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Traffic Simulation in SAGIN Air Segment Containing Ad Hoc Network of Flying Drones

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Abstract: The purpose of this article is to simulate data transmission and calculate traffic parameters in SAGIN air segment for which Ad Hoc network of flying drones is considered as a model. Traffic modeling is based on the *manet-routing-compare* example from the ns3 simulator library, which has been supplemented with the code for calculation packet losses, throughput/goodput, and message transmission delays. The program allowed considering drones movement at both low and high speeds from 3.6 km/h to 72 km/h. The dependences of traffic losses on data transmission power, transaction sizes and data transmission rate are obtained and analyzed. The distribution of the average effective arrival rate λ and the throughput/goodput for drones has been studied. Comparing traffic characteristics in models with different numbers of drones allows judging how the required quality of service can be achieved by choosing the right transmission parameters.

Keywords: SAGIN; packet loss ratio; transaction size; transmission power; throughput/goodput

Introduction

Space-Air-Ground Integrated Networks (SAGINs) have been developed over the years for providing global coverage anytime, anywhere to support custom applications. Integrated networks such as Globalstar [1], Global Information Grid (GIG) [2], Transformational Satellite Communications System (TSAT) [3], Integral Satcom Initiative (ISICOM) [4], OneWeb constellation [5], O3b system satellite [6], IridiumNEXT [7] and SpaceX Starlink [8] are already in use. Such networks have new architectures, are intensively researched, and offer significant benefits for practical services and applications (Figure 1).

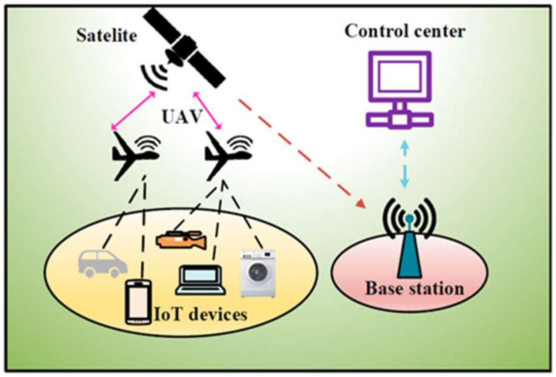

Fig. 1. SAGIN architecture [9]

Building SAGIN faces difficult challenges due to its characteristics such as heterogeneity, self-organization and variability over time. Limited resources in all three network segments affect SAGIN, making it difficult to obtain the required performance to deliver traffic. It is known that not all network performance metrics can be optimized at the same time. When you achieve maximum network reliability and invulnerability, then you have to sacrifice delay or data transfer rate. Therefore, system integration, protocol optimization, resource management and resource allocation in SAGIN are of great importance.

Satellites, airplanes, balloons and drones in SAGIN move, which leads to a constant dynamic change in the network topology and restructuring of packets delivery paths. Existing transport protocols assume a persistent network connection with persistent message delivery paths. However, in SAGIN, permanent delivery paths between sources and recipients rarely or never exist, resulting in much higher transmission delays than in terrestrial networks.

In this regard, the study of data traffic in SAGIN air segment is of particular interest. High-altitude platforms, stratospheric drones and low-altitude Unmanned Aerial Vehicle (UAV) swarms will most likely play the leading role in the creation of the SAGIN middle layer. With the help of such air elements, it is possible to design Flying Ad Hoc NETwork (FANET) or Mobile Ad hoc NETwork (MANET) structures. A highly mobile UAV-based air-to-ground communication system can provide significant benefits for improving network performance, giving end users instant access to real-time data. The use of a mobile relay strategy through flying UAVs reduces the distance between the source and the destination on the ground, which provides a significant improvement in throughput compared to relaying with fixed UAVs location.

The development of a fully autonomous and joint system with several UAVs requires reliable communication between UAVs [10]. Currently, there is not enough research devoted to the peculiarities of data traffic in the middle segment of SAGIN. Depending on the application, UAV networks can have stationary, slow moving or highly mobile nodes. Some applications require UAV nodes to act as base stations in the sky to provide coverage. In addition, there is a group of applications in which the nodes must be highly mobile and communicate, interact and establish the network dynamically in an arbitrary manner.

Our contributions can be summarized as follows. Using the ns3 simulator software, we created models for modeling data exchange in Ad Hoc Network of Flying Drones simulating SAGIN air layer. For this Ad Hoc Network traffic characteristics have been calculated. The results obtained are of practical importance, since they allow predicting the behavior of SAGIN.

This article is organized as follows. In *Related Works*, we review some works related to SAGIN, FANET and MANET. In *Problem Statement and Aim*, we formulate the goals of our research. In *Models*, we describe the architecture of proposed models. In *Results,* we describe obtained data. In *Conclusion*, we note the contribution of our research to the development of methods for predicting the SAGIN functioning.

Related Works

In aviation, satellite links between air traffic controllers and aircraft have been standardized in ICAO document [11]. In our work [12], we simulated the transmission of Automatic Dependent Surveillance - Broadcast (ADS-B) messages using the Low Earth Orbit satellite complex Iridium. In the article [13] dependences of the message travel time on the number of satellites and aircraft were calculated and then experimentally confirmed in 2017 in studies conducted by the USA and Canada [14].

Survey of important issues in UAV communication networks is given in the paper [10]. The article [15] notes that one of the most important problems in the design of systems with several UAVs is communication. A dedicated network connection between UAVs can solve the problems encountered with fully infrastructure UAV networks. The article [15] discusses flying peer-to-peer FANETs, which are an ad hoc network that connects UAVs. FANET is considered as a separate family of networks and several scenarios of their application are presented. The differences between FANET, MANET and Vehicle Ad-Hoc Networks (VANET) are discussed.

New MANET security schemes such as the Intrusion Detection System (IDS) can prevent black hole attacks. The study [16] proposes a new integrated inter-corporate structure for an intrusion detection system to protect the network from attacks. This algorithm is used for routing and securing nodes based on maximum throughput.

The development of wireless devices has led to the creation of the mobile peer-to-peer network MANET. It is a self-organizing network that does not have any structure. Each device in MANET can dynamically move in any direction to exchange information between devices or network nodes. MANET does not have any administrative node that is responsible for managing other nodes, each MANET node behaves like a router and a host itself and forms its own network. Various routing protocols are responsible for routing in MANET. The paper [17] introduces the routing protocol and discusses the benefits, problems, applications, and characteristics of MANET.

The paper [18] investigates wireless relay networks using drones as emergency communication systems during large-scale disasters. Flying drones tilt in the direction of their movement. This tilt causes a decrease in received power, taking into account the effects of vertical directivity and polarization plane deflection. The article simulated the relationship between tilt and flight speed of drones and calculates the power taking into account the tilt. The influence of the tilt of the drone on the delay time was estimated.

Advances in mechanical automation for drones have led to the creation of detachable access points and replaceable batteries that can be carried on drones and placed at arbitrary locations in the field. The article [19] proposes a structure of wireless networks, which depends on the capabilities of separating access points and replacing UAV batteries.

In peer-to-peer networks, communication is provided without the aid of a fixed infrastructure. Routing in MANET is challenging due to dynamic changes in node topology and lack of centralized coordination. In the paper [20], simulations were performed using NS2 with existing MANET protocols. The analysis considered network throughput, delay and packet delivery rate.

In MANET, mobile nodes can communicate with each other without relying on any infrastructure. The dynamic MANET topology complicates the design of routing protocols. Various mechanisms such as source, distance vector, and link state routing are used to discover routes in MANET. The article [21] compares several MANET routing protocols. Protocols under study: Destination Sequence Distance Vector (DSDV), Optimized Link State Routing (OLSR), Ad Hoc On-Demand Distance Vector (AODV) protocol, and Dynamic Source Routing (DSR). The range of network dynamics and node density is considered, and three mobility models are studied: steady-state random waypoint (SS-RWP), Gauss-Markov (GM), and Lévy Walk. Simulator ns-3 was used to evaluate their performance for metrics such as packet delivery rate, end-to-end delay, and routing overhead.

Problem Statement and Aim

The operation of SAGIN is impossible without reliable communication channels between all components. Our previous works [12, 13, 22-33] were devoted to the study of SAGIN communication channels using MATLAB Simulink and NetCracker software.

This study is developing methods for assessing the parameters of real traffic in SAGIN middle layer. The aim of this article is to simulate data transfer and calculate traffic parameters in SAGIN air segment using ns3 software. To do this, we need to: 1) construct models for simulating data exchange; 2) obtain dependences of Packet Loss Ratio (PLR) on the transmit power, size of transactions and data rate (bandwidth) for a different nodes speed; 3) study distribution of average effective arrival rate λ and throughput/goodput on nodes.

Models

To simulate SAGIN air layer, consisting of flying drones, we used an example from the public library ns3 *manet-routing-compare*, which was supplemented to calculate PLR, Throughput and Delay. This example program allows running ns-3 DSDV, AODV, or OLSR under a typical random waypoint mobility model. The number of nodes is 50, which move according to

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RandomWaypointMobilityModel with a speed of (1 – 20) m/s and no pause time within a 300x1500 m region. The Wi-Fi is in ad hoc mode with 2 Mb/s rate (802.11b) and Friis loss model, which determines the power received by one antenna under ideal conditions from another antenna located at a certain distance and transmitting a known power. The Friis model describes wave's propagation in free space and is used to simulate line-of-sight path loss that occurs in an environment devoid of any objects that create absorption, diffraction, reflections, or any other phenomenon that alters the characteristics of the emitted wave.

It is possible to change the mobility and density of the network by directly modifying the speed and the number of nodes. It is also possible to change the characteristics of the network by changing the transmit power. Specifying a value of 2 for the protocol we cause AODV to be used. By default, there are 10 source/sink data pairs sending UDP data at an application rate of 2.048 Kb/s each. The Model 1 and Model 2 used in traffic simulation are shown in Figures 2 and 3.

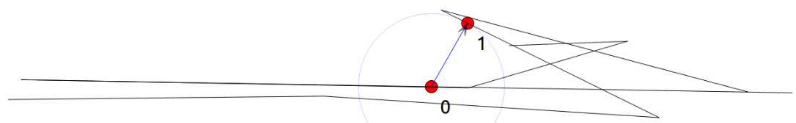

Fig. 2 Model 1 with 1 source/sink data pair and 2 nodes
The figure shows nodes trajectories and direction of data transmission at arbitrary moment of simulation

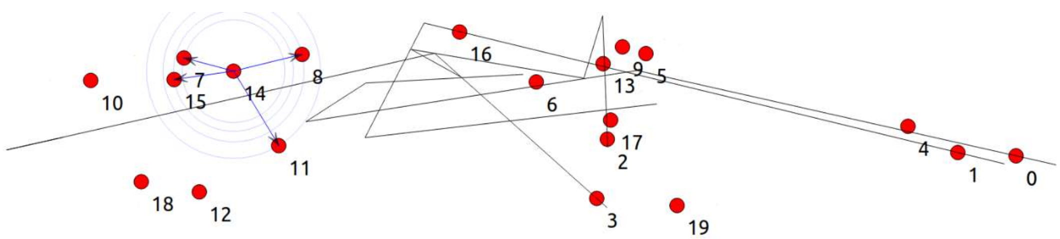

Fig. 3 Model 2 with 10 source/sink data pairs and 20 nodes
The figure shows nodes trajectories and direction of data transmission at arbitrary moment of simulation

Results

When transmitting data in SAGIN, and in the air segment in particular, it is important to understand how the features of data transmission mode are related to traffic quantitative characteristics. How do the transmit power, Transaction Size (TS), and data rate (Bandwidth) affect packet loss? How are the average effective arrival rate λ and throughput distributed over the network nodes?

It is interesting to establish how much packet loss can change with increasing transmit power. Figures 4, 5 show PLR dependences on Transmit Power in Models 1 and 2 for different nodes speed. Here two facts can be noted. First, increasing the transmit power leads to a significant decrease in losses. Secondly, losses decrease with decreasing speed of network nodes, regardless of the transmission power in both models.

Figures 6, 7 show the dependences of PLR parameter on transaction size in Models 1, 2, respectively, for different nodes speed for a fixed total simulation time. In such a situation, an increase in the size of transactions leads to a decrease in the total number of transmitted packets. When calculating these dependences, TS parameter varied in the range from 10 Bytes to 1000 Bytes, and the power and data transfer rate were set. For Model 1 (Fig. 6), PLR parameter weakly depends on the size of transactions and practically does not change at a speed of 1 m/s. With an increase in the speed of nodes to 20 m/s, the losses more than double. For Model 2 (Fig. 7), there is a significant dependence of losses on the size of transactions due to a decrease in the total number of transmitted packets for a fixed simulation time. It should be noted that NetCracker software allows you to set the transaction size, data transfer rate and calculate the average workload and average utilization of the communication channel, regardless of the simulation time.

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The data in Figures 8, 9 show dependences of PLR parameter on the data transfer rate in Models 1, 2 for different nodes speed. In the calculations, the data transfer rate varied from 2 Kbps to 12 Kbps, and the transmission power and transaction size were specified. At low node speeds for Model 1, the losses practically do not change with an increase in the data transfer rate, and at high speeds, they slowly increase almost linearly. At low node speeds for Model 2, PLR parameter also changes insignificantly with increasing bandwidth, although more than twice the values for Model 1. At high speeds of nodes, PLR parameter slowly increases with increasing data transfer rate.

P*ropagationDelayModel* in ns3 calculate the propagation delay between the specified source and destination and in our case varied from 0.96 s to 15.0 s, depending in TS parameter and data rate. Figures 10 and 11 show the results obtained using the *tracemetrics.1.4.0* program, which provide an indication of the data traffic in Model 2.

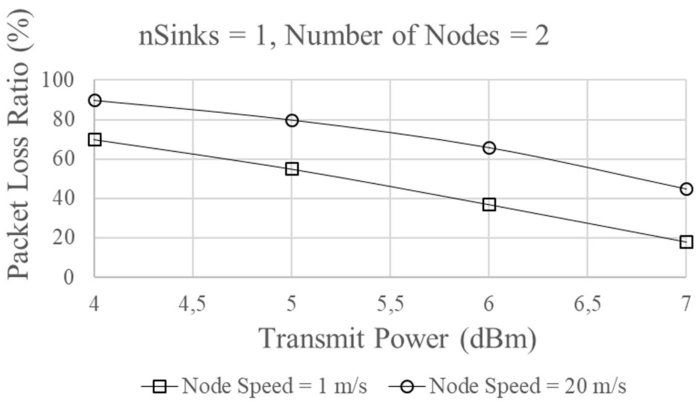

Fig. 4 Dependences of PLR on Transmit Power in Model 1 for different nodes speed (TS = 100 Bytes, Total Time = 200 s)

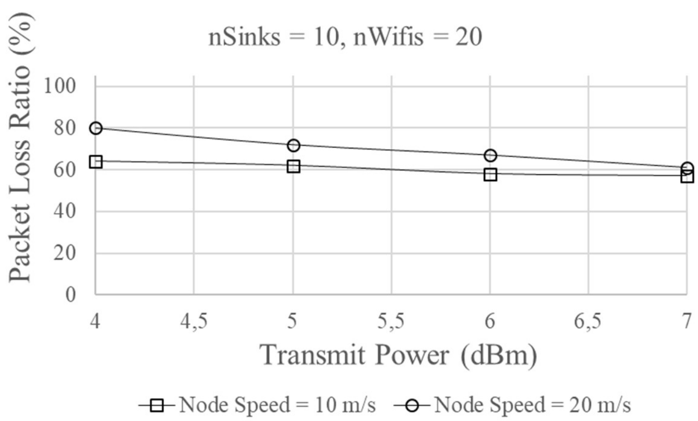

Fig. 5 Dependences of PLR on Transmit Power in Model 2 for different nodes speed (TS = 100 Bytes, Total Time = 200 s)

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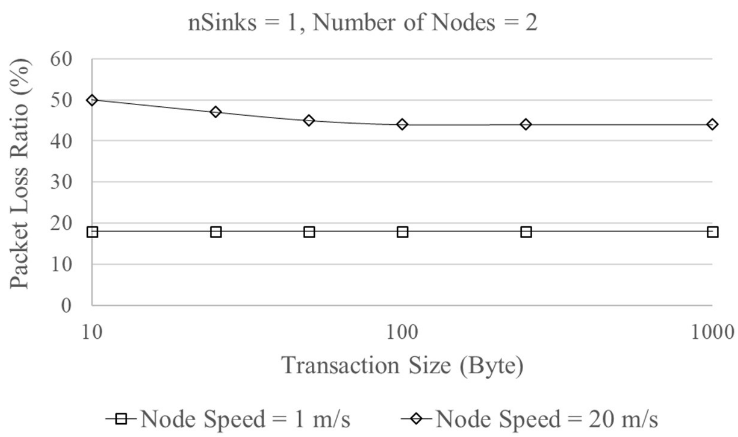

Fig. 6 Dependences of PLR on Transaction Size in Model 1 for different nodes speed (Transmit Power = 7 dBm, Bandwidth = 2048 bps, Total Time = 200 s)

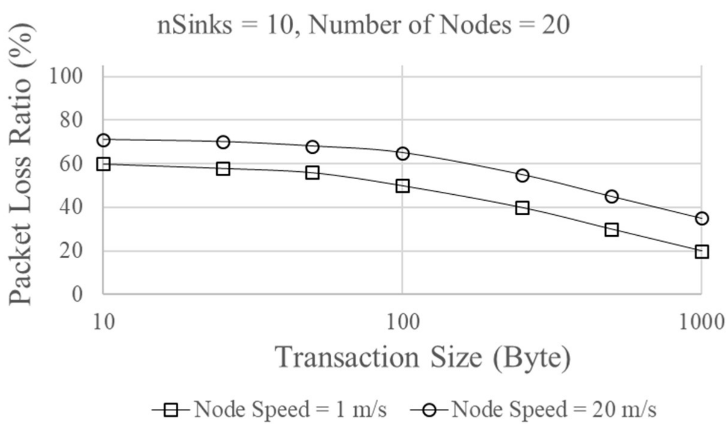

Fig. 7 Dependences of PLR on Transaction Size in Model 2 for different nodes speed (Transmit Power = 7 dBm, Bandwidth = 2048 kbps, Total Time = 200 s)

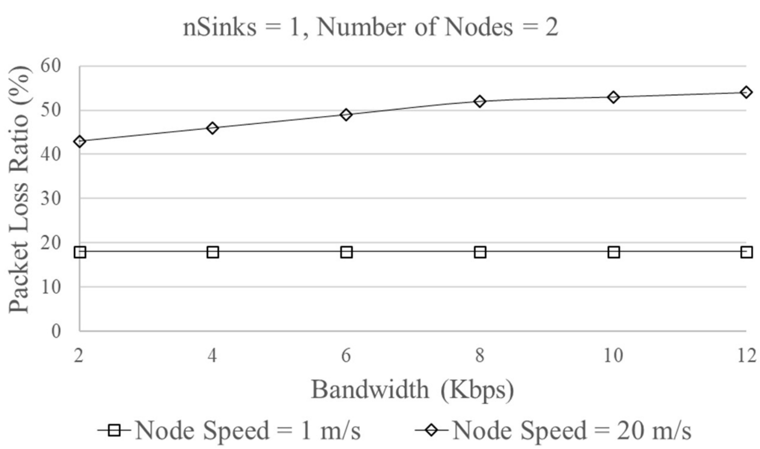

Fig. 8 Dependences of PLR on Bandwidth in Model 1 for different nodes speed (Transmit Power = 7 dBm, TS = 100 Bytes, Total Time = 200 s)

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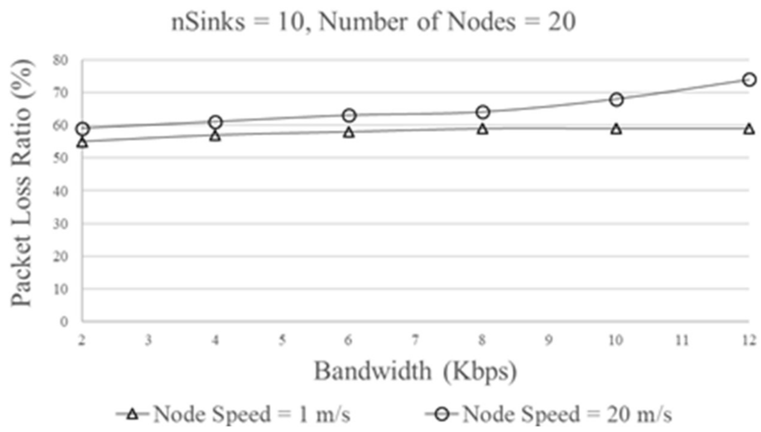

Fig. 9 Dependences of PLR on Bandwidth in Model 2 for different nodes speed
(Transmit Power = 7 dBm, TS = 100 Bytes, Total Time = 200 s)

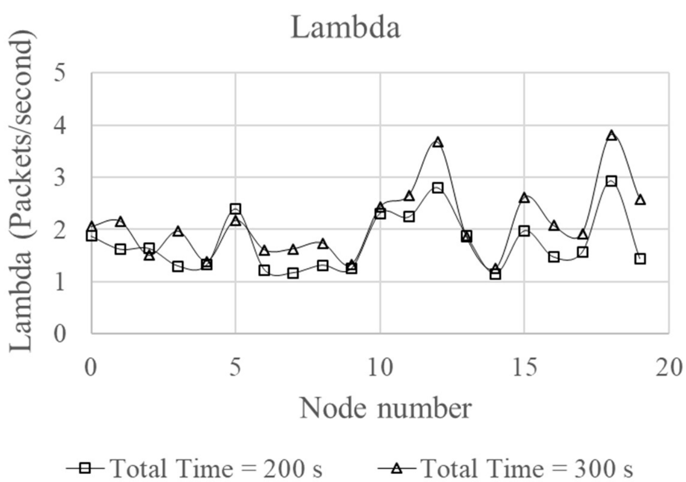

Fig. 10 Dependences of Lambda on Node Number in Model 2 for different simulation time
(Transmit Power = 7 dBm, TS = 2500 Bytes, Bandwidth = 2048 bps, Nodes speed = 20 m/s)

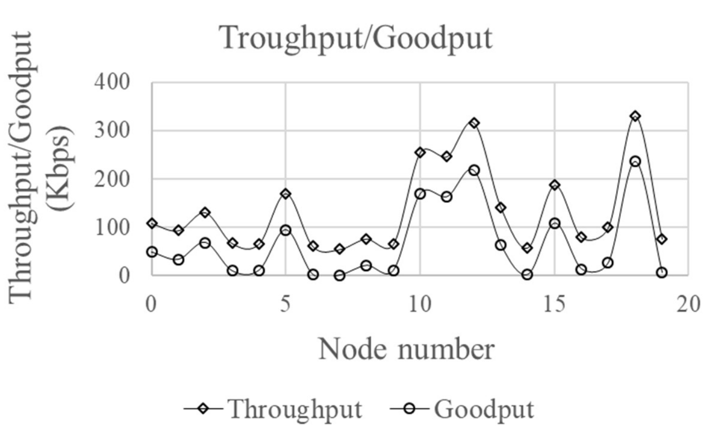

Fig. 11 Dependences of Throughput and Goodput on Node Number in Model 2
(Transmit Power = 7 dBm, TS = 2500 Bytes, Bandwidth = 2048 bps, Total Time = 200 s, Nodes speed = 20 m/s)

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Conclusion

This work is devoted to modeling traffic in SAGIN air segment containing ad hoc network of flying drones. The presented study contains traffic parameters for two models based on the example *manet-routing-compare* from ns3 library. The dependences of traffic losses on data transmission power, transaction sizes and data transmission rate are obtained and analyzed.

Traffic characteristics were compared in models with different numbers of nodes and their speed. This comparison provides a quantitative understanding of how the required quality of service can be achieved in SAGIN air segment by choosing the right transmission parameters.

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Conflict of interest: The authors declare no conflict of interest.

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