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RIGA TECHNICAL UNIVERSITY
Transport and Aerospace Engineering
ISSN 2255-9876 (online)
ISSN 2255-968X (print)
2019, vol. 7, pp. 32–40
https://doi.org/10.2478/tae-2019-0004
https://content.sciendo.com

RPAS Satellite Communication Channel Based on IEEE 802.11b Standard

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***Abstract* – Original models of RPAS communication channels based on IEEE 802.11b Standard, including both Base Station transmission within the Radio Line of Sight, and through the satellite using Beyond Radio Line of Sight, were built. Dependencies of the Bit Error Rate on the Signal-Noise Ratio for different payload data rates were obtained. Transponder nonlinearity and Base Station antenna diameter impact were analysed.**

***Keywords* – Antenna diameter, nonlinearity, RPAS, satellite channel.**

I. INTRODUCTION

Remotely Piloted Air Systems (RPASs) can be connected to cellular networks as new types of user equipment. At the same time, they will be able to bring significant income to network operators that will serve such traffic. In addition, RPASs can be used as flying base stations that can dynamically move and improve coverage, spectral efficiency and user experience. Therefore, operators are already exploring the possibility of servicing commercial RPASs with cellular networks, starting to experience prototypes of flying base stations, and researchers are developing mathematical and algorithmic solutions to new problems arising from mobile nodes in cellular networks.

The third-generation partnership group (3GPP) in 2017 conducted a study to find out the traffic requirements for RPASs, develop RPAS communication channel model to get its characteristics, and find out the capabilities of the existing infrastructure to provide RPAS cellular services. The importance of providing support to low-level RPASs for establishing communication with RPASs outside of line of sight and establishing reliable communication was recognized [1], [2].

In recent years, review articles have been published on the practical aspects of RPAS cellular communications. Studies [3], [4] consider the formation of special networks between many drones in the sky. Communication requirements for various RPAS applications and the suitability of existing wireless technologies, including Bluetooth, ZigBee, Wi-Fi, WiMAX, were analysed in work [5]. In article [6], the possibilities of unmanned aerial vehicles in extending the capabilities of cellular networks by combining drones from different heights for the formation of a multi-level network of RPASs were considered. Problems and possibilities of using drones to help wireless networks were generally reviewed in study [7]. A comprehensive guide to the use of unmanned aerial vehicles is given in publication [8].

In 1999, IEEE expanded the 802.11 standard for wireless products that operate at 11 Mbps (like Ethernet), and called it IEEE 802.11b. The Wireless Ethernet Compatibility Alliance (WECA) guarantees compatibility of products from different manufacturers. The need for wireless access to local networks is growing with the increase in the number of mobile devices, such as laptops, personal digital assistants and electronic handheld information devices, as well as the growth of RPASs, wishing to be connected to the network.

The basic architecture features, and services of 802.11b are defined in the original 802.11 standard. The 802.11b specification only affects the physical layer, adding only higher access speeds. The main addition introduced by 802.11b to the main standard is the support of two new data transfer speeds – 5.5 and 11 Mbps. To achieve these speeds, the Direct Sequence Spread Spectrum (DSSS) method was chosen. This implies that 802.11b systems will be compatible with

DSSS 802.11 systems, but will not work with 802.11 Frequency Hopping Spread Spectrum (FHSS) systems.

The results of satellite communication channels simulation were published in articles [9]–[19] and summarized in a monograph [20].

II. PROBLEM STATEMENT

The purpose of this work is:

1. to build models of RPAS communication channels based on IEEE 802.11b Standard, including both 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 different payload data rates;
3. to obtain the dependencies of the BER on the SNR for different levels of satellite transponder nonlinearity;
4. to study the dependence of the BER on the BS antenna diameter.

III. "BASE STATION – RPAS" LINK MODEL

Proposed model (Fig. 1) is designed using MATLAB demo example and consists of the "Base Station Transmitter", "Channel" and "RPAS Receiver". In the *IEEE 802.11b WLAN Physical Layer* example a system with DSSS and data rates of 1 Mbps, 2 Mbps, 5.5 Mbps and 11 Mbps is implemented. When transmitting data, Multiplexed Protocol Data Unit (MPDU) are converted to PHY Protocol Data Units (PPDU). The conversion is performed by adding the Physical Layer Convergence Protocol (PLCP) preamble and PLCP header to the MPDU. Long and short formats are used PLCP PPDU. The PLCP preamble and the PLCP header are modulated using the Differential Binary Phase Shift Keying (DBPSK) modulation scheme. Depending on the data rate used, the MPDU is modulated using DBPSK or a combination of Differential Quadrature Phase Shift Keying (DQPSK), QPSK and Complementary Code Keying (CCK). CCK was adopted to supplement the Barker code in wireless digital networks to achieve data rate higher than 2 Mbps. Both in the transmitter and in the receiver, the root raised cosine pulse shaping filter is used. To simulate the transmission AWGN channel is used. It is possible to observe the constellation and the spectrum of the received signal, as well as to see the calculated BER values.

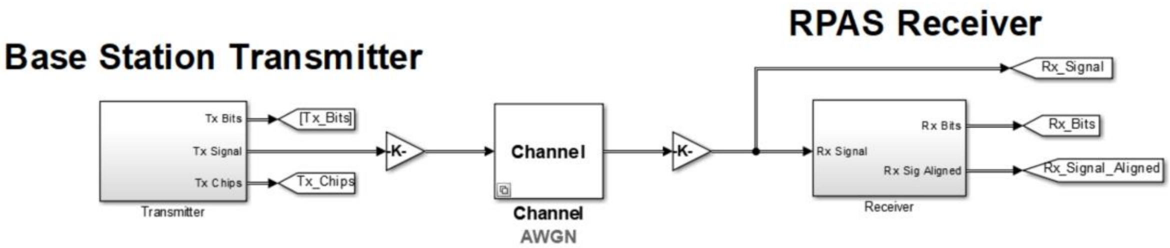

Fig. 1. "Base Station-RPAS" link.

The operation of IEEE 802.11b standard is based on the DSSS method using eight-bit Walsh sequences. In addition, each data bit is encoded using a sequence of additional codes. This allows a data transfer rate of 11 Mbps to be achieved. Like the basic standard, IEEE 802.11b operates at 2.4 GHz using no more than three non-overlapping channels. A distinctive feature of this standard is that, if necessary (for example, when signal quality deteriorates and is very remote from an access point, various interference occurs), the data transfer rate can be reduced up to 1 Mbps.

To support very noisy environments, as well as work over long distances, 802.11b networks use a dynamic speed offset, which allows automatically change the data transfer rate depending on the properties of the radio channel. A user can connect with a maximum speed of 11 Mbps, but if the level of interference rises, or the user moves away a long distance, the mobile device starts transmitting at a slower speed – 5.5, 2 or 1 Mbps. In the event that stable operation at a higher speed is possible, the mobile device will automatically begin to transmit at a higher speed.

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).

Figure 2 shows the obtained dependencies of the BER on the SNR for different data rates. It is clear that to increase the data transfer rate from 1 Mbps to 11 Mbps, the signal-to-noise ratio should be approximately doubled.

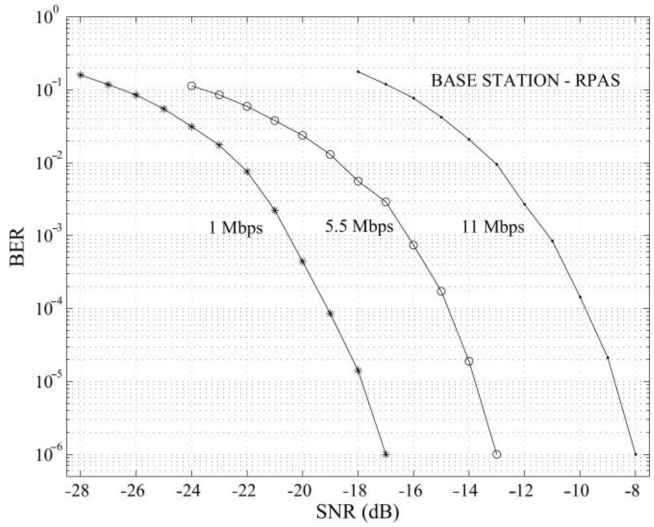

Fig. 2. Dependencies of the BER on the SNR for RLOS AWGN channel with different data rates (BS antenna diameter ≈ 0.4 m, RPAS antenna diameter ≈ 0.2 m).

The size of the BS and the RPAS antennas significantly affect the maximum communication range. For RPAS communication systems, the decisive factors are the weight and dimensions of the onboard transceiver and the antenna-feeder device. When using the ultra-high frequency range, it is possible to create a small antenna that can fit in the wing profile. The dense layout of the equipment inside the RPAS does not allow for efficient use of high-power transceivers with shortened ultrashort antennas due to problems with electromagnetic compatibility and the large influence of surrounding objects on the antenna characteristics. The medium and large class RPAS communication systems are subject to stringent requirements for operating range, noise immunity, and bit error probability.

Ground equipment does not have strict requirements for mass-dimensional characteristics, so the use of the BS antenna with sufficiently large diameter can significantly affect the quality of communication.

A simulation of the communication channel with BS antennas of different sizes was carried out. Dependencies of the BER on the signal-to-noise ratio for different diameters of BS antennas are shown in Fig. 3. In this model, the simplest case of the AWGN channel without fading is considered. From the data obtained it follows that reducing or increasing the diameter of the BS antenna significantly affects the operation of the communication channel.

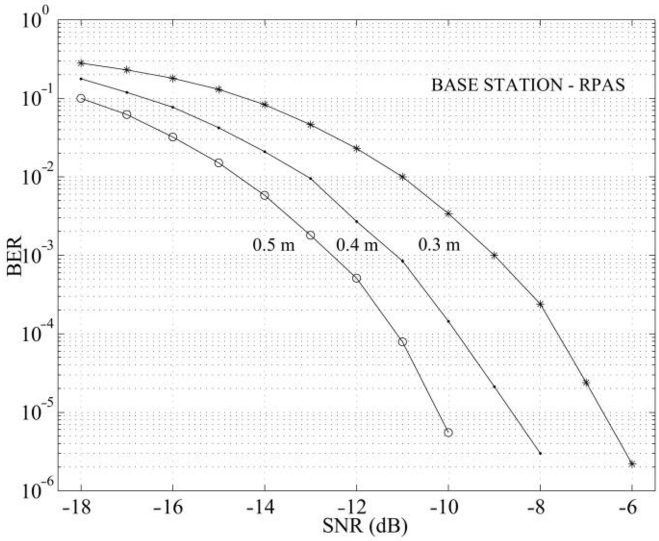

Fig. 3. Dependencies of the BER on diameters of BS antenna
(RLOS AWGN, RPAS antenna diameter ≈ 0.2 m, data rate 11 Mbps)

IV. "BASE STATION – SATELLITE – RPAS" LINK MODEL

The model "Base Station-Satellite-RPAS" was designed on the base of "Base Station-RPAS" model (Fig. 1) by adding the Satellite Transponder (Fig. 4). The Satellite Transponder includes an antenna amplifier, a low-frequency amplifier with noise temperature, a phase-frequency shift unit and an antenna amplifier that transmits data to the RPAS. Phase and frequency shifts were chosen to be zero.

In the amplifier block, there is a linear mode and modes for modelling nonlinearity (Cubic Polynomial, Hyperbolic Tangent, Saleh, Ghorbani and Rapp models [14]). For simplicity, it was considered that the data from the base station to the satellite is transmitted without loss, and the downlink is taken as the AWGN channel.

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

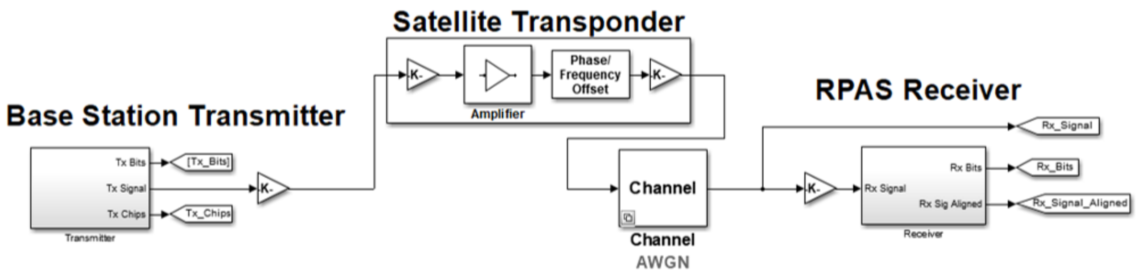

Fig. 4. "Base Station-Satellite-RPAS" link.

As a rule, the maximum distance for direct radio communication between the RPAS and the BS is about 100 km. For command-telemetric communications over long distances, the use of satellite communications is necessary. In this case, the data stream contains the necessary information about the status of the RPAS and the payload. The factors limiting the range of a radio communication system are the strong dependence of the propagation conditions on weather conditions and the influence of multipath.

Obtained dependencies of the BER on the SNR for different data rates are given in Fig. 5. Compared with the case of the RLOS communication of the BS with the RPAS (Fig. 2), the channel can work at three times smaller values of the SNR ratio. This is due to the additional amplification of the satellite transponder, which significantly increases the communication range. In this case, to increase the data transfer rate from 1 Mbps to 11 Mbps it is necessary to increase the SNR parameter by a smaller amount compared with the case of a direct link.

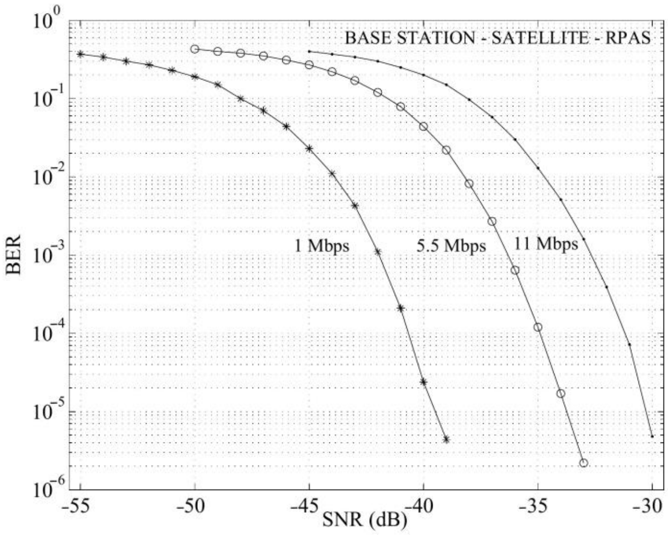

Fig. 5. Dependencies of the BER on different data rates: BRLOS AWGN downlink, noise temperature 290 K; BS antenna diameter ≈0.4 m, satellite antennas diameter ≈0.4 m, RPAS antenna diameter ≈0.2 m, linear transponder gain.

Dependencies of the BER on diameters of BS antennas are shown in Fig. 6. As can be seen from the figure, in contrast to the case of a direct link, here an increase in the diameter of the antenna leads to a relatively smaller decrease in the SNR ratio.

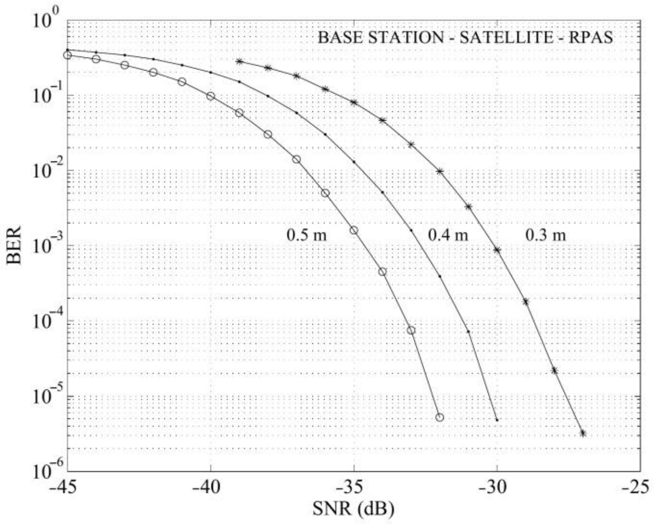

Fig. 6. Dependencies of the BER on diameters of BS antennas: BRLOS AWGN downlink, noise temperature 290 K; satellite antennas diameters ≈0.4 m, RPAS antenna diameter ≈0.2 m, linear transponder gain, data rate 11 Mbps.

Dependencies of the BER on the SNR for different levels of satellite transponder nonlinearity are shown in Fig. 7.

For *Cubic Polynomial* model, the Amplifier block models the AM/AM nonlinearity by using the third-order input intercept point IIP3 = 30 dBm parameter to compute the factor f, which scales the input signal before the Amplifier block applies the nonlinearity, computing the scaled input signal by multiplying the amplifier input signal by *f*, limiting the scaled input signal to a maximum value of 1, applying an AM/AM conversion to the amplifier gain, according to the cubic polynomial equation. The Amplifier block uses the AM/PM conversion (10 degrees per dB) parameter, which specifies the linear phase change, to add the AM/PM nonlinearity within the power limits specified by the Lower input power limit for AM/PM conversion (10 dBm) parameter and the Upper input power limit for AM/PM conversion (infinite dBm) parameter. Outside those limits, the phase change is constant at the values corresponding to the lower and upper input power limits. The Linear gain (10 dB) parameter scales the output signal.

In *Hyperbolic Tangent* model, data are processed as in Cubic Polynomial Model with the exception of applying an AM/AM conversion to the amplifier gain.

For *Saleh* model, with a moderate nonlinearity the Input scaling (1.4 dB) parameter scales the input signal before the nonlinearity is applied. The block multiplies the input signal by the parameter value, converted from decibels to linear units. The AM/AM parameters [alpha = 2.1587 beta = 1.1517] are used to compute the amplitude gain for an input signal. The AM/PM parameters [alpha = 4.0033 beta = 9.1040] are used to compute the phase change for an input signal. The Output scaling (9.9 dB) parameter scales the output signal.

For *Ghorbani* model, the Input scaling (−1.5957 dB) parameter scales the input signal before the nonlinearity is applied. The block multiplies the input signal by the parameter value, converted from decibels to linear units. The AM/AM parameters [x_1 = 8.1081 x_2 = 1.5413 x_3 = 6.5202 x_4 = −0.0718] are used to compute the amplitude gain for an input signal. The AM/PM parameters [y_1 = 4.6645 y_2 = 2.0965 y_3 = 10.88 y_4 = −0.003] are used to compute the phase change for an input signal. The Output scaling (32.9118 dB) parameter scales the output signal.

For *Rapp* model the amplitude gain for an input signal is computed using special function.

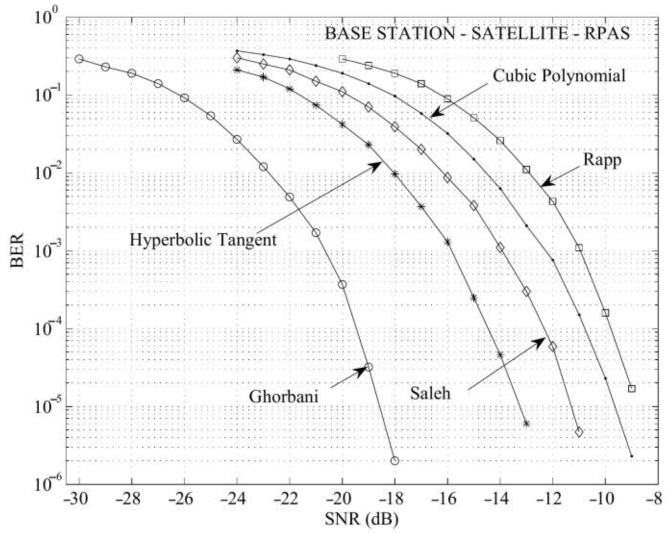

Fig. 7. Dependencies of the BER on the SNR for different levels of satellite transponder nonlinearity: BRLOS AWGN downlink, noise temperature 290 K; BS antenna diameter ≈ 0.4 m, satellite antennas diameters ≈ 0.4 m, RPAS antenna diameter ≈ 0.2 m, data rate 11 Mbps.

Linearity is determined by the degree to which the ratio between the input and output signal amplitudes is the same for high amplitude input and low amplitude input. Nonlinear distortion describes the phenomenon of a non-linear relationship between input and output signals. Nonlinearity leads to undesirable consequences in the transmission of data, the main of which is an increase in the number of bit errors. Nonlinear distortions are caused by the nonlinearity of the signal processing and transmission system. These distortions cause the appearance of components in the frequency spectrum of the output signal, which are absent in the input signal. From comparison Fig. 5 and Fig. 7 follows that in the presence of any of the considered nonlinearities the channel operation requires a significant increase in the SNR ratio. In addition, different types of nonlinearities differ significantly in the degree of influence on data transfer.

V. Conclusions

For the construction of aviation satellite data transmission systems, numerical information is required on the characteristics of the RPAS channels. The development of theoretical foundations is necessary to predict the behaviour of such systems. This article carried out the first calculation of the characteristics of the RPAS communication channel based on the IEEE 802.11b standard with direct and satellite links.

The BER dependencies on the signal-to-noise ratio for different BS antenna diameters for direct and satellite channels, as well as the effect of transponder amplifier non-linearity, are analysed.

The results can be used to design the RPAS channel and to minimize errors, reduce time and cost. The presented data can be viewed as a way to estimate the parameters of such channels using the MATLAB Simulink package.

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