Nonlinearities Impact on Satellite RP AS Communication in Clusters

S. Ilnytska

Received: 12 December 2017 Accepted: 4 January 2018 Published: 15 January 2018

Abstract

For modeling of data transmission from Remotely Piloted Air System (RPAS) clusters (or swarms), the original models of communication channels with Radio Line of Sight (RLOS) and Beyond Radio Line of Sight (BRLOS) were built using MATLAB Simulink. Models comprise of ?"Base Station Transmitter?"; RLOS channel: ?"Uplink Path?", ?"RPAS Receiver?"; BRLOS channel: ?"Uplink Path?", ?"Satellite Transponder?", ?"Downlink Path?"; ?"RPAS Receiver?". Dependences of the Bit Error Rate (BER) on the Signal-to-Noise Ratio (SNR) for different levels of the Base Station (BS) transmitter nonlinearity, its gain, the BS antenna and Satellite Transponder antennas diameters were received.

Index terms— RPAS clusters, swarms, satellite links, data transmission; transmitternonlinearity.

1 I. PROBLEM STATEMENT

he importance of Remotely Piloted Air Systems (RPASs) or Unmanned Aerial Vehicles (UAVs) networks is continuously growing, as they are new technologies for civilian and military purposes. Common use of RPASs is carried out by state bodies, police, transport management systems, medical personnel and used to warn about natural disasters and to promote the acceleration of rescue operations in absence of public communication networks. Military use of RPAS consists of border surveillance, reconnaissance, and strikes [1].

The Federal Aviation Administration guidelines allow the use of RPAS up to 4.4 pounds within the operator's visibility during the day at heights of up to 400 feet above ground in Class G airspace and beyond 5 miles from any airport [2].

RPAS technologies are improving and expanding the amount of memory, onboard data processing capabilities, information storage and communication. For widespread use in commercial, military, civil, agricultural and environmental purposes, RPASs should be able effectively to communicate with each other and with existing network infrastructures **??**3].

The registered number of RPASs in use in the U.S. exceed 200 thousand just in the first 20 days of January 2016 **??**4]. However, the deployment of a considerable number of RPASs leads to substantial problems. It is necessary to ensure collision-free and seamless operation of RPASs in the conventional airspace to maintain standard levels of safety.

In the review[5] RPAS's classification, possible cluster architectures, RPAS-based services, obstacle detection techniques, RPAS's networks, RPAS equipment, data collection methods, communication technologies, processing of collected data, use of clouds for computational unloading of an RPAS resource are considered.

The cluster has several RPASs working synchronously to solve a single task **??**6]. Swarm Coordination refers to communication with individual RPAS, regardless of the ground control station and information exchange between RPASs. Cluster members report their position and other useful information at predetermined intervals. To ensure such coordination, members of the RPASs swarm should communicate with each other [6]. In the case of a dedicated communication infrastructure, the hive itself establishes and maintains a specific communication network. Communication in the Flying Ad-hoc Network (FANET) includes UAV-UAV (U2U) and UAV-Infrastructure (U2I) communications [1]. Thus, the mobility of nodes is higher than the Mobile Ad-hoc network (MANET) and the Vehicular Ad-hoc network (VANET) **??**6]. The topology often changes (it requires a peer-to-peer network). The communication range should be bigger than in other systems [7].

Collaborative mission planning for UAV cluster to optimize relay distance is considered in a paper [8]. The concept of RPAS Required Communication Performance Methodology for the Command, Control, and Communication Link is given in [9].

Requirements for RPAS data rate indicated in the NATO standards [10][11][12].

In connection with the need to evaluate the parameters of aeronautical satellite communication channels, methods have been developed by us that makes it possible to predict the behavior of the communication channel with sufficient accuracy under different conditions. transponder high power amplifier back off level, and phase noise were received and analyzed.

Automatic Dependent Surveillance-Broadcast (ADS-B) message traveling time and average downlink utilization for different Iridium link architectures were estimated in the paper [15]. The delay is about 1.4-1.5 seconds, which agrees well with the experimental data recently obtained in the USA and Canada. Dependences of message travelling time on the different number of satellites (N = 1-10) for several aircraft (n = 1-3) were obtained on the base of original models.

A modeling of "Satellite-to-Aircraft" link for selfseparation was provided in an article [16].

A simulation of satellite communication links operation with orthogonal frequency-division multiplexing was done in papers [17][18][19].

An impact of transmitter nonlinearity on satellite channel parameters was studied in articles [19][20][21].

Nevertheless, now in the literature, there are no studies devoted to the calculation of satellite communication channels characteristics in RPAS clusters, taking into account the nonlinearities of the transmitter.

2 II. AIM OF THE WORK

Transmitter nonlinearities are critical for wireless communications systems and have a significant impact on the transmission of RPAS's data.

The purpose of this work is: 1) to build models of RPAS clusters, including both transmission within the Radio Line of Sight (RLOS), and through the satellite using Beyond Radio Line of Sight (BRLOS); 2) to investigate and compare the features of data transmission on both channels; 3) to obtain the dependences of the BER on the SNR for different levels of transmitter nonlinearity of the Base Station (BS), on the BS transmitter gain, on the BS antenna diameter for different levels of the BS transmitter nonlinearity, on the diameter of the satellite transponder antennas.

3 III. Models for Rpas Communication Channels in Clusters

Clusters of RPASs can have a wide variety of architecture and organization, depending on the tasks assigned to perform. The main difference is the nature of communication with the BS -RLOS or BRLOS. Figure 1 shows, as an example, a cluster of five RPASs with RLOS and five RPASs with BRLOS communicating with the BS via a satellite. In this paper, we present only results obtained for QPSK1/2 modulation on the model shown in Fig. **??**. This model contains one RPAS with RLOS and one with BRLOS. As our calculations have shown, the addition of any number of RPASs to the base station directly or to the satellite results in the same BER values that are typical for specifictype of communication.

A model (Fig. **??**) comprises of "Base Station Transmitter" (Bernoulli Random Binary Generator, Convolutional Encoder, QPSK Baseband Modulator, High Power Amplifier with a memoryless nonlinearity, Transmitter Dish Antenna Gain); RLOS channel: "Uplink Path" (AWGN), "RPAS Receiver" (Receiver Dish Antenna Gain, RPAS Receiver System Temperature, Viterbi Decoder), "Error Rate Calculation" block and "Display"; BLOS channel: "Uplink Path" (AWGN), "Satellite Transponder" (Receiver Dish Antenna Gain, Satellite Receiver System Temperature, Complex Baseband Amplifier, Phase Noise, Transmitter Dish Antenna Gain), "Downlink Path" (AWGN); "RPAS Receiver".

4 Fig. 2: Communication Links in RPAS Cluster

In the "Base Station Transmitter", the Bernoulli Binary Generator block generates random binary numbers using a Bernoulli distribution with parameter p, produces "zero" with probability p and "one" with probability 1-p (here the value p=0,5).

A model employs forward error correction coding in the form of convolutional encoding with Viterbi decoding [22]. A model uses a rate 3/4, constraint length 7, (r=3/4; K=7) convolutional code on both transmission and reception. The Convolutional Encoder block is using the poly2trellis (7, [171 133], 171) function with a constraint length of 7, code generator polynomials of 171 and 133 (in octal numbers), and a feedback connection of 171 (in octal). The puncture vector is [1; 1; 0; 1; 1; 0]. The QPSK1/2 Baseband Modulator block modulates a signal using the binary phase shift keying method.

The High Power Amplifier block applies memoryless nonlinearity to a complex baseband signal and provides five different methods for modeling the nonlinearity. In this paper results for Saleh model with standard AM/AM and AM/PM parameters [23] and linear amplifier gain are given. An HPA backoff level determines how close the satellite high power amplifier is to the saturation. When the backoff is 30 dB the average input power is 30 decibels below the input power that causes amplifier saturation and, in this case, AM/AM and AM/PM conversion is negligible. For the backoff ?7 dB -moderate nonlinearity exists and for the backoff ?1 dB -severe nonlinearity takes place.

The Transmitter (Receiver) Dish Antenna Gain block multiplies the input by a constant value (gain).The relationship between the antenna gain and the antenna diameter and the wavelength is the following:G=?(?D/?) 2 ,

Where ? is the antenna efficiency. For calculations (here ? = 1), the following parameters in antenna diameter ? 0.12 m at 1 GHz), Base Station

In the "Uplink (Downlink) Path" the AWGN block add white Gaussian noise to the input signal.

5 IV. RPAS COMMUNICATION CHANNELS SIMULATION

From dependences of the BER on the SNR for different levels of BS transmitter nonlinearity (Fig. **??**) it follows that, a transmission with increasing nonlinearity requires an increase in the SNR. The transmission of data through the satellite and directly has significant differences (dotted and solid curves). Interestingly, with negligible nonlinearity (crosses) of the BS transmitter amplifier, transmission through the satellite gives fewer errors than for direct transmission. However, with moderate and severe non-linearity, everything happens We draw attention to the fact that here we are talking about the transmission, in which the SNR is the same for RLOS and BRLOS. Upon obtaining the dependencies, we consciously changed the SNR in all channels shown in Fig. **??**in the same way. BRLOS signal path is, of course, longer and in a real situation, the SNR for BRLOS will be lower in comparison with RLOS.

As follows from dependencies of the BER on the linear gain of BS amplifier (Fig. **??**) the BER is lower when transmitting data through the satellite with the selected values of SNR = -20 dB and nonlinearity absence (since the BS amplifier has the linear gain).It is so due to the additional amplification of the signal by antennas of the satellite transponder and its power amplifier. It would be so if the SNR in RLOS and BRLOS were equal. Fig. **??** shows dependencies of the BER on BS antenna diameter for different levels of BS transmitter amplifier nonlinearity. All curves use the same value SNR = -30 dB. RLOS and BRLOS channels for a negligible nonlinearity (points)can operate when BS For a severe nonlinearity, we need bigger values of the SNR, and Fig. **??** shows how the BER changes in dependence on BS antenna diameter for different levels of nonlinearity. For negligible and moderate nonlinearities the channel can operate at SNR = -30 dB, but for a severe nonlinearity we need a much bigger value of the SNR. In this case, the following BS antenna diameters are required for the channel operation: at SNR = -18 dB (circles) a diameter ?0.38 m is required for RLOS and ? 0. F decrease in the SNR to -20 dB (squares) requires a significant increase in BS antenna diameter. That is, for a severe nonlinearity the "sensitivity" of the BER to the value of the antenna diameter is much higher than for negligible and moderate nonlinearities. antenna diameter is ? 0.28 m (with satellite transponder antennas ? 0.28 m and the RPAS antenna diameter ?0.12 m). However, the BER is higher with moderate nonlinearity (crosses), and the BS antenna diameter is required ? 0.5 m for an operation of channels.

Dependencies of the BER on satellite transponder antennas diameters for different levels of BS station amplifier nonlinearity (Fig. 7) show less influence of nonlinearity. In contrast to the curves in Fig. **??**, 6 dependencies for all levels of nonlinearity change ("fall") more slowly with an increase in satellite antennas diameters(with constant diameters of BS and RPAS antennas). Therefore, the effect of transponder antennas diameters is not very noticeable, and the data for all levels of nonlinearity are close.

V.

6 CONCLUSION

This work is the first calculation of RPAS data links characteristics in clusters with satellite (BRLOS) and direct (RLOS) connections. It is a way for estimating the parameters of such channels using the MATLAB Simulink package.

The task of the RPAS is to collect data using embedded devices and programs and to transmit them over communication channels. The centralized communication includes a topology with the BS as the central node to which all RPASs of clusters with RLOS and BRLOS are connected. In this architecture, RPAS sare not directly connected, and the connection between the two RPASs is realized via the BS.

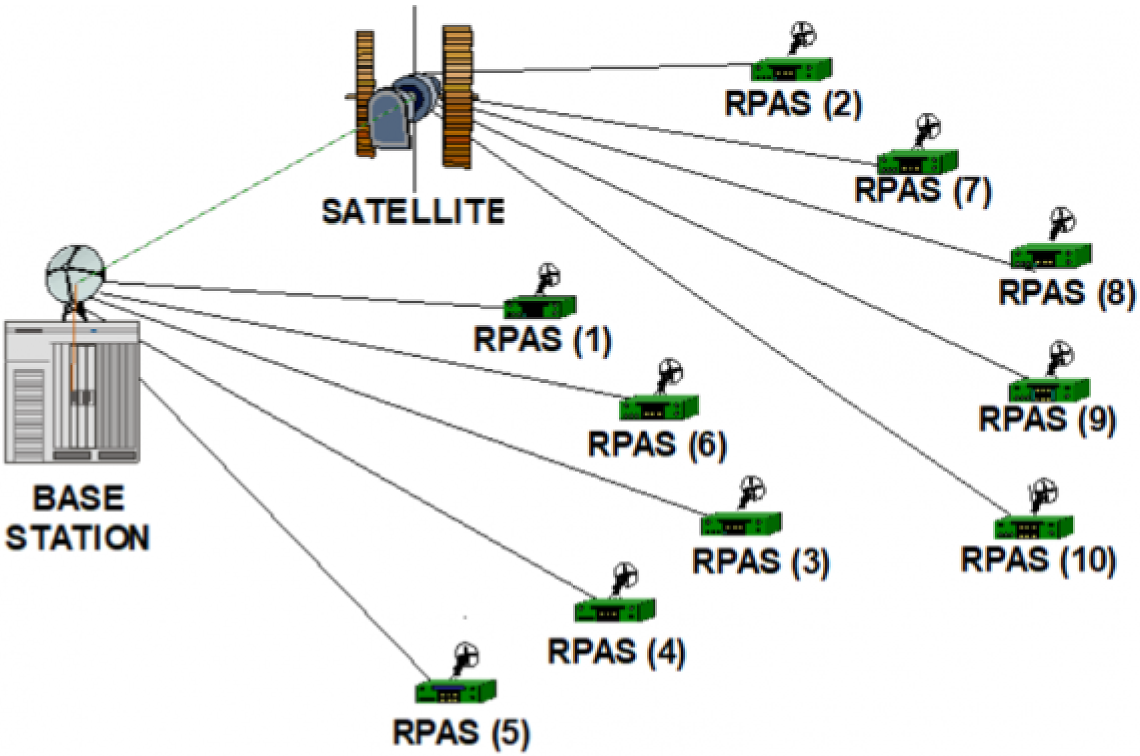
The direct connection between the RPAS and the BS is the simplest one. In this study, we also consider the architecture with satellite exchange, which exists at different levels of RPASs interaction. The development of a fully autonomous and cooperative RPAS cluster system requires reliable communication. At present, there is insufficient research in this area.

The development of theoretical bases for the construction of aeronautical satellite data transmission systems and obtaining of numerical information about RPAS digital channel characteristics in clusters is necessary for predicting the behavior of such systems. To achieve this goal, it is necessary to solve the following main tasks: 1. To create RPAS cluster models for the digital data transmission via satellite. 2. To develop a method for RPAS channel parameters estimation based on the MATLAB Simulink software package. 3. To investigate RPAS transmission system in dependence of a SNR, transmitter nonlinearity levels, the type of signal modulation, RPAS and satellite antenna diameters, the nonlinearity of the amplifier and the noise temperature of the satellite transponder.

Nonlinear distortions are the reason for a degradation. The primary source of nonlinear distortions is the transmitter power amplifier. Nonlinear power amplifiers for wireless communications were modeled [24], and nonlinear power amplifier effects in multiantenna OFDM systems were analyzed [25].The influence of aircraft transmitter nonlinearity for different types of fading in the channel (Rayleigh and Rician) was studied, and the possibility of correcting nonlinearity by using pre-distortion was revealed in a paper [26].

The significance of the obtained results consists in the fact that calculations and modeling of the dependencies presented above can not only reveal problems in the early stages of RPAS channels designing, but also minimize errors, reduce time and cost, and provide scalability for future needs. As a result, such calculations quickly become a necessary tool for the researcher and developer of RPAS communication systems in clusters. Channel nonlinearity is critical for wireless communications systems. Therefore here models of RPAS clusters were constructed for the first time, including both RLOS and BRLOS (Fig. **??**). The obtained data (Fig. 3-7) allow comparing quantitatively data transmission on both channels. The dependencies of the BER on the SNR (Fig. **??**) for different nonlinearity levels of BS transmitter show that data transfer with increasing nonlinearity requires an increase in the SNR on average by ?10 dB in the transition from negligible to moderate nonlinearity and from moderate to severe nonlinearity. The BER dependencies on BS transmitter gain (Fig. **??**), on BS antenna diameter for different nonlinearity levels of the BS transmitter (Fig. **??**, 6) and on the satellite transponder antennas diameters (Fig. 7) allow analyzing and predicting the behavior of communication channels for various conditions of data transmission.

7 Global



1

Figure 1: Fig. 1 :

[1]

[1]Nonlinearities Impact on Satellite Rpas Communication in Clusters© 2018 Global Journals

46

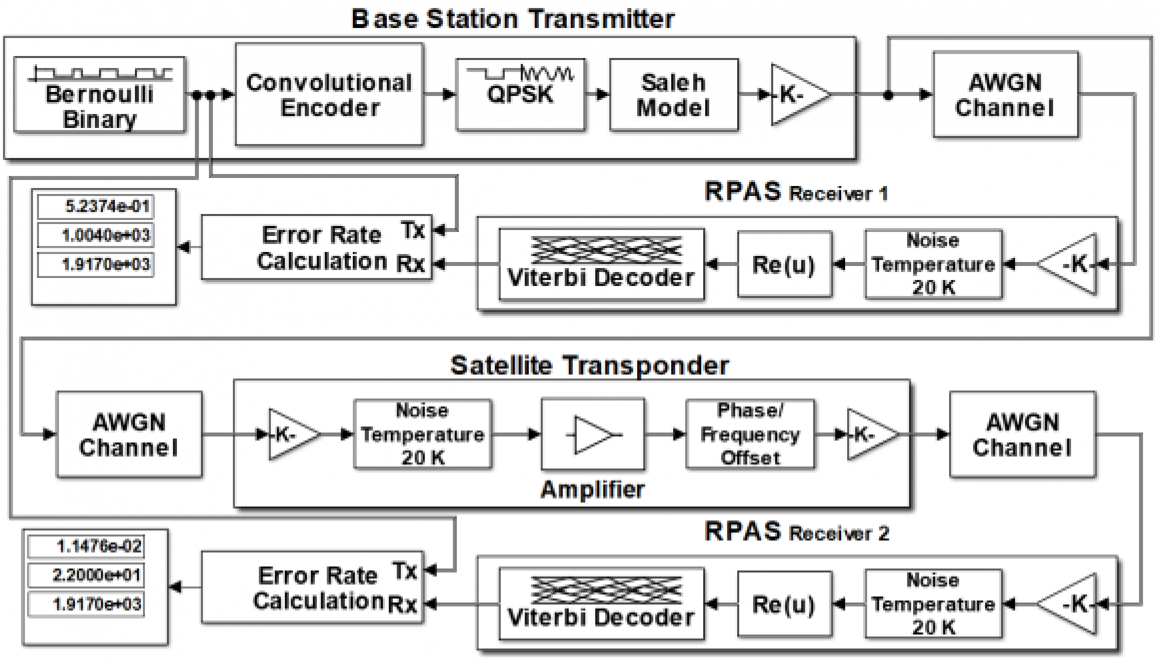


Figure 2: FFig. 4 :FFig. 6 :

7

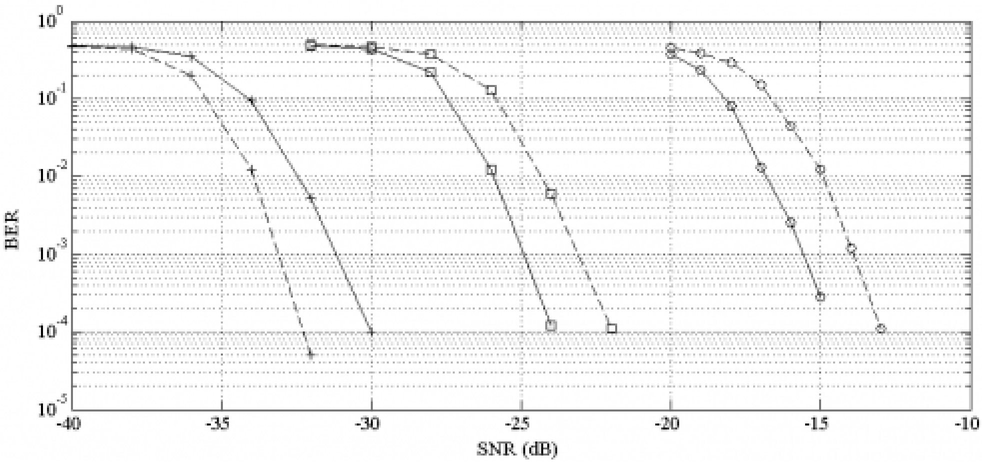


Figure 3: Fig. 7 :

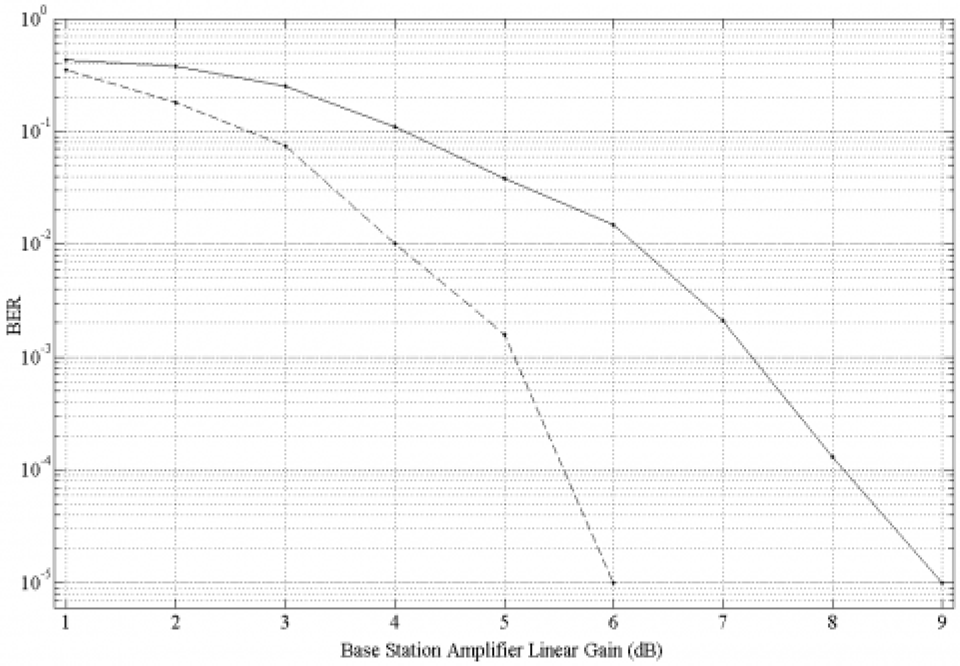


Figure 4:

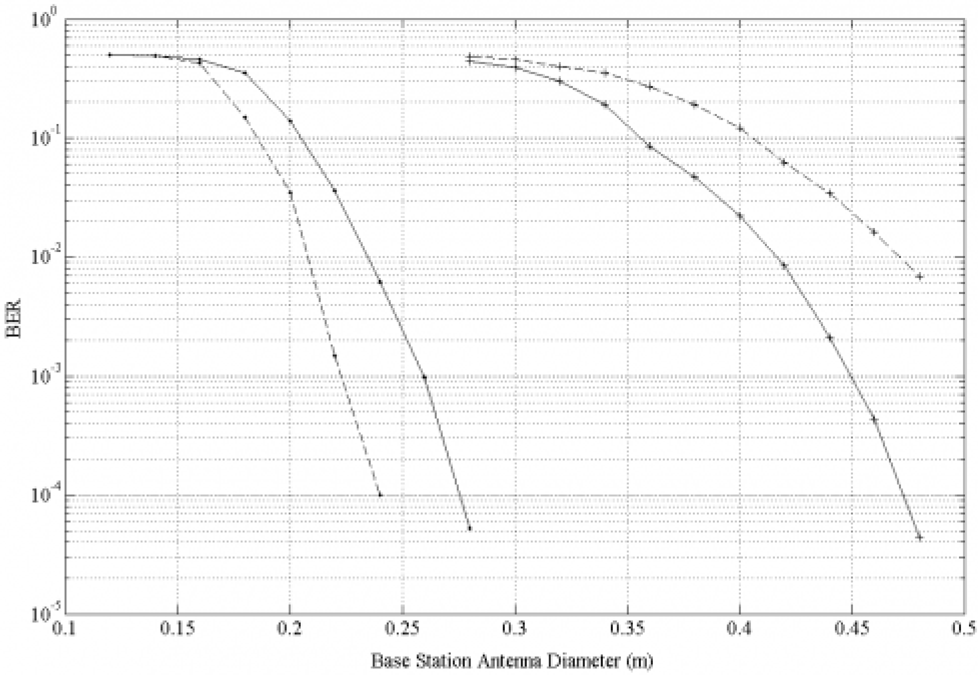


Figure 5:

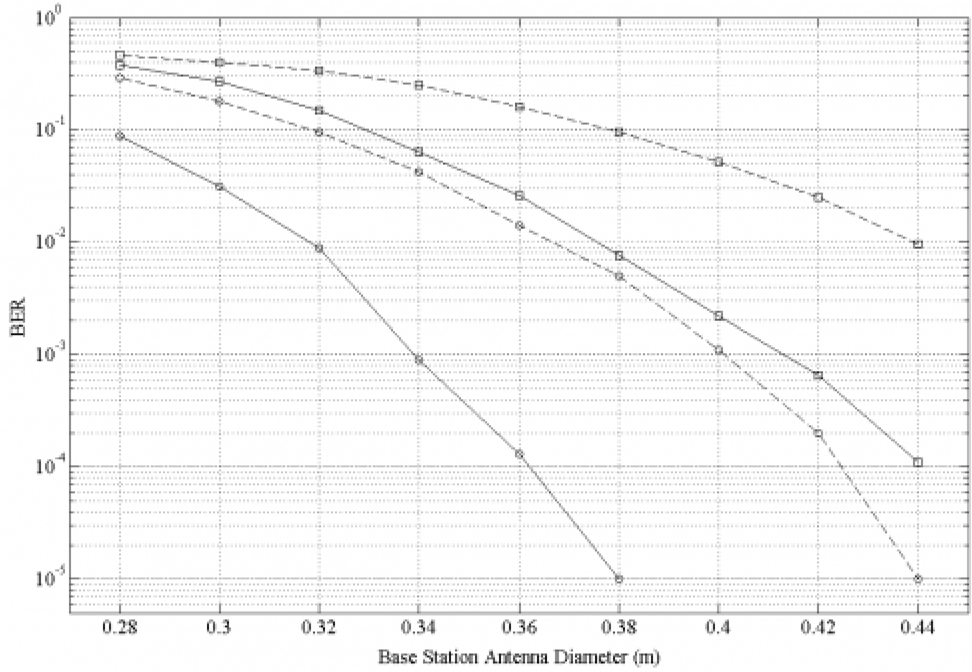


Figure 6:

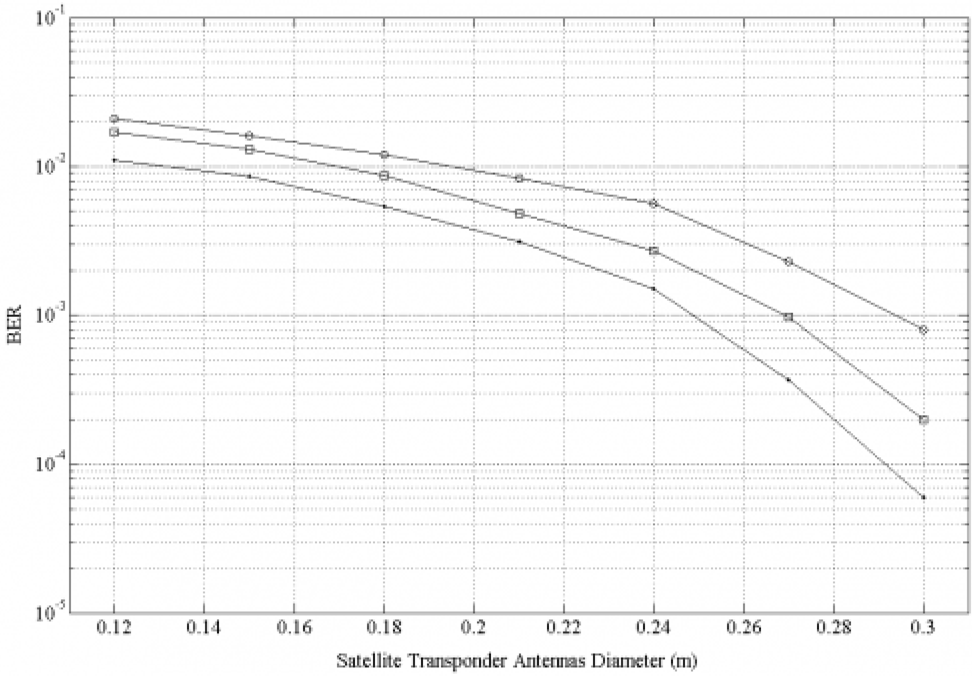


Figure 7:

[Kharchenko et al. ()] ‘ADS-B Satellite Communication Channel Based on IEEE 802.16 Standard’. V Kharchenko , A Grekhov , V Kondratiuk , K Nagorna . *Transport and Aerospace Engineering* 2017. 5 p. .

[Gregorio ()] *Analysis and Compensation of Nonlinear Power Amplifier Effects in Multi-Antenna OFDM Systems. Dissertation for the degree of Doctor of Science in Technology*, F Gregorio . 2007. (133 p.)

[Tanil et al. (2013)] *Collaborative Mission Planning for UAV Cluster to Optimize Relay Distance*, Ç Tanil , C Warty , E Obiedat . March 2013. IEEE Aerospace Conference. p. .

[Viterbi ()] ‘Convolutional Codes and Their Performance in Communications Systems’. I Viterbi . *IEEE Trans. Commun. Technol* 1971. (5) p. . (COM-19)

[Kharchenko et al. ()] ‘Effects of Rician Fading on the Operation of Aeronautical Satellite OFDM Channel’. V Kharchenko , A Grekhov , I Ali , Y Udod . *Proceedings of the National Aviation University*, (the National Aviation University) 2016. 67 p. .

[Szabolcsi ()] ‘Establishment of the Unmanned Aerial Vehicle System Cluster: Mission, Motivation, Vision’. R Szabolcsi . *Goals. Review of the Air Force Academy* 2015. 28 (1) p. .

[EUROCAE WG73 UAS -Concept of RPAS Required Communication Performance Methodology for the Command, Control and *EUROCAE WG73 UAS -Concept of RPAS Required Communication Performance Methodology for the Command, Control and Communication Link*, https://www.uavdach.org/News/WG73_CClink_RRCPDraftforWG73CommentV0%2010.pdf

[Saleh ()] ‘Frequency-Independent and Frequency-Dependent Nonlinear Models of TWT Amplifiers’. Saleh . *IEEE Trans. Communications* 1981. 29 (11) p. .

[Kharchenko et al. ()] *Influence of Nonlinearity on Aviation Satellite Communication Channel Parameters*, V Kharchenko , A Grekhov , I Ali . 2016. 65 p. . Pro?eedings of the National Aviation University

[Grekhov et al. ()] ‘Influence of Transmitter Nonlinearities on Data Transmission from Remotely Piloted Air System’. A Grekhov , V Kondratiuk , A Ermakov , E Chernyuk . *Proceedings of the National Aviation University*, (the National Aviation University) 2017. 72 p. .

[Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap ()] *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap*, http://www.faa.gov/uas/media/uas_roadmap_2013.pdf 2013. US Department of Transportation Federal Aviation Authority (First Edition)

[Kharchenko et al. ()] ‘Investigation of ADS-B Messages Traffic via Satellite Communication Channel’. V Kharchenko , W Bo , A Grekhov , M Kovalenko . *Proceedings of the National Aviation University*, (the National Aviation University) 2014. 61 p. .

[Kharchenko et al. ()] *Investigation of Modulation Scheme and Transmitter Nonlinearity Impact on ADS-B Messages Transmission via OFDM Satellite Link*, V Kharchenko , W Bo , A Grekhov , D Bezsmertna . 2014. 61 p. . Pro?eedings of the National Aviation University

[Jantunen ()] *Modeling of Nonlinear Power Amplifiers for Wireless Communications. The thesis for the degree of Master of Science*, P Jantunen . <http://www.researchgate.net/publication/224263342_Nonlinear_RF_power_amplifier_behavioural_analysis_of_wireless_OFDM_systems> 2004.

[Kharchenko et al. ()] ‘Modelling of ’Satellite-to-Aircraft’ Link for Self-separation’. V Kharchenko , Barabanov , Grekhov . *Transport* 2013. 28 (4) p. .

[Kharchenko et al. ()] *Modelling of ADS-B Data Transmission via Satellite. Aviation*, V Kharchenko , Y Barabanov , A Grekhov . 2013. 17 p. .

[Kharchenko et al. ()] *Modelling of Aviation Telecommunications*, Y Kharchenko , A Barabanov , Grekhov . 2012. 16 p. . Proceedings of the National Aviation University

[Kharchenko et al.] *Modelling the Satellite Communication Links with Orthogonal Frequency-Division Multiplexing*, V Kharchenko , W Bo , A Grekhov , A Leschenko .

[NATO Digital Motion Imagery Format] STANAG 4609/AEDP-8. http://www.gwg.nga.mil/misb/docs/nato_docs/STANAG_4609_Ed3.pdf *NATO Digital Motion Imagery Format*,

[NATO Ground Moving Target Indicator Format] *NATO Ground Moving Target Indicator Format*, STANAG 4607/AEDP-7. http://standards.globalspec.com/std/1300603/nato-stanag-4607

[STANAG 7023/AEDP-9 NATO Primary Image Format] https://booksmovie.org/similar-pdf-stanag-7023-nato.html *STANAG 7023/AEDP-9 NATO Primary Image Format*,

[Gupta et al. ()] ‘Survey of Important Issues in UAV Communication Networks’. L Gupta , R Jain , G Vaszkun . *IEEE Communications Surveys and Tutorials*, 2015. p. . (Published in)

[Vikranth ()] ‘UAV Swarm Co-Ordination and Control Using Grossberg Neural Network.International Perspectives’. D Vikranth . *Journal of Computer Science Trends and Technology (IJCST)* 2016. 2017. 3 (6) p. . (IEEE Internetof Things Journal)