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Design, Implementation and Evaluation of a Telemetry Channel Coding Sublayer

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Abstract

Coding layer protects the transferred data frames against errors induced during transmission through the noisy physical communications channel and offers security to the transmitted data. The main objective of this paper is to evaluate the performance of a concatenated Reed-Solomon and convolutional code in a noisy space telemetry channel. To do so, data is encoded and decoded according to CCSDS recommendations. Coding sublayer is implemented in a Spartan3E series (XC3S500E) target device with use of VHDL as the hardware description language. In order to simulate the additive noise of the communication channel, we gradually reduced the signal level at the transmitter end. Experimental results revealed that the implemented error correction codes improved the SNR of the space telemetry link about 6 dB. In addition, the measured power consumption of the coding sublayer was about 200mW which is easily negligible in comparison to the power budget of the receiver board.

Key Words: Reed-Solomon code; Convolutional Encoder; Viterbi Decoder; CCSDS

1. Introduction

Wireless channel effects such as noise and attenuation lead to data corruption. These effects are especially obvious in satellite communication links where links are usually designed with extremely low margin of link budget. Therefore low Eb/N0 ratios at the point of receiver are typical [1]. In low SNR regimes, powerful coding methods are utilized to compensate the low transmitted power [2].

Reed-Solomon (RS) code is a powerful burst error correcting code in a burst-noise channel. In addition, this code has the capability of indicating the presence of uncorrectable errors, with an extremely low undetected error rate [3]. Convolutional code is a real-time coding method suitable for channels with predominantly Gaussian noise. The basic convolutional code is a rate 1/2. For telecommunication channels that are constrained by bandwidth, a punctured convolutional code is proposed. Punctured code is a code obtained by deleting some of the parity symbols before transmission. This coding method enhances the spectrum efficiency while decreases the minimum weight and therefore degrades the error-correcting performance [3]. To achieve a higher coding gain than the one that can be provided by the convolutional code or RS code alone, a concatenation of the convolutional code as the inner code with the RS code as the outer code can be used [4].

The Consultative Committee for Space Data Systems (CCSDS) security working group has developed a space security architecture which is in fact a space mission threat document. The purpose of this document is to establish a common recommendation for space telemetry channel coding systems [5].

This paper presents design, implementation and evaluation of a CCSDS recommended space telemetry channel coding sublayer. The remainders of this paper is organized as follows. Sec. 2, firstly describes the CCSDS recommended coding sublayer model. Sec. 3, and Sec. 4, describe the transmitter and the receiver coding sublayers respectively. In Sec. 5, experimental framework and results are represented and finally the paper is concluded in Sec. 6.

2. Coding Sublayer Model

Design of a coding block in a space telemetry link is accomplished considering the transmitted power limitation of satellite, decoding algorithm complexity, Quality of Service (QoS) of link, spectrum efficiency and the transfer sublayer protocol type. Sublayer protocol type determines the necessity of error correction in the receiver (Rx) end. In a space telemetry link, it is not recommended to use Automatic Retransmission Request (ARQ) protocol; hence it is necessary to utilize a code scheme capable of error correction corresponding to the channel conditions and power limitation. In this work, a concatenation of RS and convolutional codes is implemented to guarantee the required BER. Fig.1 demonstrates the order of the concatenated codes at the transmitter and receiving ends according to ECSS standard [4].

In this configuration, RS code is the outer code, while the convolutional code is the inner code. After being coded, an Attached Sync Marker (ASM) is added directly to the inner encoder output. ASM is a specified bit pattern used as an aid for synchronization of data frames at the receiver end. The final frame is then transferred to the modulator to be transmitted to the channel. At the baseband section of the Rx end, start of each data frame is recognized by detecting the ASM pattern in the received data stream.

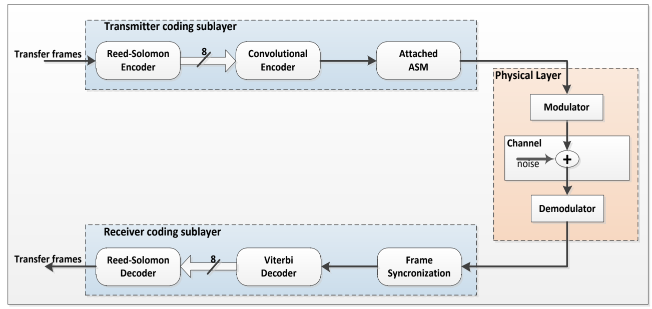

Fig.1 block diagram of concatenated codes according to ECSS

This data packet is then transferred to a Viterbi decoder to become decoded in the inner decoder. The decoded data is then transferred to the RS decoder.

In the following sections, the transmitter and receiver coding sublayers will be described with more details.

3. Transmitter Coding Sublayer

Telemetry transfer frame is partitioned as shown in Fig.2. Each transfer frame is started by the specific bit pattern of the ASM. ASM should be selected so that the "*main lobe-to-peak-side lobe* ratio" of its autocorrelation function is maximized. In this work, we have used the CCSDS recommended ASM pattern which is represented in hexadecimal notation as: 0x1ACFFC1D.

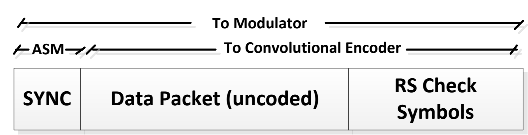

Fig.2 telemetry transfer frame

A block diagram of the transmitter (Tx) coding sublayer is depicted in Fig.3. In this work, FPGA board is linked to a PC using RS232 protocol. Data with a configurable baud rate is received from PC. UART module at the beginning of the coding sublayer is responsible for receiving this data and sending it to a buffer named FIFO_in. After receiving 223 bytes of data, this buffer sets

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a flag which indicates that a frame of data has been received completely and RS encoder is now enabled. The RS encoder is in fact a Xilinx IP-core which has been configured according to the CCSDS requirements. In this configuration, each 223 bytes of data along with 32 bytes of parity is converted to a frame of 255 bytes. This configuration makes the corresponding RS decoder capable of detecting and correcting of 16 corrupted bytes of data out of each 255 bytes.

After coding the data, RS-encoder sends the coded data to another module known as Serializer. This module receives the data in byte and by managing the timing, sends it bit by bit to the next coding block which is a convolutional encoder. For convolutional encoder, Xilinx IP-core has been used and configured according to CCSDS which is a basic convolutional coder with rate 1/2.

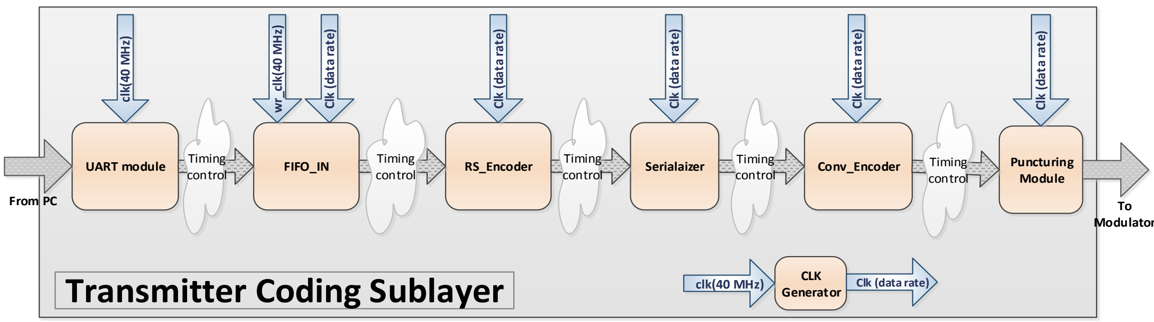

Fig.3 transmitter coding sublayer

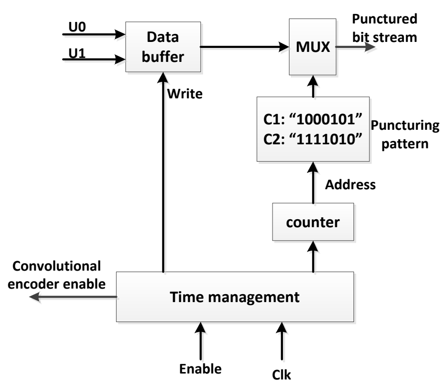

Fig.4 Puncturing module

Coded data stream is then transferred to a puncturing module to delete some of its parity bits according to the CCSDS recommended puncturing pattern. Fig.4 shows this puncturing module. Each 14 bits of data from convolutional encoder is reduced to 8 bits so that the total rate of the convolutional encoder would become 7/8.

Finally, the coded data is transferred to the modulator. In order to generate the required data clock for transmission, a clock generator module has been used. This module is a Xilinx Direct Digital Synthesizer (DDS) IP-core. The input clock frequency of this IP-core is 40MHz and its output frequency is the transmission bitrate.

4. Receiver coding sublayer

A block diagram of the receiver coding sublayer is depicted in Fig.5. Data and its clock are recovered in the previous stage which is a demodulator.

At the beginning of the coding sublayer, data is transferred to the Sync module. This module searches for the ASM pattern via a matched filter. After detecting the ASM pattern, it sets a flag which indicates the start of a frame that should be stored in a buffer called FIFO_IN. After storing a whole frame, the buffer sets another flag that tells the Depuncture module to start its process. Fig.6 shows the Depuncture

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module. This module reads the data from the FIFO_IN and by considering the puncturing pattern in the Tx end, it inserts null bits to the received bit stream to make it appropriate for the Viterbi Decoder.

Viterbi Decoder module has been designed using a Xilinx Viterbi IP-core. This module decodes the coded data and sends it to the next module in a bit stream form.

The Deserilizer module receives this bit stream data and by controlling the timing, converts it to a byte form appropriate for the RS decoder. RS module is a Xilinx IP- core

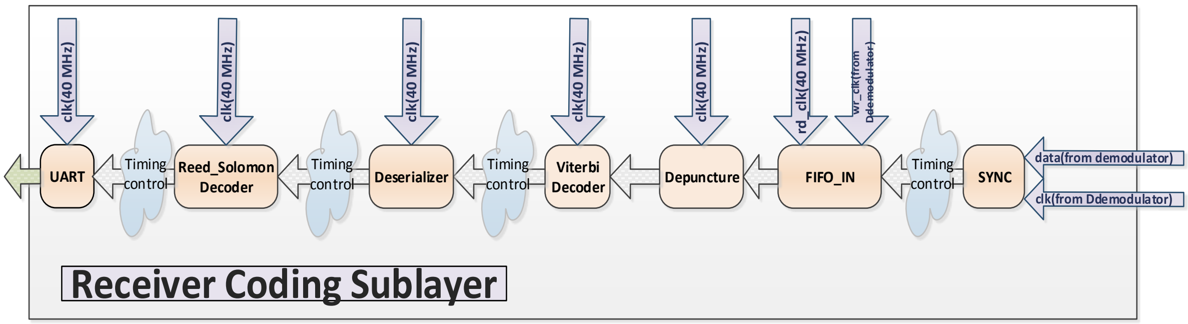

Fig.5 receiver coding sublayer

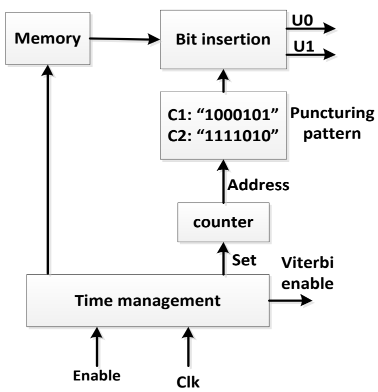

Fig.6. Depuncturing module

configured according to CCSDS recommendations. This module decodes the data frame and transfers the data packet along with a decoding status flag to the UART module. UART module transfers this data to the PC via RS232 protocol.

5. Experimental Framework and Results

In order to determine the BER performance of the designed coding sublayer of the telemetry link, the coding and decoding scheme is simulated with Modelsim SE 10.1 simulator.

In order to study the coding sublayer performance in presence of noise, an additive channel noise module was designed. Simulation results demonstrated that up to 40 corrupted data bytes in each data frame can be decoded successfully. Fig.7 illustrates the simulation results in this case. It can be seen that the Viterbi decoder along with the RS decoder could successfully overcome the simulated noisy channel.

After evaluating the simulation results, we synthesized and implemented coding sublayers by means of the ISE Design Suite. The generated bitfiles then were

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programmed on our transmitter and receiver boards separately.

In order to test the implemented codes, a Graphical User Interface (GUI) has been set up by means of which one megabyte of data was transmitted from PC to the transmitter board. This data was encoded in the FPGA and then transferred to an Agilent Vector Signal Generator (VSG) to become modulated. After being modulated in the VSG, the signal was transferred to the LNA of the receiver board.

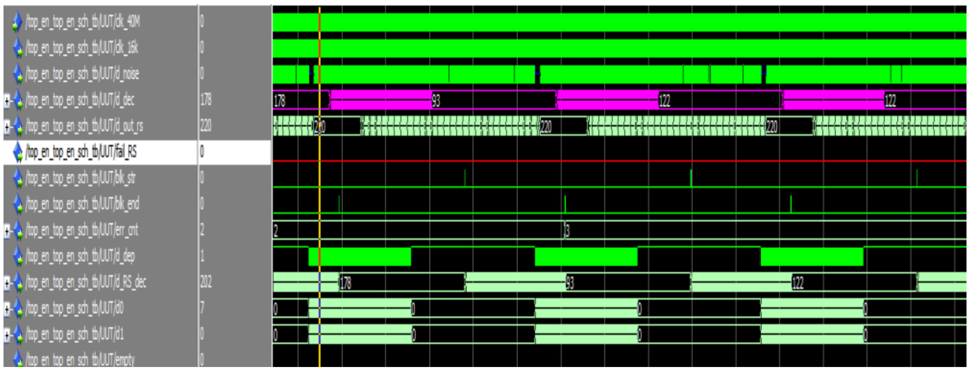

Fig.7 Modelsim Simulation results of coding sublayer over a AWGN channel

According to the test results, in absence of coding system, we could still detect the data correctly even if we reduced the transmitted signal level to -114dBm at the VSG. For lower signal levels, data could not be retrieved correctly and even some data frames might get lost. After testing the communication link in presence of the implemented coding scheme, we observed that we could retrieve the data correctly and without any data loss even when we decrease the signal level to -120dBm. This means that the designed coding sublayer improves the SNR of the communication link about 6 dB.

In addition, a comparison has been done between the DC power consumption of the receiver board in presence and absence of the coding sublayer. According to this comparison, the power consumption of the implemented coding sublayer was about 200mW which is easily negligible in comparison to the receiver board power budget.

6. Conclusion

In this paper a concatenated coding scheme was designed, simulated and implemented for a space telemetry channel according to the CCSDS recommendation. Experimental results revealed that the designed coding sublayer improved the SNR of the communication link about 6 dB. In addition, according to a comparison which has been done between the DC power consumption of the receiver board in presence and absence of the coding, it was observed that the implemented coding sublayer consumes about only 200mW which is not a burden on the receiver board power budget.

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