Transport and Aerospace Engineering
ISSN 2255-9876 (online)
ISSN 2255-968X (print)
2020, vol. 8, pp. 1–14
https://doi.org/10.2478/tae-2020-0001
https://content.sciendo.com

RPAS Satellite Communication Channel Based on Long-Term Evolution (LTE) Standard

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***Abstract* – MIMO-OFDM models of RPAS communication channels based on LTE Standard were built. Dependencies of the BER on the SNR for Extended Pedestrian A and Extended Vehicular A models using 2-by-2 multiple antennas were obtained. Dependencies of the BER on the SNR for different levels of Frequency Offset at satellite transponder were studied.**

***Keywords* – BRLOS; frequency offset; LTE, MIMO-OFDM; RLOS; RPAS; satellite channel.**

I. Introduction

The growing demand for the use of Remotely Piloted Air Systems (RPASs) leads to an increase in investment in the development and implementation of reliable, cost-effective small unmanned vehicle. In this regard, the characteristics and requirements for prospective civilian networks applications are investigated and general network requirements are developed, such as connectivity, adaptability, security, confidentiality, safety and scalability. Small RPASs are well suited for commercial applications due to ease of deployment, low cost and maintenance costs, high manoeuvrability and soaring capacity. Such RPASs are used for environmental monitoring, disaster management, border and transport control, emergency assistance, search and rescue operations, delivery of goods and construction [1].

Of particular interest is the use of RPASs as a communication relay or aerial base stations for the rapid deployment of a network with wide coverage capabilities. A swarm of RPASs can be effectively used to perform various tasks due to their size, capabilities, payload and flight time [2].

The distances that the RPAS needs to be moved can vary widely for different applications. At the same time, a communication can be established both within the Radio Line of Sight (RLOS) and the Beyond Radio Line of Sight (BRLOS) using A2A (Air-to-Air), G2A (Ground-to-Air), and A2G (Air-to-Air) links. Reliable communication and networks are necessary to ensure teamwork and coordination of multiple units. What is important is the selection of a suitable wireless technology that must be able to support air-ground and air-air communication, considering data needs, regardless of altitude and distance [3].

The high mobility of the RPAS in the air networks imposes special requirements on the network protocols developed for the terrestrial networks. For wireless communication, several technologies can be used, such as IEEE 802.11 (Wi-Fi – Wireless Fidelity), 802.16 (WiMAX – Worldwide Interoperability for Microwave Access), GSM (Global System for Mobile Communications), GPRS (General Packet Radio Service), EDGE (Enhanced Data rates for GSM Evolution), UMTS (Universal Mobile Telecommunications System) and LTE (Long-Term Evolution) [4–8].

In terms of scalability, each technology must take into account the maximum allowable number of devices, network topology, network infrastructure and network control (centralized or distributed). Important factors such as maximum communication range, maximum data transfer rate and delay

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should also be considered. Communication requirements for providing coverage of the air network are investigated by the authors in [9, 10]. Data on the throughput of aerial Wi-Fi networks for RLOS links A2A, A2G, G2A and comparison with G2G link are given in paper [11].

LTE, often referred to as 4G LTE, is a standard for wireless data transmission and is a development of GSM/UMTS standards. The goal of LTE was to increase bandwidth and speed using a new method of digital signal processing and modulation, to reconstruct and simplify the network architecture for reducing data transfer delays. The range of the LTE base station depends on the radiation power and is theoretically unlimited. The maximum data transfer rate depends on the radio frequency and distance from the base station. The LTE specification allows for download speeds of up to 326.4 Mbps, upload speeds of up to 172.8 Mbps, and the delay in data transfer can be reduced to 5 milliseconds. LTE supports bandwidths from 1.4 MHz to 20 MHz and supports both frequency division channels and time divisions [12–16].

For effective practical application of the RPAS, it is important to carry out modelling of their communication channels operation in various conditions. The simulation results for satellite communication channels, including IEEE 802.11 and IEEE 802.16 standards, are published in [17–27]. A relatively small amount of works is devoted to communication channels modelling using the existing LTE cellular communication infrastructure.

The aim of this paper is:

1. to create MIMO-OFDM (Multi Input Multi Output – Orthogonal Frequency Division Multiplexing) models of RPAS communication channels based on LTE Standard, including Base Station (BS) transmission within the Radio Line of Sight (RLOS) and through the satellite using Beyond Radio Line of Sight (BRLOS);
2. to obtain the dependencies of the Bit Error Rate (BER) on the Signal-Noise Ratio (SNR) for Extended Pedestrian A models (EPA) and Extended Vehicular A models (EVA) using 2-by-2 multiple antennas at both BS transmitter and RPAS receiver;
3. to study the dependencies of the BER on the SNR for different levels of Frequency Offset at satellite transponder.

II. "BASE STATION – RPAS" LINK MODEL

The RLOS model (Fig. 1) is designed using MATLAB demo example and consists of the "Base Station Transmitter", "Channel" and "RPAS Receiver". In the *LTE PHY Downlink with Spatial Multiplexing* example, the physical layer simulation of the downlink is developed in the framework of the third-generation partnership project (3GPP). LTE-Advanced is one of the fourth-generation (4G) communication systems approved by the International Telecommunication Union (ITU), with expected downlink data transfer rates in excess of 1 Gbps (for version 10 and above). This model uses a 2-by-2 antenna configuration on both the transmitter and receiver for spatial multiplexed transmission with multiple code words using code-based pre-coding with feedback. In the calculations, the channel bandwidth was 10 MHz and the number of OFDM symbols per subframe was equal to two.

When the BS transmitter is in operation, a variable size payload is created, Cyclic Redundancy Code (CRC) is inserted into the transport block, code block segmentation with CRC insertion for each code block, channel (turbo) coding, bit rate matching, bit-level scrambling, data modulation (QPSK, 16QAM or 64QAM), layer mapping for two antennas, codebook based pre-coding, and OFDM signal generation.

In a linear MIMO receiver, a channel is estimated using a least-squares method with interpolation and criteria based on the minimum mean square error for selecting the codebook when feedback with the pre-coding matrix indicator is selected. The model uses the frequency division duplex mode and uses a 10 ms radio frame consisting of 10 subframes. Each 1 ms subframe has two consecutive slots. The Simulink model processes one subframe per time step.

The Downlink Shared Channel (DL-SCH) is the main type of transport channel in LTE. It is used for user data, for specific control information, and also for downlink system information. In this model, two code words of the same size, modulation, and code rate are transmitted. Each codeword corresponds to a single transport block. DL-SCH uses turbo coding as a channel coder. Rate matching extracts the exact set of bits to be transmitted within a subframe from the encoded bits. In this model, alternation of subblocks is implemented, the creation of a circular buffer and the selection of the actual bit using the parameters of the selected scenario for data transfer conditions. Several code blocks are then combined together to process the physical channel in a downstream direction.

A physical channel corresponds to a set of time-frequency resources used to transmit a particular transport channel. Each transport channel is mapped to the corresponding physical channel. The Physical Downlink Shared Channel (PDSCH) is the main physical channel used for unicast data transfer. This model uses transmission based on spatial multiplexed codebook. The coded bits of the transport channel are scrambled by a bit-level scrambling sequence. The scrambling sequence depends on the identity of the cells of the physical layer to ensure randomization of interference between cells.

Modulation of downlink data converts the scrambled bits into complex modulated symbols. The set of supported modulation schemes includes QPSK, 16QAM and 64QAM, which corresponds to two, four and six bits per modulation symbol, respectively.

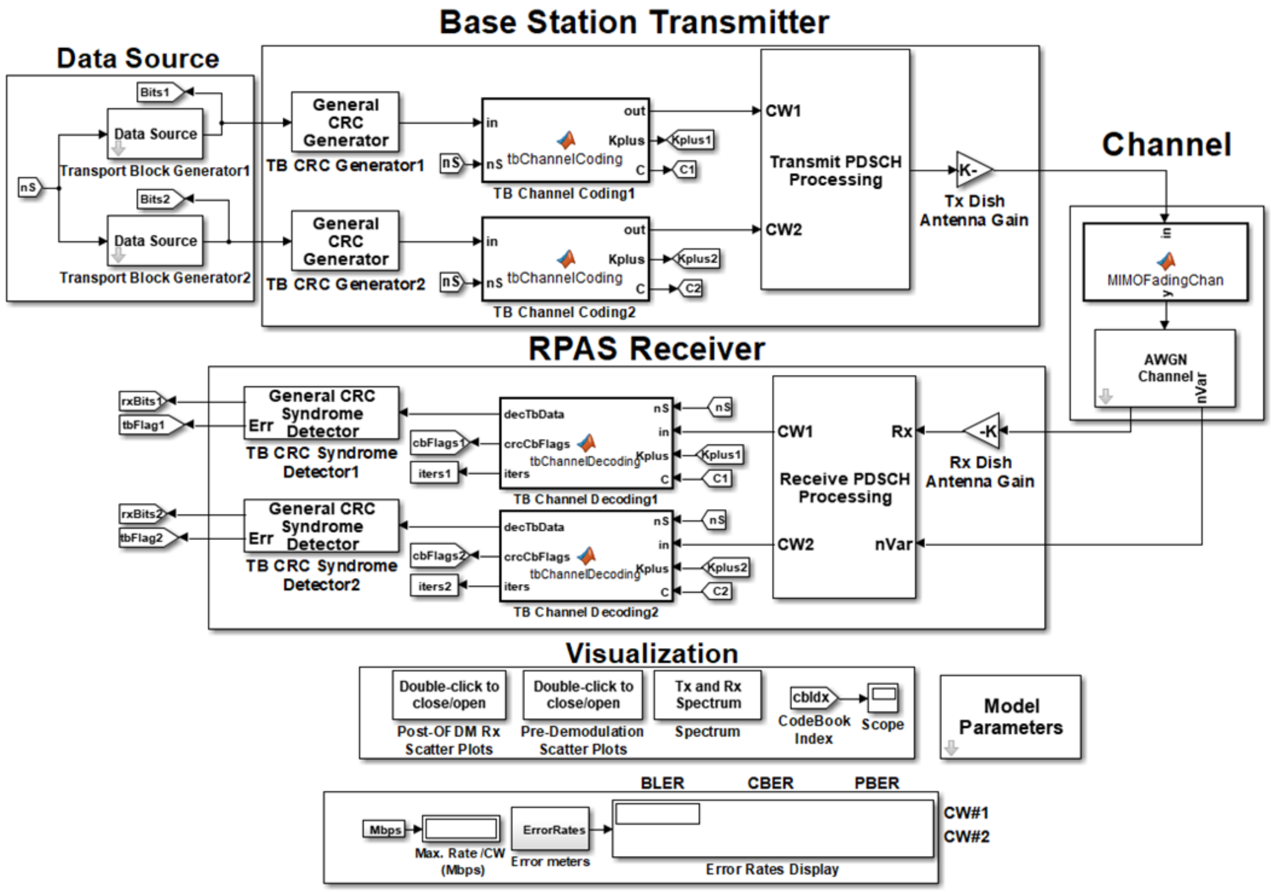

Fig. 1. “Base Station-RPAS” link.

The complex OFDM signal in the time domain for each antenna is generated separately using an OFDM modulator unit. The number of FFT (Fast Fourier Transform) points depends on the selected channel bandwidth. For the cyclic prefix, the seven OFDM symbols in the interval use different cyclic prefix lengths. The MIMO Fading Channel block implements different MIMO fading profiles.

For channel estimation, the least squares method is used using averaging over a subframe to reduce noise for reference signals and linear interpolation over subcarriers for data elements. When selecting a codebook, the minimum mean square error (MMSE) criterion is used to calculate the codebook index for the subframe. The MIMO receiver uses the MMSE line receiver to combat interference from multiple antenna transmissions. A soft decision demodulation is used for each codeword to facilitate turbo coding in the downstream direction.

The following channel data transfer scenarios are implemented in the model: Frequency-flat static MIMO, Extended Pedestrian A model (EPA0Hz), Extended Pedestrian A model (EPA5Hz), Extended Vehicular A model (EVA5Hz), and Extended Vehicular A model (EVA70Hz) [28]. For the transmitter operation frequency 1.0 GHz, the Doppler frequency of 5 Hz corresponds to the movement of the RPAS at approximately 3.0 km/h, and the frequency 70 Hz – to 36 km/h.

In the case of the Frequency-flat static MIMO scenario, a medium with additive white Gaussian noise (AWGN) is used to simulate the static channel characteristics, for which no fading or multipath propagation exists. In the case of multipath fading for the Extended Pedestrian A model and Extended Vehicle A model scenarios, the delay profiles given in Tables B.2-1 to B.2-2 are used [28].

Modulated symbols are precoded using codebooks. For two antennas a codebook is used which allows for only two entries. After completion of the simulation, the number of decoding iterations used for each code block per transport block in time is displayed on two 3D graphics. These plots are used for turbo decoding.

For calculations, the following parameters in the model were set up: “Base Station Transmitter” antenna gain was taken 3.1 (an antenna diameter ≈ 0.4 m at 1 GHz), “RPAS Receiver” antenna gain – 1.55 (an antenna diameter ≈ 0.2 m at 1 GHz).

For RPASs communication systems of the middle and large class, requirements that are more stringent are imposed on the range of operation, noise immunity and the probability of a bit error. During the operation of the communication system, the bit error probabilities for the communication channel are estimated. An important issue is the choice of a signal modulation in the transceiver. When comparing different types of modulation use the criteria of spectral and energy efficiency. The main requirement when creating RPAS communication system is to ensure the possibility of data transmission at a given speed and likelihood of error at large distances between the RPAS and the base station. To ensure maximum communication range, it is necessary to use the most energy efficient modulation methods.

Fig. 2 shows dependencies of the BER for the SNR for the Frequency-flat static MIMO channel in the case of QPSK modulation, for which there is a significant difference between code words. The channel is open for only one code word.

Fig. 3 shows dependencies of the BER on the SNR for the EPA0Hz MIMO channel. Dependencies for different code words are close and the channel is open in both cases, but the BER values are higher than for the CodeWord#2 in Fig. 2.

Dependencies of the BER on the SNR for a scenario with low-speed motion (EPA5Hz) are shown in Fig. 4. The movement immediately impairs data transmission and increases the values of the BER in the considered range of SNR values.

Dependencies of the BER on the SNR for the EVA5Hz data transfer scenario are given in Fig. 5. The channel is open at much larger values of the SNR – about 50 dB. Both code words give similar BER values.

Fig. 6 shows dependencies of the BER on the SNR for the EVA70Hz scenario, which corresponds to the RPAS movement at a high speed. The BER values increase by orders of magnitude and the channel in the considered range of the SNR is closed.

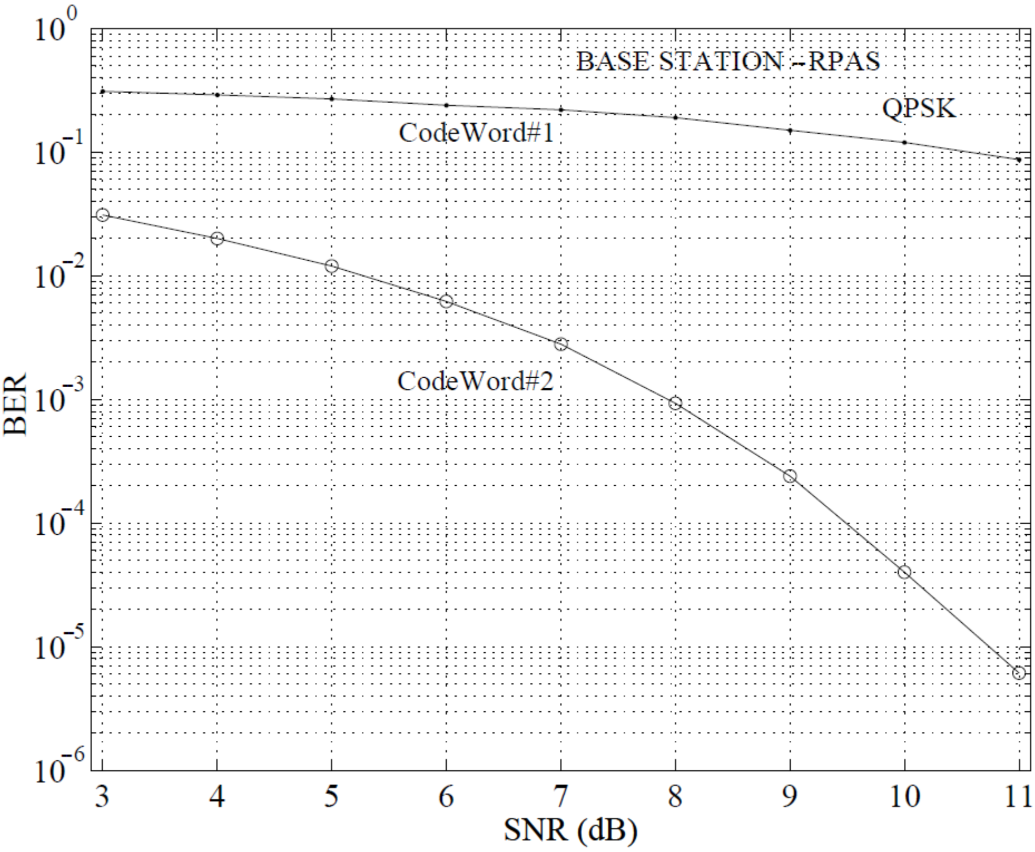

Fig. 2. Dependencies of the BER on the SNR for RLOS Frequency-flat static MIMO channel.

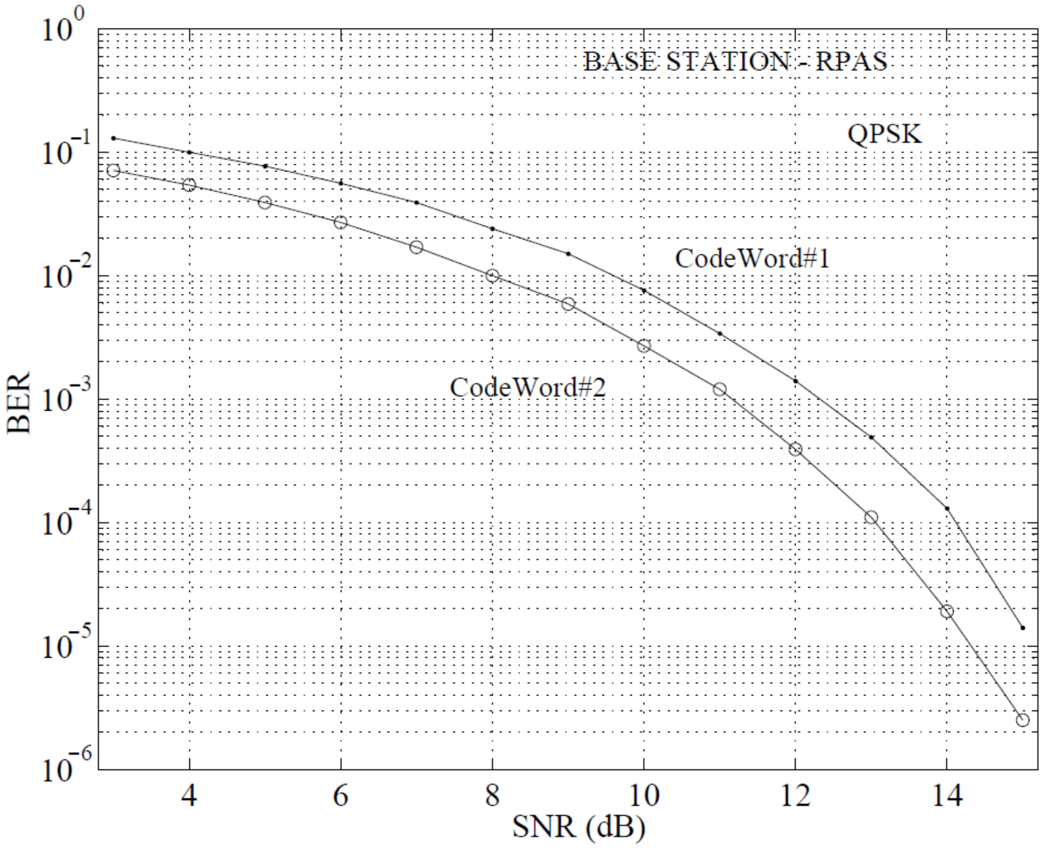

Fig. 3. Dependencies of the BER on the SNR for RLOS EPA0Hz MIMO channel.

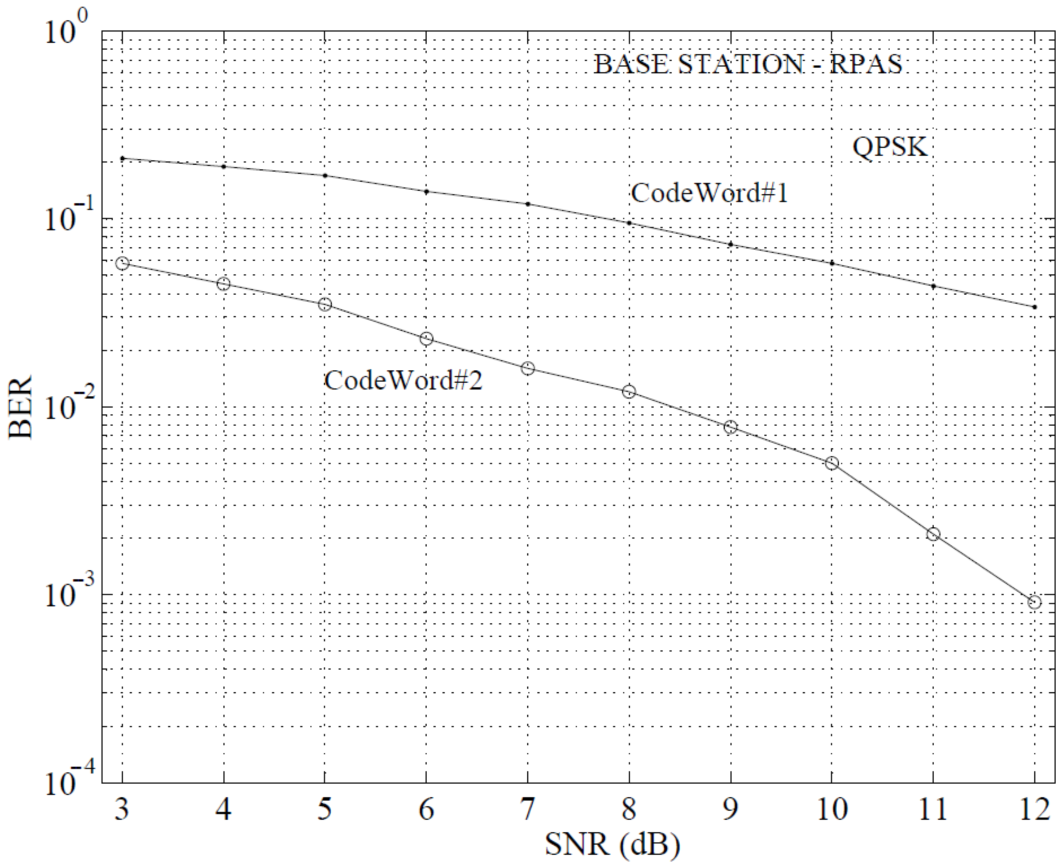

Fig. 4. Dependencies of the BER on the SNR for RLOS EPA5Hz MIMO channel.

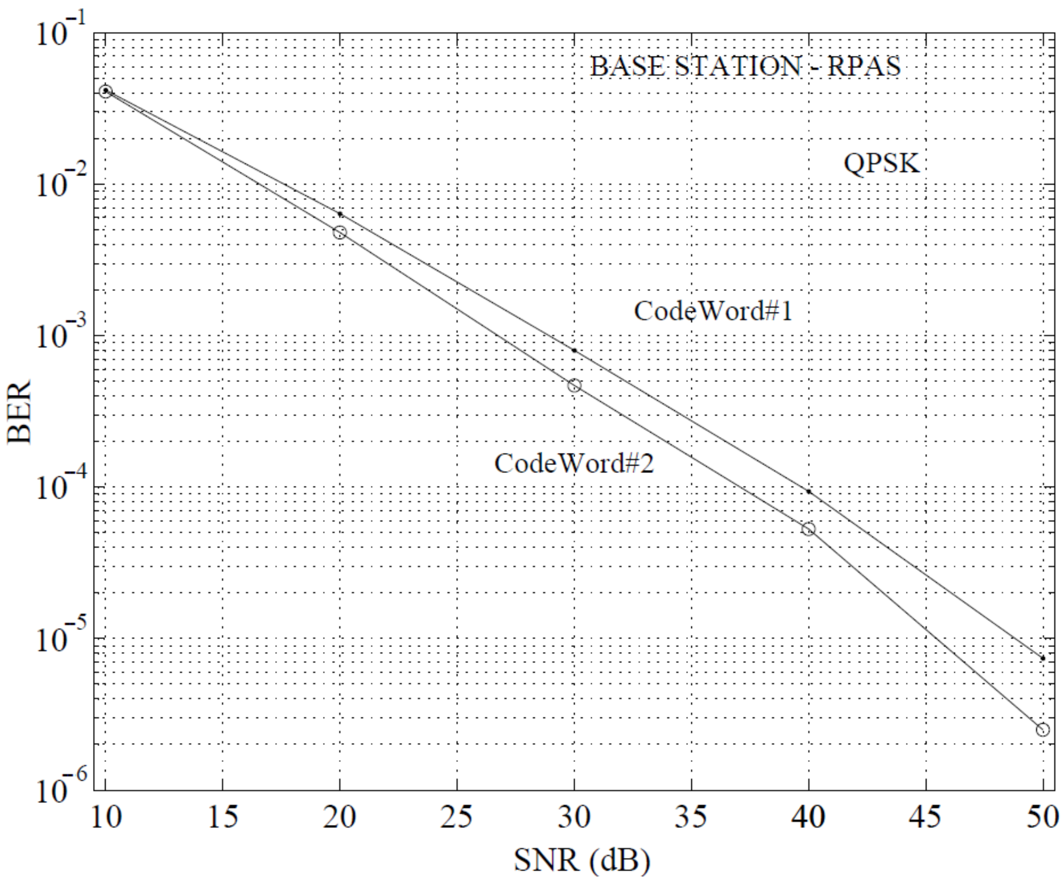

Fig. 5. Dependencies of the BER on the SNR for RLOS EVA5Hz MIMO channel.

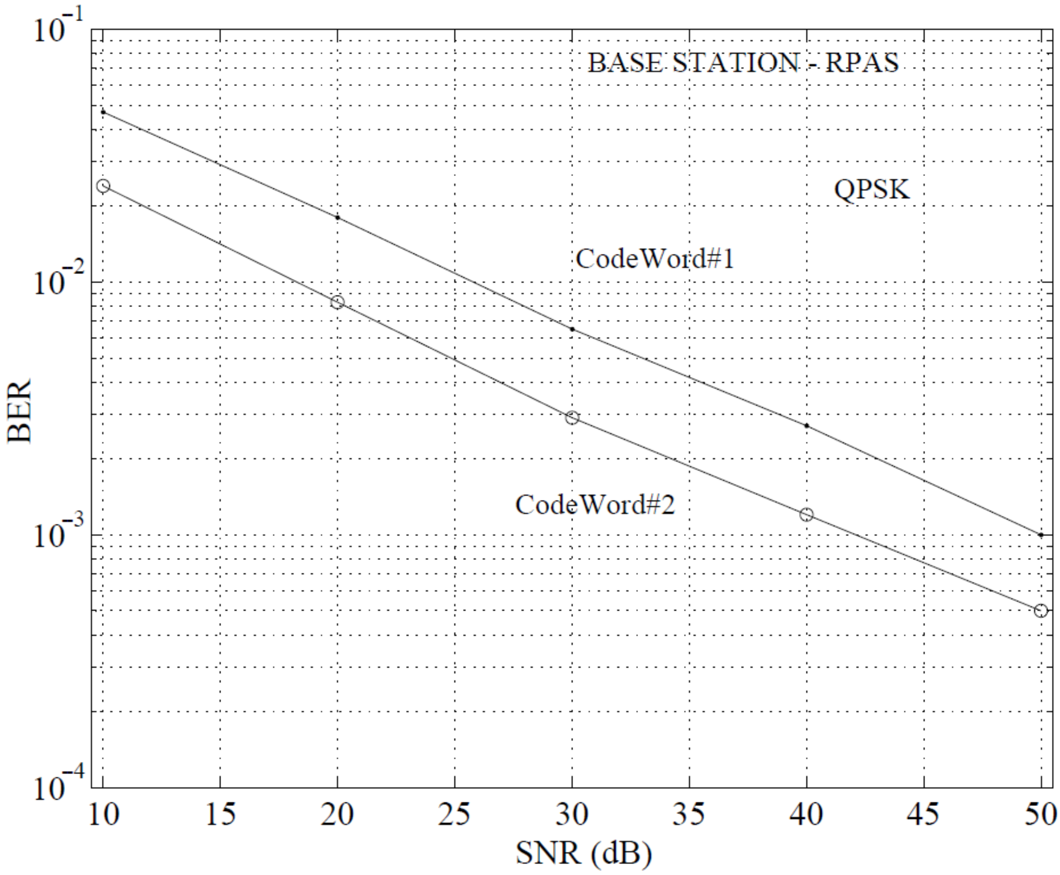

Fig. 6. Dependencies of the BER on the SNR for RLOS EVA70Hz MIMO channel.

III. "Base Station – Satellite – RPAS" Link Model

The model "Base Station-Satellite-RPAS" (Fig. 7) was designed on the base of "Base Station-RPAS" model (Fig. 1) by adding the Satellite Transponder. The Satellite Transponder includes an antenna amplifier, a low-frequency amplifier, a phase-frequency shift unit and an antenna amplifier that transmits data to the RPAS. Frequency offset for different modulations was changed.

For calculations, the following parameters in the models were set up: "Base Station Transmitter" antenna gain was taken 3.1 (an antenna diameter ≈ 0.4 m at 1 GHz), "Satellite Transponder" antennas gain were taken 7.8 (an antenna diameter ≈ 1.0 m at 1 GHz) "RPAS Receiver" antenna gain – 1.55 (an antenna diameter ≈ 0.2 m at 1 GHz).

The channel data transfer scenarios are implemented the same as in the previous model. The values of the BER in the uplink and downlink were changed symmetrically. Fig. 8 shows dependencies of the BER on the SNR for the Frequency-flat static MIMO channel. The plots for both code words are close enough. The range of changes in the SNR compared with the RLOS has shifted towards smaller values, which is associated with the presence of a satellite transponder, which amplifies the signal and increases the transmission range.

In Fig. 9 dependencies of the BER on the SNR for the EPA0Hz scenario are presented. In this case, the BER values are close to the data in Fig. 8. The graphs in Fig. 10, representing dependencies of the BER on the SNR for the EPA5Hz MIMO channel, are close in terms of the BER values to the data in Fig. 8 and 9.

Fig. 11 shows dependencies of the BER on the SNR for the EVA5Hz scenario. The BER values are higher than for Figs. 8–10, but the impact of RPAS movement is less than for data transmission without the use of a satellite transponder (compare with Figs. 2–6). In this case, the channel is already open when the SNR values are greater than 10 dB. For the case of RPAS high speed movement with the scenario EVA5Hz (Fig. 12), the channel is closed at the SNR values of up to 50 dB.

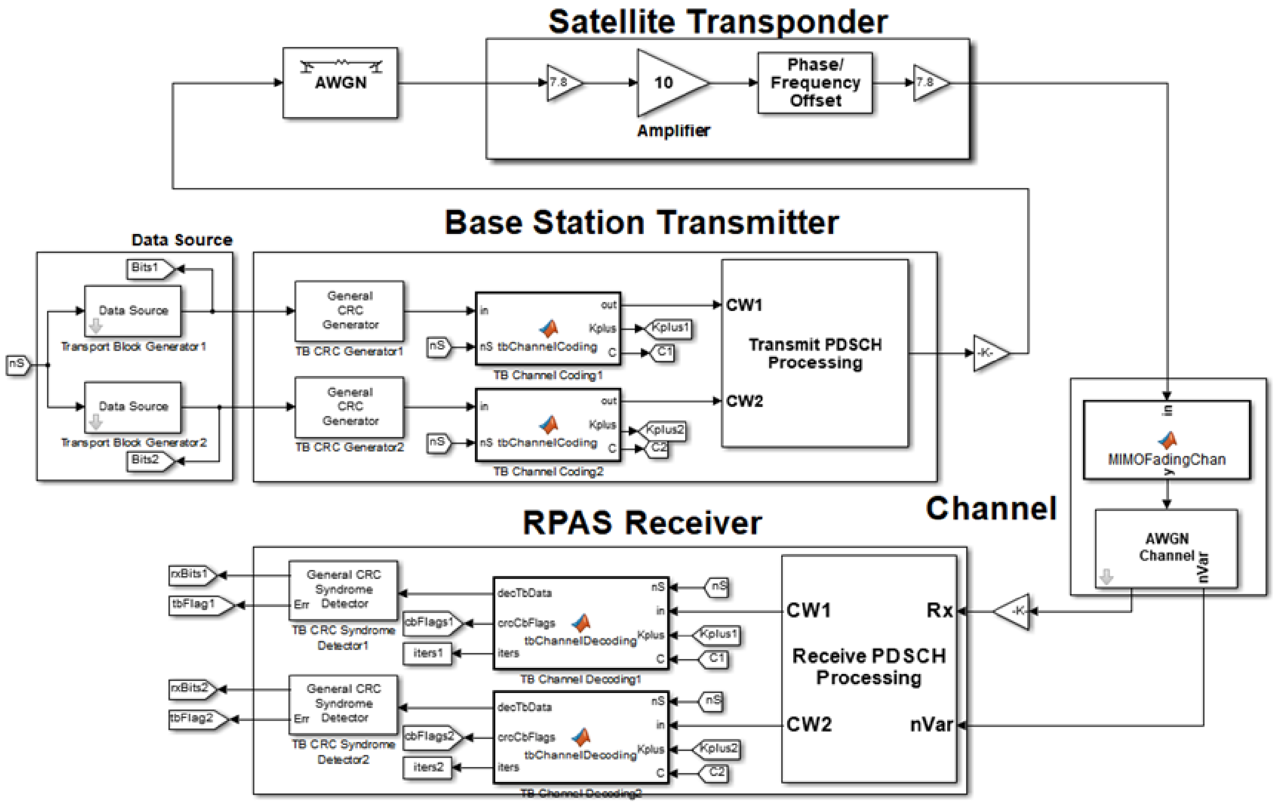

Fig. 7. “Base Station-Satellite – RPAS” link.

An important issue is the choice of the signal modulation in the transceiver. When comparing different types of modulation use the criteria of spectral and energy efficiency. The main requirement when creating RPAS communication system is to ensure the possibility of data transmission at a given speed and likelihood of error at large distances between the RPAS and the base station. It is necessary to use the most energy efficient modulation methods to ensure maximum communication range.

The effect of Frequency Offset on the BER parameter for various signal modulations was investigated using EVA5Hz MIMO channel and the SNR in Uplink and Downlink 5 dB parameter as an example. From Fig. 13 it follows that with increasing modulation positioning the probability of bit error increases, i.e., to maintain a given level of the bit error, it is necessary to increase the SNR at the receiver input. Therefore, it is advisable to use multi-modulation only for small distances between the RPAS and the base station. It is necessary to use the most energetically beneficial modulation types to ensure maximum communication range, such as QPSK. Frequency Offset significantly affects the probability of a bit error, and the effect is most pronounced in the case of QPSK.

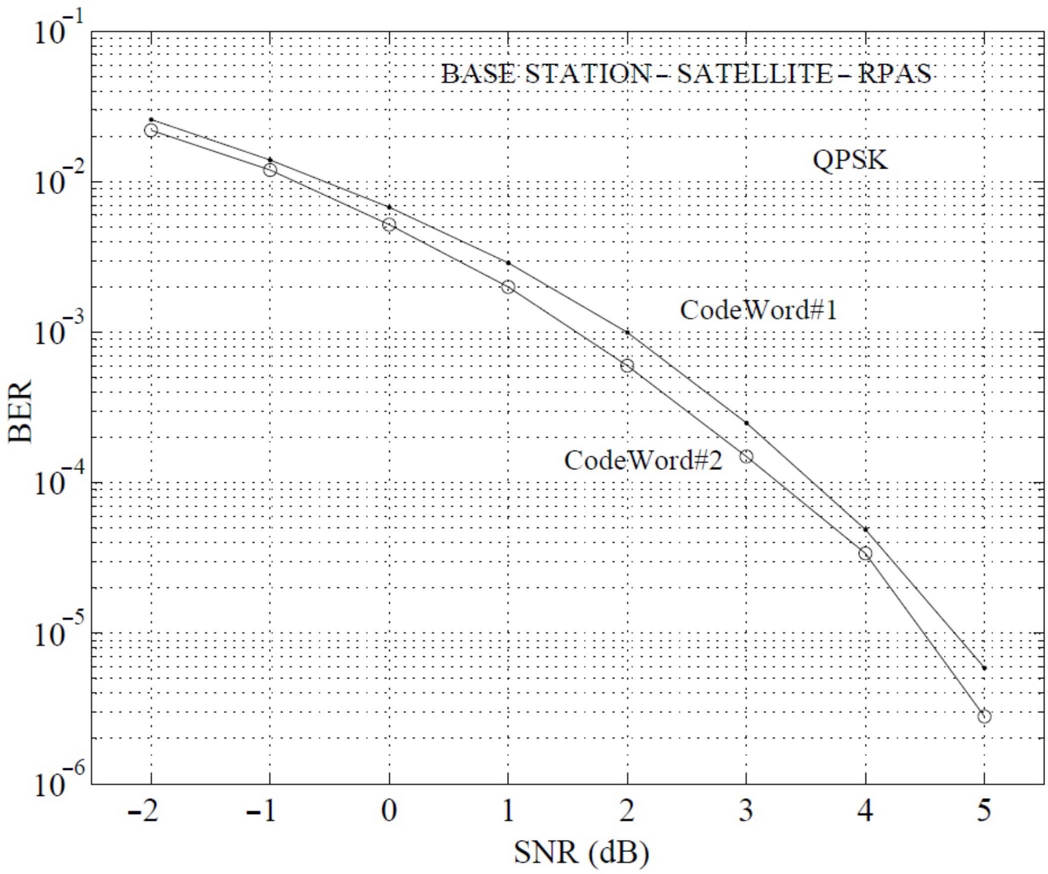

Fig. 8. Dependencies of the BER on the SNR for BRLOS Frequency-flat static MIMO channel (SNR in Uplink and Downlink is 5 dB).

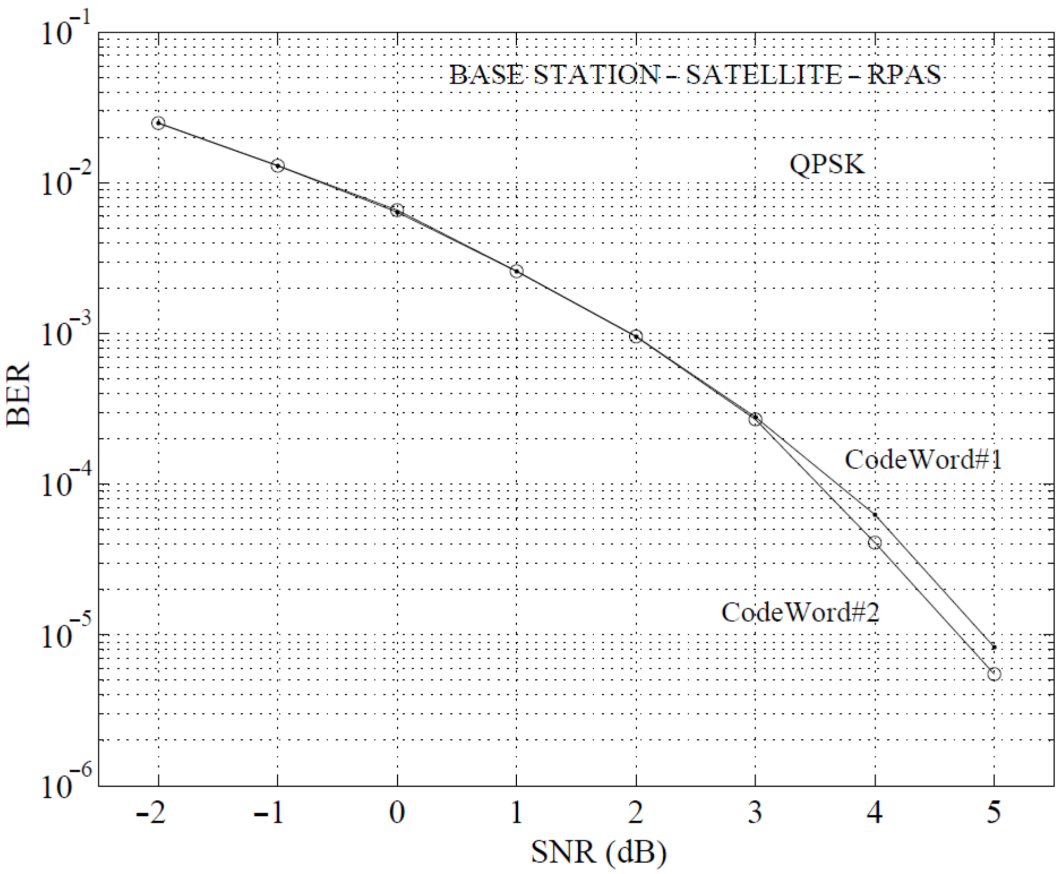

Fig. 9. Dependencies of the BER on the SNR for BRLOS EPA0Hz MIMO channel (SNR in Uplink and Downlink is 5 dB).

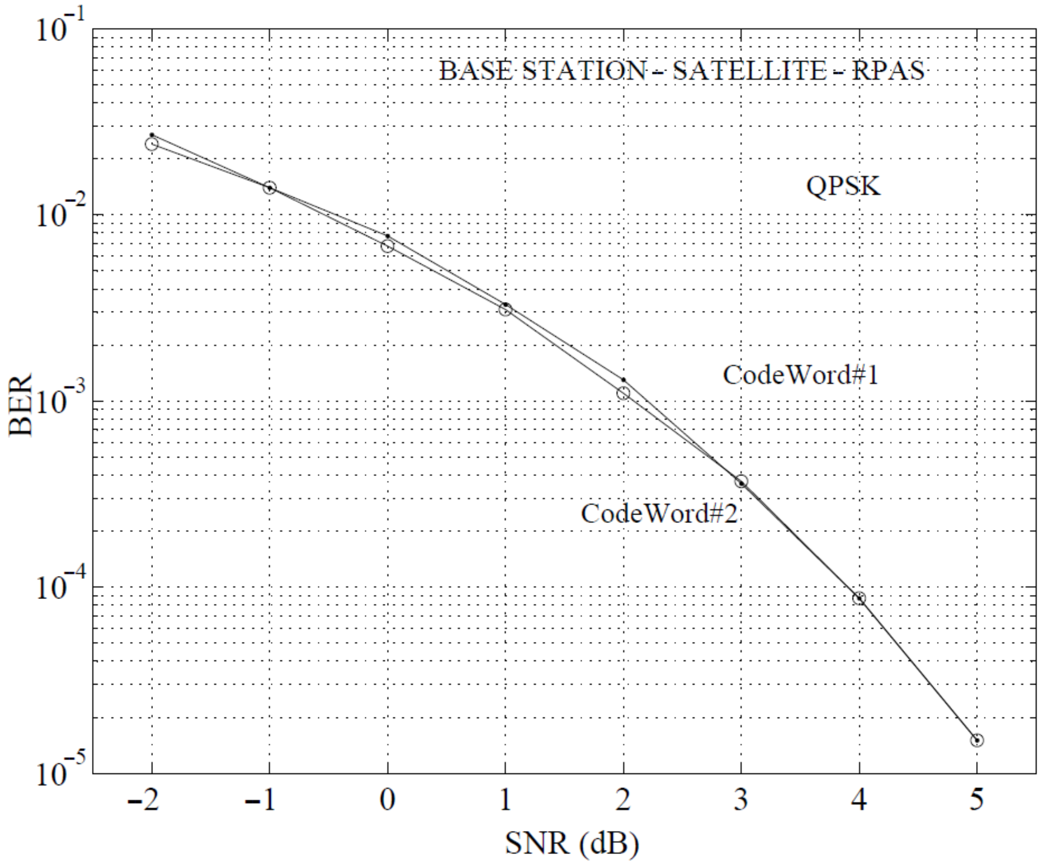

Fig. 10. Dependencies of the BER on the SNR for BRLOS EPA5Hz MIMO channel (SNR in Uplink and Downlink is 5 dB).

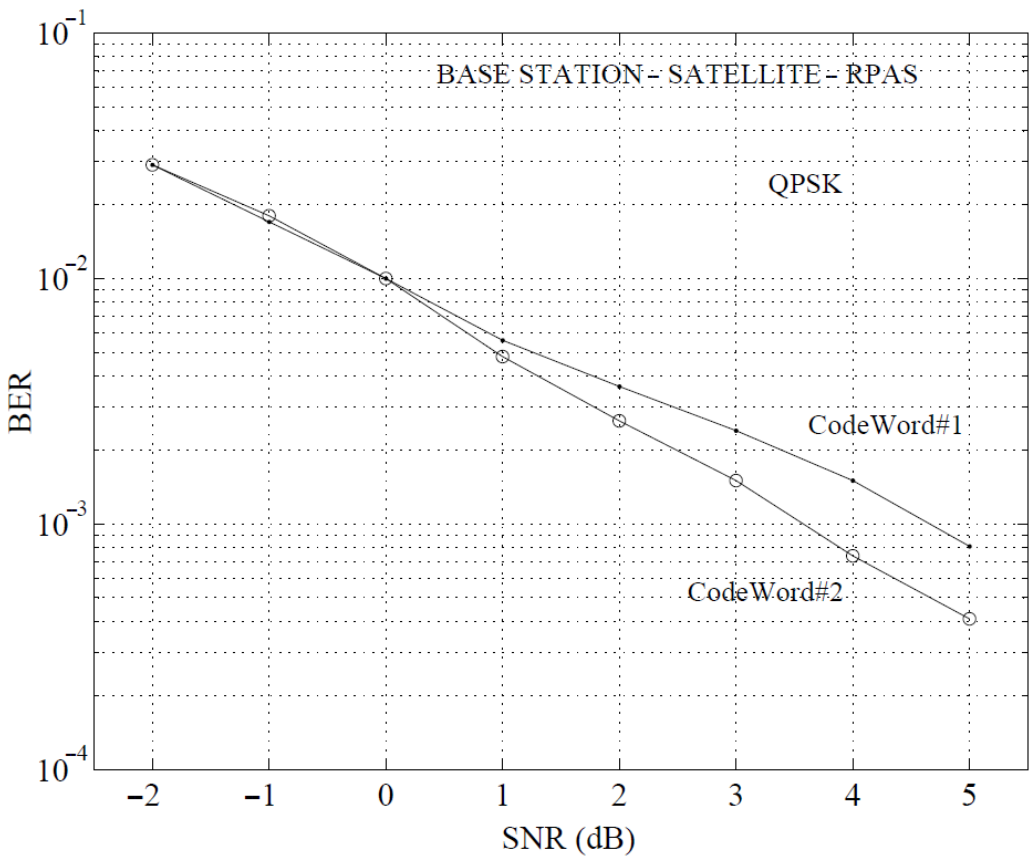

Fig. 11. Dependencies of the BER on the SNR for BRLOS EVA5Hz MIMO channel (SNR in Uplink and Downlink is 5 dB).

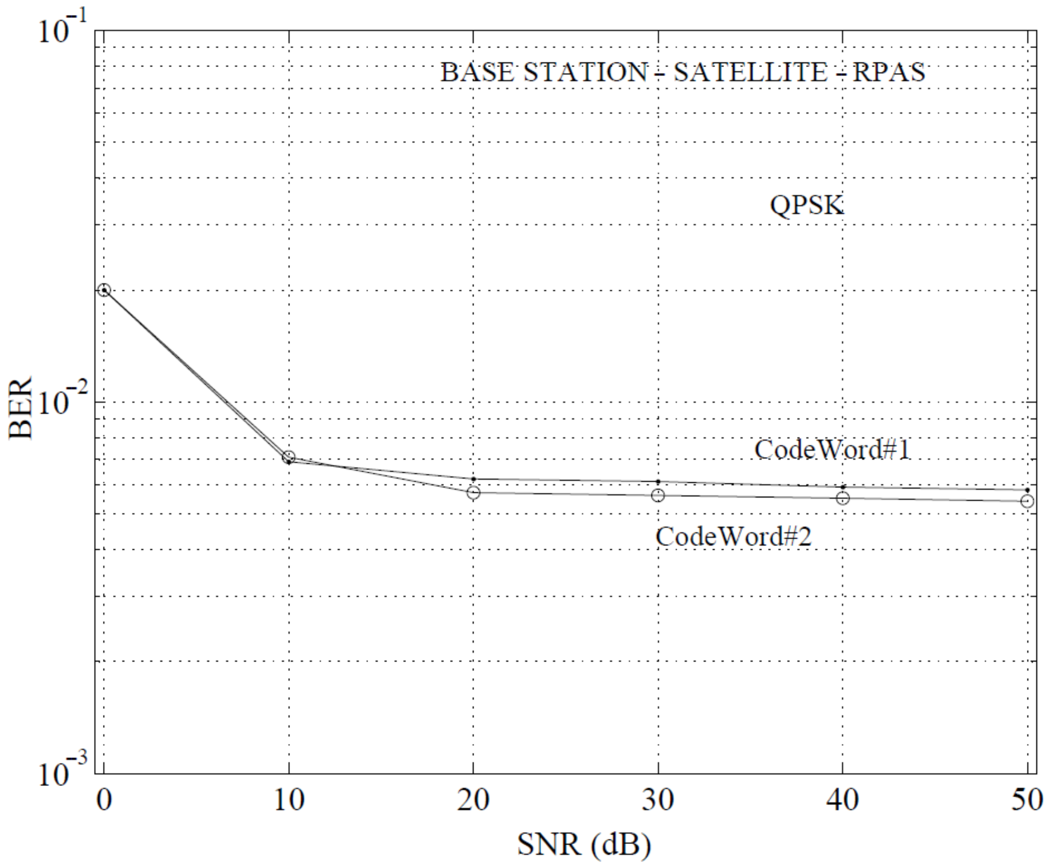

Fig. 12. Dependencies of the BER on the SNR for BRLOS EVA70Hz MIMO channel (SNR in Uplink and Downlink is 5 dB).

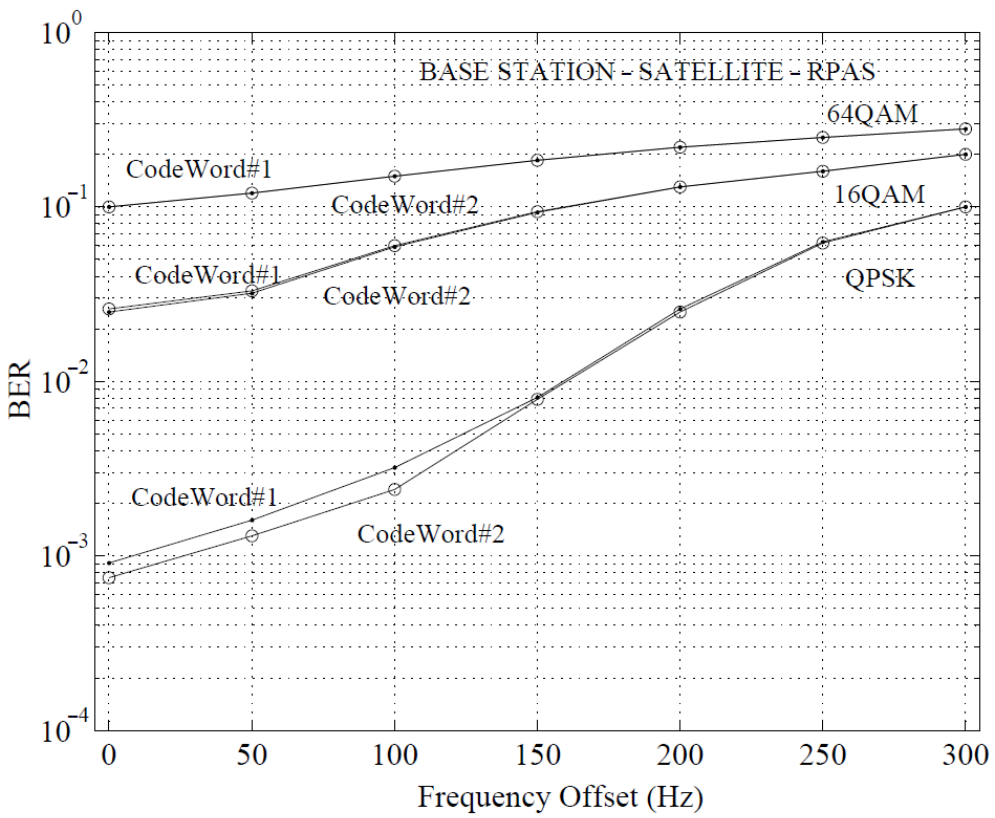

Fig. 13. Dependencies of the BER on the Satellite Frequency Offset for BRLOS EVA5Hz MIMO channel with different signal modulations (SNR in Uplink and Downlink is 5 dB).

IV. CONCLUSIONS

For the first time MIMO-OFDM models of RPAS satellite communication channels based on LTE Standard were created. Dependencies of the BER on the SNR for Extended Pedestrian A models (EPA) and Extended Vehicular A models (EVA) using 2-by-2 multiple antennas at both BS transmitter and RPAS receiver were obtained.

In the case of RLOS the EPA and EVA scenarios differ significantly. For the EPA model, the communication channel is open in the 3–15 dB range for the Frequency-flat static MIMO channel and EPA0Hz but closed for the EPA5Hz scenario. In the case of the EVA model, the channel is open for the EVA5Hz scenario with SNR values greater than 40 dB, but it is closed for the EVA70Hz scenario even with SNR values greater than 50 dB.

In the case of satellite communications (BRLOS), the results for the EPA0Hz, EPA5Hz and EVA5Hz scenarios turn out to be quite close, although the BER values in the latter case turn out to be higher. Due to the signal amplification by the satellite transponder, these scenarios operate in the range from −2 dB to +5 dB. The channel is closed for SNP values up to 50 dB for the EVA70 Hz scenario.

Dependencies of the BER for QPSK, 16QAM and 64QAM signal modulations on the SNR for different levels of Frequency Offset at satellite transponder were studied.

The results can be used for analysis and prediction the RPAS satellite channel operation.

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