Adaptive Communication System using Software Defined Radio

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***Abstract*—The article describes an adaptive communication system for small satellites in low earth orbit (LEO). The aim of the research was to increase downlink throughput in LEO satellite system. To achieve that modulation and channel coding parameters are changed during transmission to compensate for variable channel parameters. System model was created using software defined radio modules and PC computers.**

***Keywords*—Adaptive Systems; SDR;Satellites;Doppler effect;**

I. INTRODUCTION (*HEADING 1*)

Small satellites especially those stationed on low earth (LEO) orbit are often not able to achieve high data rates due to lower power budget, variable channel characteristic and limited time over a ground station. During flight over the ground station the distance between transmitter and receiver changes and with it the channel attenuation. Doppler shift is also changing during the flight relative to the ground station position.

A. *Adaptive transmission*

In order to increase efficiency of communication between the satellite and the ground station an adaptive communication system can be used. Adaptive transmission is a technique of changing transmission parameters such as modulation and channel code scheme to better fit current channel parameters. In this paper we propose a communication system using adaptive techniques to improve performance over the LEO satellite channel. The laboratory model for the system was created and tested using software defined radio (SDR).

B. *Software defined radio*

Software defined radio is a combination of hardware analogue front end with digital signal processing preformed in software. This allows for easy reconfiguration and reuse of hardware. SDR already made its way into satellite communication systems. Examples of proposed use can be found in multiple projects both for communication modules i.e. PULSAR [1], FCP [2], Electra [3], and also ground stations ACCORD [4] In context of the proposed system model SDR allows for rapid prototyping and future reuse of system elements.

II. SYSTEM STRUCTURE

Proposed system is based on adaptive radio concept. The receiver in the ground station is able to issue modulation and code rate change based on the channel estimation. The system supports four modulation schemes (BPSK, QPSK, 8PSK, 16APSK) and uses convolutional code for the channel coding with five available code rates (1/2, 2/3, 3/4, 5/6, 7/8).

Transmission is performed using frames with constant symbol length. Each frame consists of preamble, packet header and packet data. The preamble is used for synchronization and consists of known sequence of 64 modulation symbols, regardless of transmission mode. The header contains basic frame information and CRC. The data packet has it’s separate CRC appended at the end.

The system model consists of four SDR modules presented in Fig. 1: one for transmitter (SDR_TX), one for receiver (SDR_RX), and another two modules for the satellite channel model (SDR_CH_RX, SDR_CH_TX). For the transmitter and the channel simulator SDR modules Ettus Research USRP N210 with WBX radio interfaces [5] were used. For the receiver National Instruments NI USRP 2920 radio [6] was used. All radio modules were connected to an external frequency generator for increased frequency stability.

A. *Adaptation Scheme*

The decision to change transmission scheme is done by the receiver. It is based on estimated signal to noise ratio. Not all possible modulation scheme and code rate combinations are used, due to SNR variance in the channel. Due to very fast SNR changes decisions on mode change are taken based on SNR averaged over 20 frames.

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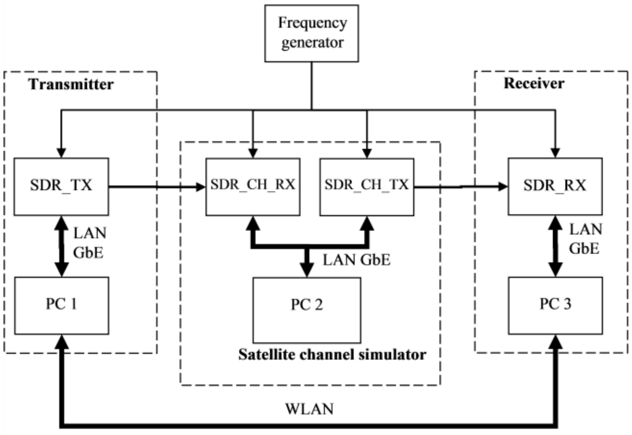

Fig. 1. System structure

SNR estimation result is compared with two threshold values. Transmission modes used in the system and corresponding threshold values for all modes are presented in TABLE I. If one of the thresholds is exceeded decision is taken to change to higher or lower transmission mode. In case of prolonged transmission failure both the transmitter and the receiver revert to mode 1.

TABLE I. TRANSMISSION MODES, THRESHOLD VALUES AND BIT RATE EFFICIENCY

Mode ID	Modulation and code rate	SNR up [dB]	SNR up [dB]	Rb [b/Symbol]
1	BPSK 1/2	10	6	0,5
2	BPSK 2/3	12	8	0,67
3	QPSK 1/2	14	10	1
4	QPSK 2/3	16	12	1,33
5	8-PSK 1/2	18	14	1,5
6	16-APSK 1/2	20	16	2
7	16-APSK 2/3	22	18	2,67
8	16-APSK 3/4	24	20	3
9	16-APSK 5/6	26	22	3,33
10	16-APSK 7/8	-	24	3,5

B. *Transmitter*

The transmitter consists of SDR module and PC computer with C++ application. The application is responsible for preparing complex baseband signal and sending it to SDR. It is divided into three program threads: return channel receiver, data preparation, and SDR control. The input bit stream is divided into frames. For each frame CRC is calculated and convolutional coding is performed on the data. The header with its own CRC code is placed before coded data. Symbol mapping is preformed on the frame and the preamble is added. The signal is upsampled to 8 samples/symbol and filtered with the root raised cosine filter with a roll-off factor of R = 0.9. The baseband signal is sent to the SDR module where it is converted into the analog form and frequency shifted into the operating band.

C. *Receiver*

The receiver consists of the SDR module and PC console based application written in C. To increase processing speed the program was divided into three threads: data acquisition, data processing and soft-decision decoding. To further increase throughput Single Instruction Multiple Data (SIMD) instructions were used. The receiver is using 32-bit float data types in internal processing. Intel SSE 128 bit instructions allowed for up to four times increase in speed of mathematical operations.

The received signal is sampled at 4 samples/symbol. At first coarse Doppler shift correction is performed. The signal is then filtered with the root raised cosine filter. After filtration fine frequency correction is performed using the multiply-filter-divide algorithm. The filtered signal is exponentiated to the n-th power where n depends on the modulation scheme. Fourier transform is performed and the highest peak in spectrum is used to determine the carrier frequency. To obtain frame synchronization and symbol timing, the preamble is used. Correlation allows for finding the beginning of the frame. Interpolation of the signal allows for fine correction of the beginning of the frame and acquiring the symbol synchronization. The channel estimation is done by using the preamble to find baseband, complex impulse response (CIR) of the channel. This value is used in the equalizer to normalize incoming symbol values.

Soft-decoding thread contains soft-decision demapping and Viterbi decoding. SNR is estimated by comparing demapped symbol values with the ones. The decoding thread is responsible for issuing decisions to change modulation scheme and code rate.

III. SYSTEM TESTS

The channel model simulator was developed to test the proposed adaptive system. Simulator capabilities include frequency shift caused by Doppler effect, attenuation, and noise. It is able to simulate pass of the satellite over the ground station. Simulation environment allowed for verifying received data and calculation of the frame error rate (FER) based on CRC check of both the header and the data.

Worst channel conditions, caused by Doppler effect, can be observed for very low orbit and a pass right above the ground station. In this case the frequency synchronization error is highest. In **Błąd! Nie można odnaleźć źródła odwołania.** SNR changes recorded during system operation at 300 km orbit can be seen. About 15 dB difference between peak and lowest SNR can be noticed. During this test FER of 2.7E-03 was achieved (summary of signal reception is presented in TABLE II.).

The system was able to transmit with speeds of up to 500 ksymbols/s. The limiting factor was the speed of implemented digital signal processing algorithms. The tests were performed with frame length never exceeding 10 ms. Lower SNR at the top of the curve is due to lower power of 16-APSK constellation used in the system compared to other modulations.

Fig. 3 shows transmission modes switching and achieved bit rates. Transmission starts from mode no. 1 (BPSK 1/2) when the satellite is just above the horizon and reaches mode no. 7 (16APSK 2/3) when the satellite is passing over the GS.

There is noticeable switching back and forth between two modes at one point during the pass caused by drops in SNR.

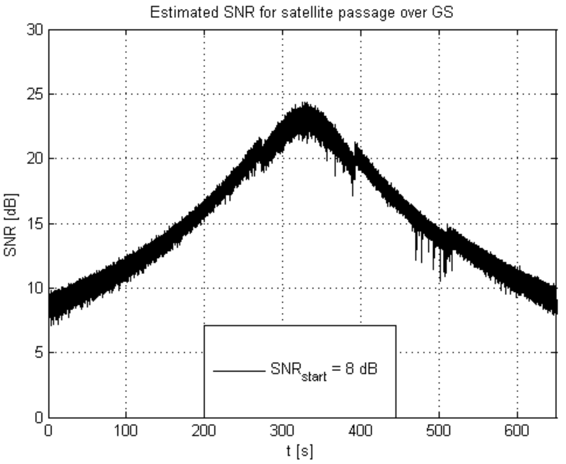

Fig. 2. Estimated SNR for satellite passage over GS

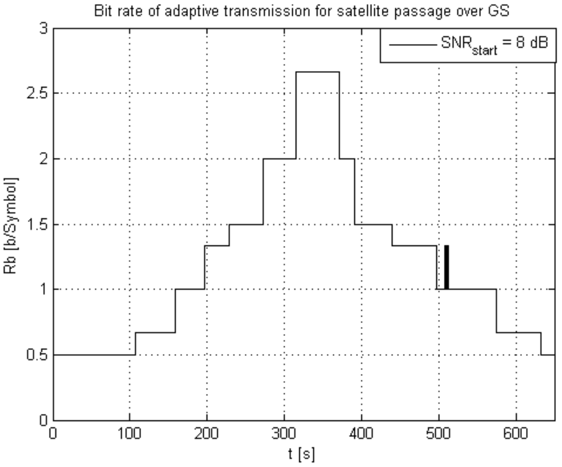

Fig. 3. Bit rate of adaptive transmission for satellite passage over GS

Based on simulation results LEO orbit channel allows for theoretical transmission rate of about 1 Msymbol/s using 10080 symbols long frames. The receiver of presented system is not able to handle longer frames due to an assumption that the channel is stationary during transmission of a single frame. Especially during the pass through the zenith over the ground station, where the Doppler shift change is highest, synchronization errors can occur at the end of the frame. There is a tradeoff between frame length and system efficiency. Shorter frames are more resistant to frequency shift but become less efficient due to the preamble and header overhead.

TABLE II. SUMMARY OF THE SIGNAL RECEPTION FOR SINGLE SATELLITE PASSAGE OVER THE GS AGE (300 KM ORBIT, ZENITH PASSAGE)

Estimated start SNR	**8 dB**
Total number of transmitted frames	270116
Number of received frames	270109
Number of decoded Data frames	269956
Number of decoded frames without errors	269377
Total Frame Error Rate	**2.7E-03**

IV. SUMMARY

In the article structure of the adaptive satellite communications system was proposed. The laboratory model of the system was created and tested. Software defined radio was used for prototyping, allowing for faster development and modifications of the system.

The system model was tested with channel simulator in multiple passes on different orbits over the ground station. The system showed successful performance of the adaptive transmission mode switches over the satellite channel. Use of the adaptive communication system allowed for about 2-2.5 times increase in system throughput compared to base modulation of BPSK with 1/2 code rate.

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