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Andrii Grekhov[1]
Vasyl Kondratiuk[2]
Svitlana Ilnytska[3]

RPAS DATA TRANSMISSION VIA GROUND NETWORK

[1,2]National Aviation University, 1, Lubomyr Husar ave., Kyiv, 03058, Ukraine
[3]Wenzhou University, Wenzhou, Zhejiang, 325000, China
E-mails: grekhovam@gmail.com, kon_vm@ukr.net, ilnytskasv84@gmail.com

Abstract

First built RPAS communication channel models including ground network was created, the dependencies of channel's average utilization on the transaction size with various statistical distribution laws for the time between transactions were analyzed. Communication links with different bandwidths were investigated, the influence of the bit error rate and the packet fail chance on the communication channel utilization were studied. The results indicate that the most preferable for data transmission is LogNormal distribution law. Data transmission over a line-of-sight RPAS communication channel and over terrestrial network (beyond-line-of-sight) was compared for the first time.

Keywords: Remotely Piloted Air System (RPAS), Unmanned Aerial Vehicle (UAV), communication channel, line-of-sight (LOS), beyond-line-of-sight (BLOS), ground network, data traffic, Transaction Size, Time Between Transactions, Bit Error Rate, Packet Fail Chance

1. Introduction

Remotely Piloted Air Systems (RPASs) or Unmanned Aerial Vehicles (UAVs) use computers, telecommunication technologies, sensors, and artificial intelligence. This allows applying these systems for a variety of civil and military purposes, which are considered reviews [1-13].

The main problems of dynamic, intermittent links and fluid topology in UAV networks, significantly different from Mobile Ad Hoc Networks (MANETs), and Vehicular Ad Hoc Networks (VANETs), are considered in the survey [1]. Characteristics and requirements for UAV networks, swarms, Quality of Service (QoS), aerial networks, communications and cooperative UAVs are presented in the survey [2]. A comprehensive study and future prospects in the field of Internet of Things services for UAVs are given in the survey [3]. A survey of cooperative frameworks and network models for flying ad hoc networks is given in [4]. Existing problems in UAV channel modeling, UAV channel characteristics, spatial and temporal changes in non-stationary channels are presented in article [5]. Air-to-ground UAV channel models are reviewed in the survey [6], which presents channel measurement campaigns, large- and small-scale fading channel models and their limitations. Overview of airborne communication networks is given in paper [7]. In paper [8] a survey on UAV 5G wireless networks is presented. Background and the space-air-ground integrated networks were considered and a review of various 5G techniques based on UAV platforms was provided, including physical layer, network layer, joint communication, computing and caching.

An overview of aerial user equipment, channels and their models are given in a tutorial [9]. The basics for channel modeling and recommendations on the use of various channel models are given. The optimization of network parameters has been shown in [9] based on a theoretical analysis. Three-dimensional UAVs' deployment, analysis of their performance, communication channels modeling, and the effectiveness of their use are considered in a tutorial [10]. Recommendations are given regarding analysis, optimization, and design of wireless communication systems based on UAVs.

The current state and achievements in the field of UAV wireless communications are described in reference [11]. Research and development related to the Flying Ad-Hoc Network (FANET) has doubled in recent years. FANET hybrid wireless communication scheme that uses the capabilities of high-speed 802.11 data transmission and low power consumption of 802.15.1 was proposed in article [12]. The proposed scheme reduces the cost of communication and improves network performance in terms of bandwidth and latency.

The work [13] is devoted to the review of UAV air-to-ground (A2G), ground-to-ground (G2G) and air-to-air (A2A) communication channels and the modeling of these channels in different scenarios.

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Recommendations for managing the link budget of UAV communications are given, taking into account line losses and channel fading effects. The receive/transmit diversity gain and spatial multiplexing gain achieved by multiple-antenna-aided UAV communications were also analyzed in [13].

Statistical modelling of UAV communication channel is given in paper [14]. Interrelated parameters and PDF (probability density function) of parameters were analyzed. The performance of large-scale fading as well as small-scale fading, according to roughness path loss and free-space loss theoretic were discussed.

Studies for channel modeling and real experiments can be found in a survey [15]. The hybrid Terrestrial-Satellite networks and role of RPAS in their deployment is addressed in [16]. The influence of transmitter nonlinearities on data transmission from the RPAS was studied in the article [17]. Computer modeling of RPAS satellite communication channels was published in [18 – 20].

Modeling of aircraft and RPAS data transmission via satellites using MATLAB software, parameters estimation of satellite channels based on IEEE 802.11a IEEE and 802.16 Standards, investigation of aircraft and RPAS data traffic via satellite channel using NetCracker software were summarized in [21].

The rapid growth of drones' market is expected in the nearest time, which is supported by analysis and forecasts of American and European bodies. The Federal Aviation Administration (FAA) projects to have 451,800 units of small commercial, 2.4 million units of hobbyist RPAS fleet and 301,000 of remote pilots by 2022 [22]. The SESAR Joint Undertaking in its "European Drones Outlook Study" [23] predicts more than 7 million consumer RPASs operating across Europe in 2050.

Several areas of research are leading to new trends. Among the emerging research areas and potential applications, the most attractive are use of RPASs in the fifth generation (5G) wireless networks [8, 16, 24], use in IoT [3, 25-28] and the combination of RPASs in swarms [29-33]. Although these applications are very promising and useful, many technical and organizational challenges have to be addressed in order to exploit successfully drones there. Among the crucial issues needed to be solved are the following: navigation, guidance, control, reliable communication between drones and the ground control station, good collaboration between drones in swarms, regulatory framework, safe operations in non-segregated environment. Moreover, now the efficiency and economy of RPASs using comes to the forefront [34]. Enabling reliable and efficient communications between RPAS units in line of sight and through the available infrastructure plays an important role in achieving the necessary performance and safety requirements.

2. Problem statement

The conditions for the most efficient data transfer between the RPAS and the ground infrastructure are the most relevant at present. The choice of telecommunication technologies, data transfer protocol, the transaction size, the time between transactions, the type of statistical traffic distribution will determine the high or low level of RPAS communication channel utilization. Until now, these issues have not been comprehensively considered and theoretically studied properly. Although they can help to understand the behavior of the RPAS communication system in critical conditions and be crucial for reconnecting. A correct understanding of what is happening may be can restore data exchange with RPAS by simple switching to other operating modes. Modeling the operation of RPAS communication channel allows saving money when designing and deploying new systems.

The aim of this article is:

1) to create models of RPAS channel including Line-of-Sight (LOS) and Beyond-Line-of-Sight (BLOS) communication with the help of NetCracker Professional 4.1 software;

2) to analyze the dependencies of the Average Utilization (AU) on the Transaction Size (TS) with different distribution laws for the Time Between Transactions (TBT);

3) to investigate RPAS links with different bandwidths;

4) to study effect of the AU parameter on the Bit Error Rate (BER) and the Packet Fail Chance.

3. Model "BS – RPAS" communication channel simulation

Communication channel simulation was carried out using Professional NetCracker 4.1 software. Fig. 1 shows the BLOS model containing the Base Station (BS), the "cloud" simulating ATM network, the HUB — Wireless Local Area Network (WLAN) station, and the RPAS. The LOS model without the ATM "cloud" will be designated as Model 1 (BS-HUB-RPAS), and a model with the ATM "cloud" as Model 2 (BS-ATM-HUB-RPAS).

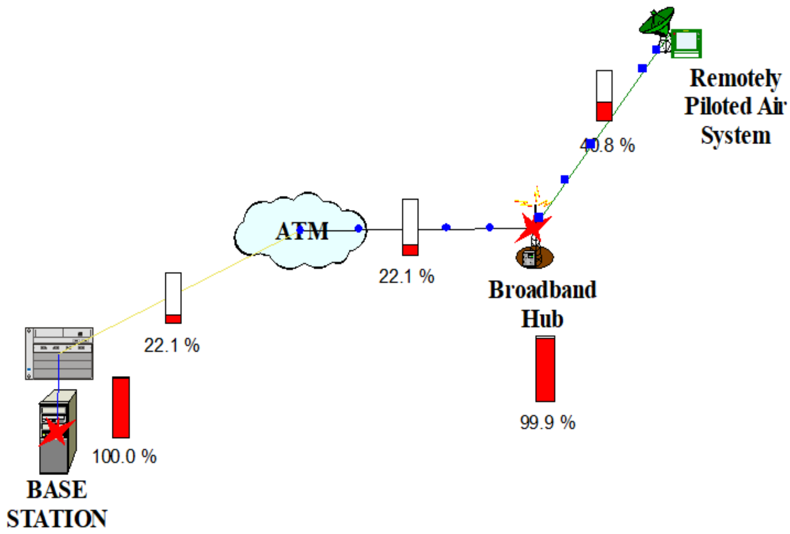

Fig. 1. Model 2: BS-ATM-HUB-RPAS (BLOS channel)

The model uses specifically the ATM “cloud”, for which it is possible changing two parameters - “Packet Latency” and “Packet Fail Chance”. Only these two parameters can be changed in other clouds - X.25, Frame Relay, SMDS, PSTN, ISDN, SONET, WAN available in NetCracker. Real ATM uses asynchronous TDM and encodes data into small cells of a fixed size, which cannot be modeled in Professional NetCracker 4.1 software. ATM resembles a network with both circuit switching and packet switching. This feature is suitable for the RPAS two-way data exchange with the BS. In this case, both command data traffic for flight control and real-time content with low latency, such as the actual operational situation on the battlefield, should be processed with high throughput.

The BS contains an Ethernet server with 10 Mbps bandwidth and the Ethernet-ATM switch with 10 Mbps bandwidth too. The Ethernet-ATM switch is connected to the ATM “cloud” using a link having T3 = 44.736 Mbps bandwidth, the Packet Latency and the BER equal to zero. In the ATM “cloud”, the packet latency was zero seconds, and the Packet Fail Chance could vary from zero to 0.8. The ATM “cloud” is connected to the HUB using a link with T3 data rate, the Packet Latency and the BER equal to zero. The HUB has 10 Mbps bandwidth and Time Division Multiplexing (TDM) type. The HUB – RPAS link has T3 data rate, the Packet Latency of zero and the BER, which varied from zero to 0.7%. The RPAS is the usual WLAN equipment with a bandwidth of 10 Mbps and TDM multiplexing.

A traffic with LAN peer-to-peer profile was specified for the created model with the topology according to Fig. 1. This means decentralized network based on the equal rights of participants. There are no dedicated servers in such a network, and each peer is both a client and acts as a server. Such an organization allows to maintain the network’s operability for any number and any combination of available nodes, which are understood here as RPASs. The created models allow analyzing traffic during data transmission from the BS to the RPAS and determine the most favorable conditions for data transfer.

Fig. 2-4 show results for models 1 and 2 with different distribution laws for the TBT (Const, Exponential, Lognormal), with the same distribution law for the TS (Const) and the BER = 0. This simulates data transfer with different time intervals between transactions. It can be seen that as the transaction size grows, the AU parameter for all types of the TS distribution also increases.

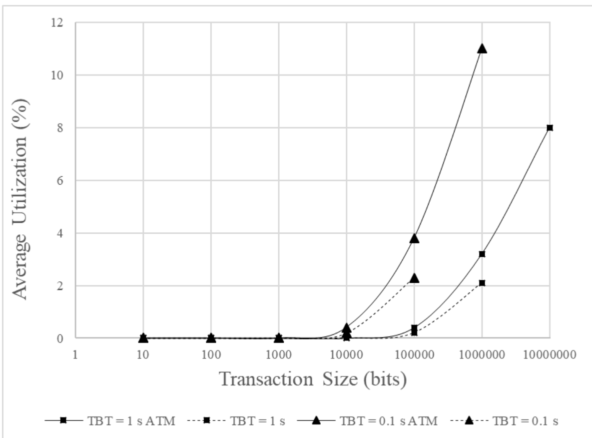

Fig. 2. Dependencies AU of RPAS link on TS: Model 1(dashed), Model 2 (solid), TS (Const), TBT (Const)

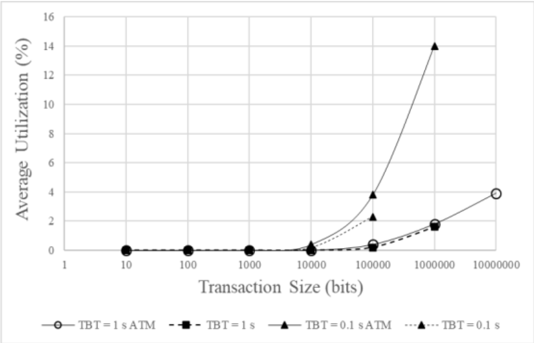

Fig. 3. Dependencies AU of RPAS link on TS: Model 1(dashed), Model 2 (solid), TS (Const), TBT (Exponential)

In Fig. 2 models 1 and 2 with the Const distribution law for TBT and TS parameters are compared. In this case, the following features are observed:

1) With a decrease of the TBT parameter for both models, the maximum message length that can still be transmitted is reduced. Fig. 2 shows the maximum possible values of the TS parameter, above which the channel closes. For example, for model 1 and TBT = 1 s, this is TS = 1 Mbits.

2) When using ATM network, it is possible to transmit larger messages. For example, for model 2 and TBT = 1 s - these are messages up to 10 Mbits in size.

3) When using ATM network for data transmission, the AU parameter increases in comparison with model 1.

In Fig. 3 models 1 and 2 with the Exponential distribution law for the TBT parameter and the Const distribution law for the TS parameter are compared. In this case, the same features 1) and 2) are observed as for Fig. 2. However, for TBT = 1 s, there is no increase in the AU parameter, and the feature 3) is manifested only for TBT = 0.1 s.

In Fig. 4 models 1 and 2 with the LogNormal distribution law for the TBT parameter and the Const distribution law for the TS parameter are compared. In this case, the feature 3) manifests itself, and features 1) and 2) are observed only for the value TBT=0.1 s.

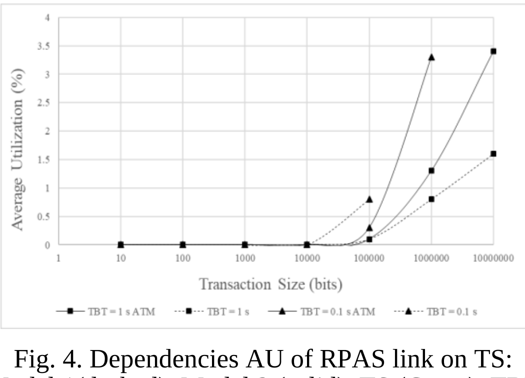

Fig. 4. Dependencies AU of RPAS link on TS: Model 1(dashed), Model 2 (solid), TS (Const), TBT (LogNormal)

Fig. 5 gives the dependencies of the AU parameter on the HUB-RPAS link bandwidth. Fig. 5 shows data only for the Exponential and LogNormal distributions for simplicity, since data for the Const distribution practically coincides with the Exponential distribution for both models. It follows that the use of an ATM "cloud" reduces the AU parameter for Exponential and LogNormal distributions. However, the LogNormal distribution gives the lowest AU, i.e. is preferred for data transmission. When transmitting data with the bandwidth greater than 10 Mbps the parameter AU < 5% for all distributions.

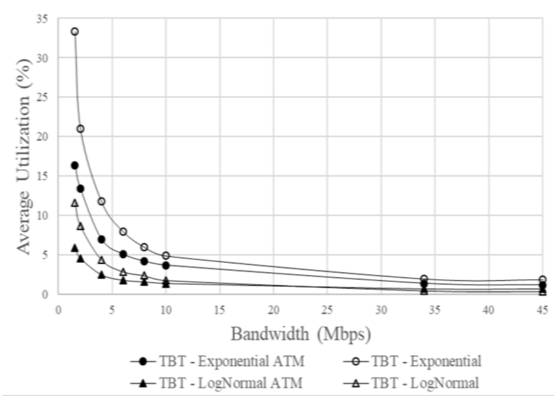

Fig. 5. Dependencies AU of RPAS link on bandwidth (TS=1 Mbits – with Constant distribution law, TBT=1 s)

Fig. 6 shows an increase in the number of bit errors with an increase of the AU parameter. The LogNormal distribution of the TBT parameter shows a significantly lower "sensitivity" to errors with increasing of the AU parameter than the Exponential and Const distribution. The data for the latter are not shown in the figure for simplicity. It turns out that data transfer through the ATM "cloud" does not "worsen" the data transfer process too.

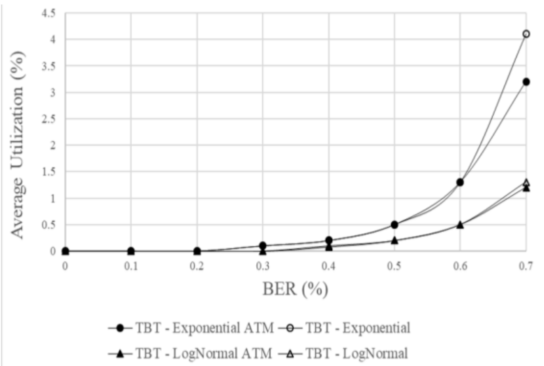

Fig. 6. Dependencies BER on AU of RPAS link (TS = 1 Kbits – with Constant distribution law, TBT=1 s)

Fig. 7. demonstrates the role of data loss in an ATM "cloud".

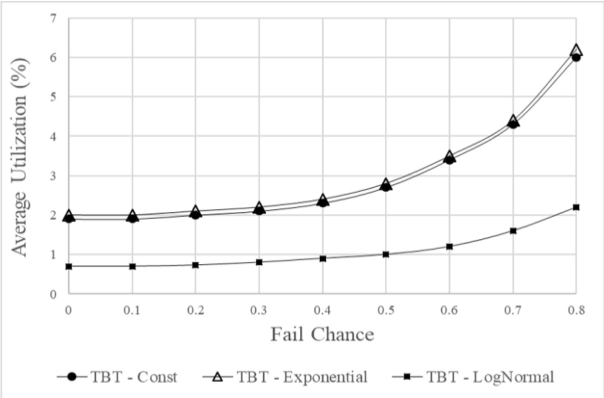

Fig. 7. Dependencies ATM Packet Fail Chance on AU of RPAS link
(TS=1 Kbits with Constant distribution law, TBT=1 s)

Packets loss is possible during data exchange between the BS and the RPAS. That occurs when one or more data packets do not reach their destination. Packets loss can be caused by errors in data transmission over networks or network congestion. Quantitatively packets loss is estimated as the percentage of packets lost in relation to sent packets. The results for the Exponential and Const distributions are close and are higher than AU values for the LogNormal distribution.

4. Conclusions

The development of theoretical foundations for creating new RPAS communication systems is important for predicting their behavior. The characteristics of two-way traffic for the RPAS channel containing ATM ground network (Fig. 1) were calculated for the first time in this article. Traffic characteristics were compared (Fig. 2-6) for RPAS communication channels with direct-visibility (LOS) and via the terrestrial network (BLOS). Such quantitative information is not available in the literature today.

Common to Fig. 2-4 is that for values up to TS = 10 Kbit, the value of the parameter AU = 0%, after which a different increase is observed for different distributions. The smallest AU of all distributions is for the LogNormal distribution - no more than 3.5%. The highest AU values can reach 11-14%. However, for all TBT distributions with TBT = 1 s and TS = 1 Mbit, the AU values are less than 1.5-3%. The ones c in Fig. Figures 2–4 show that the LogNormal distribution law for the TBT parameter is most preferable for data transmission.

Proposed models can be used for analysis the load and efficiency of RPAS communication channels in swarms, for further development and improvement the integrity and efficiency of such channels, as well as for channel characteristics modeling with other parameters and information transfer conditions.

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А.М. Грехов[1], В.М. Кондратюк[2], С.І. Ільницька[3]

Передача даних дистанційно пілотованого літального апарату через наземну мережу

[1,2]Національний авіаційний університет, просп. Любомира Гузара, 1, Київ, Україна, 03058
[3]Університет Веньчжоу, Веньчжоу, Китай, 325000
E-mails: grekhovam@gmail.com, kon_vm@ukr.net, ilnytskasv84@gmail.com

Вперше було створено моделі каналів зв'язку дистанційно пілотованих літальних апаратів, що включають наземну мережу, проаналізовано залежності середнього використання каналу від розміру транзакцій з різними законами статистичного розподілу для часу між транзакціями. Було досліджено канали зв’язку із різними смугами пропускання, вивчено вплив частоти помилок в бітах та шансів відмови пакета на використання каналу зв'язку. Результати показують, що найкращим для передачі даних є закон розподілу LogNormal. Уперше було порівняно передачу даних по каналу зв'язку прямої видимості із ДПЛА та через наземну мережу (поза зоною видимості).

Ключові слова: дистанційно пілотований літальний аппарат (ДПЛА), безпілотний літальний апарат (БПЛА), канал зв'язку, пряма видимість, поза зоною видимості, наземна мережа, трафік даних, розмір транзакції, час між транзакціями, частота помилок у бітах, вірогідність збою пакета

А.М. Грехов[1], В.М. Кондратюк[2], С.И. Ильницкая[3]

Передача данных дистанционно пилотируемого летательного аппарата через наземную сеть

[1,2]Национальный авиационный университет, просп. Любомира Гузара, 1, Киев, Украина, 03058
[3]Университет Веньчжоу, Веньчжоу, Китай, 325000
E-mails: grekhovam@gmail.com, kon_vm@ukr.net, ilnytskasv84@gmail.com

Впервые была создана модель каналов связи дистанционно пилотируемого летательного аппарата, которая включает наземную сеть, проанализированы зависимости среднего использования канала от размера транзакций с разними законами статистического распределения для времени между транзакциями. Были исследованы каналы связи с разними полосами пропускания, изучено влияние частоты ошибок в битах и шансов отказа пакета на использование канала связи. Результаты показывают, что наиболее предпочтительным для передачи данных является закон распределения LogNormal. Впервые было получено сравнение передачи данных по каналу связи прямой видимости с ДПЛА и через наземную сеть (вне зоны видимости).

Ключевые слова: дистанционно пилотируемый летательный аппарат (ДПЛА), беспилотный летательный аппарат (БПЛА), канал связи, прямая видимость, вне зоны видимости, наземная сеть, трафик данных, размер транзакции, время между транзакциями, частота битовых ошибок, вероятность сбоя пакета

Andrii Grekhov. Doctor of Physical and Mathematical Sciences, Professor, National Aviation University
Education: Kyiv State T. Shevchenko University (1973).
Research area: surveillance, ADS-B systems, telecommunications, computer modeling.
Publications: about 190
E-mail: grekhovam@gmail.com

Vasyl Kondratiuk. Director of Research and Training Centre "Aerospace Centre", National Aviation University
Education: Kyiv Polytechnic Institute (1985)
Research area: global navigation satellite systems, unmanned aerial vehicles, aviation, performance-based navigation (PBN), experimental techniques.
Publications: about 50
Email: kon_vm@ukr.net

Svitlana Ilnytska. Ph.D, Senior Researcher in the Institute of Laser and Optoelectronics Intelligent Manufacturing, Wenzhou University (China).
Education: National Aviation University (2007)
Research area: computer modelling, integrated satellite-inertial navigation systems, unmanned aerial vehicles, global navigation satellite systems, aviation, performance-based navigation (PBN), UAV communication channels, space-air-ground integrated systems, experimental techniques.
Publications: about 40
Email: ilnytskasv84@gmail.com