, and a daughterboard functioning as a RF front-end. Various plug-on daughterboards allow the USRP to be used on different radio frequency bands [7],[17].

In USRP1 the USB is used to connect the USRP to the computer. This model of USRP consists of a motherboard containing four 12-bit, 64M sample/sec ADCs, four 14-bit, 128M sample/sec DACs, Field Programmable Gate Array (FPGA) and a programmable USB 2.0 controller. The RF front ends are implemented on the daughterboards installed in slots on motherboard.

B. GnuRadio Package

GNU Radio is an open-source software toolkit founded by Eric Blossom in 1998 for development of SDR with support for USRP running on Linux Operational System on standards PCs. The software is available on wiki page www.gnuradio.org/trac [6]. The systems designed in GNU Radio for use with the USRP are done in C++ and Python. C++ is used to program the individual modules that perform digital signal processing tasks. Python in used to combine these modules in a graph that describes how the communication system functions [7]. Figure 2 shows the schemnatic flowgraph for implementation a communication system using the library of signal processing blocks available in gnuradio.

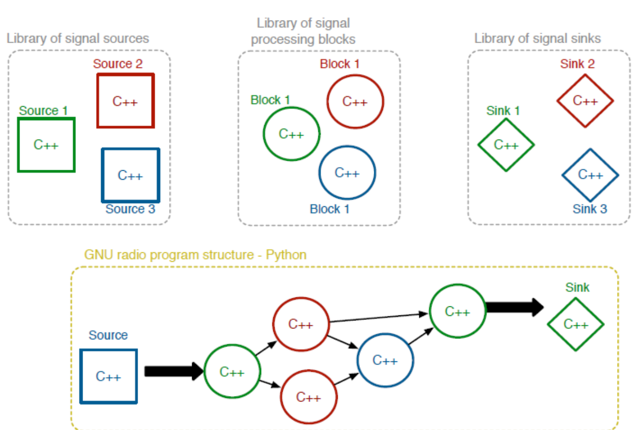

Fig. 2. Flowgraph structure used in Python codes for implement a communication system.

IV. Simulation

The validation of codes implemented in SDR was obtained by simulation of bit error performance (BER) for communication system based on QPSK using. Was verified a scenario with error control code (FEC) and without FEC under AWGN model channel for different values of SNR. The results were compared to theoretical results shown in [5]. After that, CBERS-2B sattelite images were transmitted under variable scenarios of coding channel and source and verified the recovered images quality.

A. Bit Error Rate Simulation

For BER simulation a random binary sequence were transmited under the system implemented using gnuradio software in a PC. The code created computes and plots the results for different values of SNR over AWGN model channel. Figure 3 shows a model for BER simulation with FEC for Hard and Soft decision using the convolutional code $R = 1/2$ and $K = 7$ defined in [9].

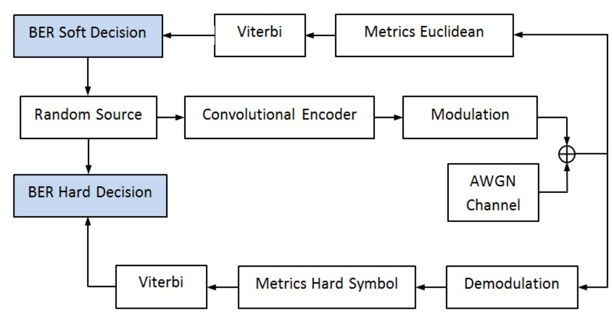

Fig. 3. Schematic model for simulation implemented in Python code.

The code is based in a Python flowgraph that connect the processing blocks of Gnuradio library and functions available in Python, resulting in a simulating model for uncoded and coded system. In the Table I there is the resumed Python code for simulating. Each flowgraph class is an implementation using the sources, processing blocks and sinks that development the coded systems for hard and soft decision.

TABLE I
Simplified Python code for simlation applying Hard and Soft decision for Viterbi decoder.

```
#!/usr/bin/env python
from gnuradio import* # libraries
  def ber_teoria(EbN0) # function
  def SNR_Noise(EbN0)  # function
  class_top_block_Soft(EbN0) # Flowgraph soft decision
  class_top_block_Hard(EbN0) # Flowgraph hard decision
if __name__ == '__main__':
        # loop
        EbN0_range
   ber_teoria(EbN0_range)
   top_block_Soft(EbN0_range)
   top_block_Hard(EbN0_range)
             # Ber Vs SNR
   subplot ber_teoria(EbNo_range)
   subplot top_block_Soft(EbNo_range)
   subplot top_block_Hard(EbNo_range)
```

The plot presented in Figure 4 shows the error performance for convolutional coding systems comparated to uncoded system. The plot obtained is in agreenment with results related in [5] and will be applied to transmission image system.

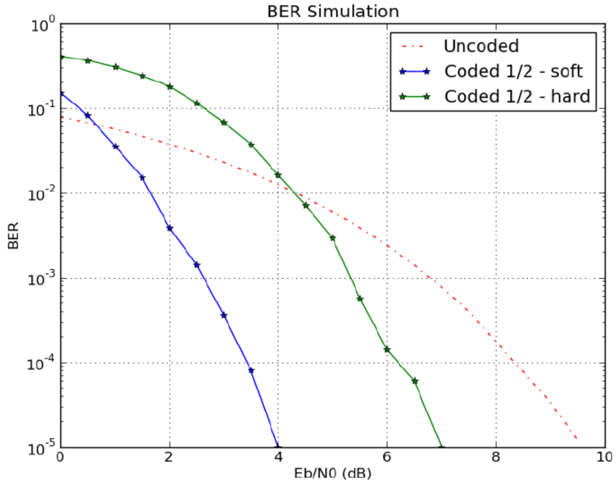

Fig. 4. Bit Error performance for simulated systems usind convolutional $(7, 1/2)$ with viterbi decoder with soft and hard decision.

B. Image Transmission

The simulation of image transmission was performed including a source image to the implemented systems in previous section. Was including the CCSDS-IDC compression at each collected image before transmission. Therefore, three variants of communication system was proposed to implemented as described in Table II.

TABLE II

VARIANTS OF COMUNICATION SYSTEM UNDER TESTS.

SYSTEM	COMPRESSION	FEC	MODULATION
S1	None	None	QPSK
S2	CCSDS 2:1	Convolutional Code	QPSK
S3	CCSDS 4:1	Convolutional Code	QPSK

The images used in simulation was obtained of original CBERS-2B CCD camera. The scenes are a raw data with 5812 x 5812 pixels and 8 bits per pixel. The RGB bands selected for simulation were extract of four segments of 128 x 128 of original image.

The compression algorithm CCSDS-IDC was obtained from University of Nebraska. An executable code of algorithm was developed Python for implemetation in flowgraph of communication system.

For transmission, the specified BER was adjusted to 10^{-6} to achieve a SNR round of $5dB$ and observed the results for each system as reported in Table III.

As metric performance was used the PSNR (Peak Signal-to-Noise Ratio) to measure the objetctive quality. The PSNR is most easily defined by the mean squared error (MSE) presented in 4.

$$PSNR = 10log10\frac{(2^B-1)^2}{(MSE)} \tag{3}$$

$$MSE = \frac{1}{wh}\sum_i\sum_j(x_{i,j}-\hat{x}_{i,j})^2 \tag{4}$$

On simulation all transmited images were recovered and recomposed in original RGB. As observed in Figure 5, the noise effect causes a distortion in resulting images. Each band is corrumpt with a equivalent bit error rate observed, obtained of the statist of all images transmitted.

TABLE III

RESULTS FOR IMAGE TRANSMISSION SIMULATED UNDER SNR 5 DB.

	S1		S2		S3	
	BER	PSNR	BER	PSNR	BER	PSNR
B1	7.0E-3	26.8	0.0	46.5	6.2E-5	47.4
B2	7.4E-3	26.9	0.0	47.2	0.0	48.0
B3	6.5E-3	27.0	0.0	46.3	2.0E-5	47.3
B4	6.8E-3	26.6	0.0	48.7	1.4E-4	47.1
G1	7.1E-3	27.3	0.0	42.8	0.0	50.2
G2	7.0E-3	27.2	0.0	43.3	1.8E-5	41.2
G3	6.7E-3	27.3	0.0	42.4	1.7E-5	49.6
G4	6.3E-3	27.4	0.0	44.3	1.1E-4	52.6
R1	7.0E-3	27.0	0.0	45.7	2.0E-5	60.4
R2	6.9E-3	27.1	0.0	45.8	4.1E-5	43.8
R3	7.4E-3	27.1	0.0	45.2	9.8E-5	56.3
R4	7.0E-3	26.8	0.0	45.7	0.0	48.9

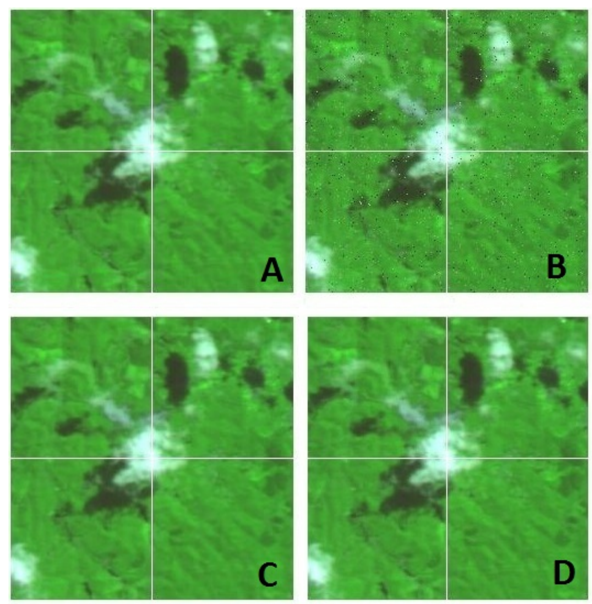

Fig. 5. Recovered images over S1, S2, and S3 systems and metrics of quality: (a) Original image; (b) Uncoded QPSK system - S1; (c) Compressed lossly image and channel coding - S2; and (d) Compressed lossless image and channel coding - S3

V. IMPLEMENTATION AND TESTS

A practical model was implemented from simulating codes and including the USRPs. The USRP allows the real transmission over physical channel. Therefore was observed the practical performance of each system implemented.

A. Modem implementation

The practical implementation of modem was obtained including the usrp and separeting the codes for transmitter and receiver. Each USRP1, uses a WBX daughterboard and the antenna SMA-703 working at 1,200 MHz band. A packet data transmission is applied for syncronization at receptor. Each packet has a fixed lenght for systems S1 and S2 with a $Preamble + Header + Payload$ having 2, 12 and 512 Bytes, respectively. Each frame is transmitted and received producing the reconstructed signal, observed in the output of the communication system. The reconstructed signal is compared to the original image. The block diagram of the complete communication system is shown in Figure 6.

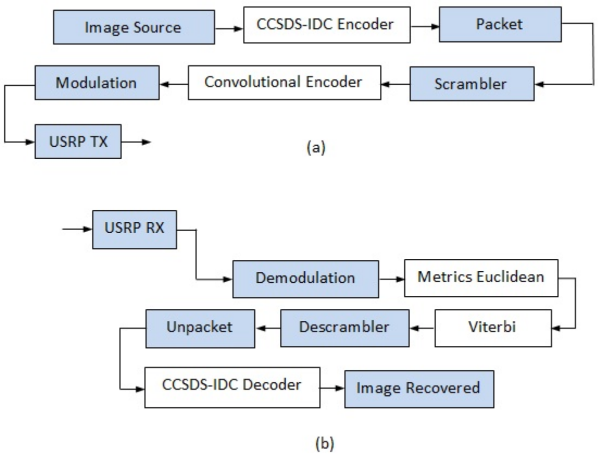

Fig. 6. Block diagram for practical communication system: (a) Transmitter, and (b) Receiver. White blocks are included for coded systems S1 and S2.

B. Tests

The receiver and transmitter were configurated to work at 2.5 meters of distance. The power transmission level and antenna gain of USRP were adjusted to achieve the operating conditions. This condition was obtained for BER test between transmitter and receiver. BER test consists in a transmittion of sequence of 1's and the estimation of BER and SNR in receptor. After USRP calibration, the image transmission was adjusted to fixed rate of 100kbps and observed the bandwidth occupancy for each system as well as the BER and PSNR of recovered image. The scenario of test is shown in Figure 7.

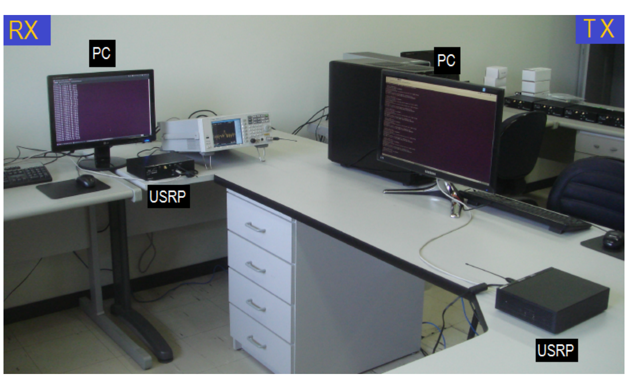

Fig. 7. Scenario for practical tests in labarotory composing for one USRP and PC for each transmitter and receiver.

VI. Results

The results obtained from practical tests are shown in Table IV, and present the performance for systems S1, S2 and S3 over calibrated SNR (5 dB). The PSNR is measured of each individual band of original image and recovery image.

TABLE IV
RESULTS FOR TRANSMISSION TESTS UNDER ESTIMATED SNR 5 DB.

	S1		S2		S3	
	BER	PSNR	BER	PSNR	BER	PSNR
B1	1.6E-3	26.8	0.0	41.5	6.2E-5	63.6
B2	1.8E-3	26.3	0.0	47.1	3.7E-5	19.1
B3	1.2E-3	27.6	2.2E-5	46.3	6.2E-5	55.9
B4	1.7E-3	27.4	0.0	48.6	0.0	64.2
G1	1.6E-3	26.1	0.0	35.0	2.2E-5	30.1
G2	1.7E-3	26.3	3.5E-5	43.2	6.2E-4	41.1
G3	1.7E-3	27.2	0.0	42.4	1.8E-5	48.3
G4	1.6E-3	27.5	0.0	44.2	4.1E-5	61.7
R1	1.8E-3	26.7	1.25E-5	45.6	1.2E-5	61.1
R2	1.6E-3	26.5	0.0	45.8	0.0	64.8
R3	1.7E-3	26.7	0.0	45.2	6.2E-5	48.8
R4	1.8E-3	27.5	2.7E-5	42.1	3.0E-5	62.6

Each recovered image was recomposed to generate orginal RGB image as showed in Figure 8. The channel noise corruption over images is observed in every communication system implemented. In uncoded system S1 degradation is more severe and the BER is above to specified for this application. On the other hand, the coded systems S2 and S3 are working in specified conditions, however are more sensible to errors that can lead to a complete loss of the signal (since the error can propagate). Hence these systems must operate in high SNR values.

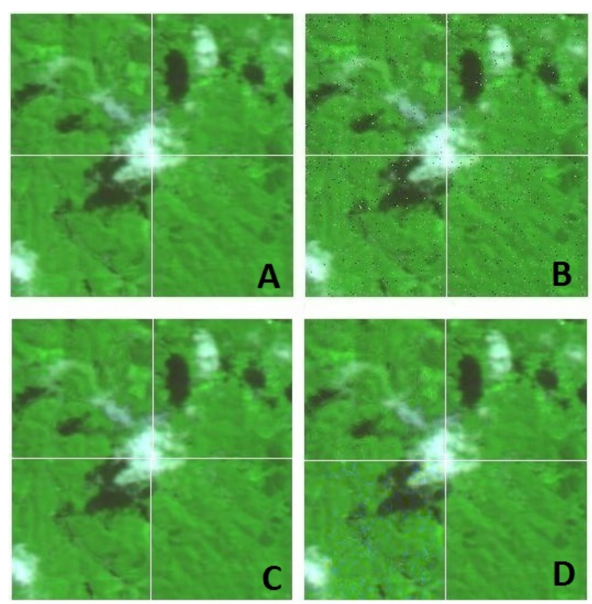

Fig. 8. Recovered images over S1, S2, and S3 systems and metrics of quality: (a) Original image; (b) Uncoded QPSK system - S1; (c) Compressed lossy image and channel coding - S2; and (d) Compressed lossless image and channel coding - S3.

VII. Final Comments

The advantage for prototyping in SDR was observed in this project. Different codes for variants communications system were proposed applying spacial recommendations for coding data. This codes run in a flexible platform representing an important issue for satellite application where the remote configuration can improve of the payload functionalities and the possibility of upgrades to existing communication standards and modifications of the mission. The validation of communication system implemented, was observed in tests performed that have conformity with results pointed in [5]. Multispectral image compression using CCSDS-IDC for lossless and lossy compression in conjunction with error control code presented advantage in performance over severe SNR levels for uncoded system and resulting of lower bandwidth occupancy. There is the possibilty to implement diferent standards and recommendations for communication systems on simulation and pratical models, however, limited to USRP rate and bandwidth capabilities.

Acknowledgements

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