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End-to-End Delay Model of the Main Types Satellites for VoIP-telephony over Satellite Links

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Abstract. *Over the past few decades, the Internet has become the world's information superhighway, leading to the development of new applications and services. Among them, Voice over IP (VoIP) is one of the most promising industries. Voice over Internet Protocol (VoIP or IP) telephony is a new way of communication. This technology allows users to make calls over a network using Internet protocols. This paper will describe VoIP-telephony, to demonstrate the ability of people to communicate through the Internet, which works via satellite links. The research in this paper demonstrates the basic formula of the latency model when using any type of satellite network such as LEO, GEO, and MEO systems for IP-telephony. In addition, this work provides methods for reducing the latency.*

Keywords: *Internet; protocol; VoIP; end-to-end delay; satellite network; packet;*

I. Introduction

With the active development of satellite systems the internet is more integrated into those. One of the areas on the Internet is VoIP-telephony [1]. Usually, when it comes to VoIP, it means the use of terrestrial networks. But it also can be arranged by using satellite communications.

With the advent of VoIP, several satellite Internet service providers have expressed interest in including it as one of their services, and the number of providers interested in this service is increasing every day. In 2018 SpaceX launched satellites for Starlink. Starlink is a satellite internet constellation providing satellite Internet access. The constellation will consist of thousands of mass-produced small satellites in low Earth orbit (LEO) [2], working in combination with ground transceivers. SpaceX needs to launch at least 12 000 satellites for covering Earth but the quantity can be till 40 000 for increased redundancy and security. The security and redundancy of transferring data have a significant impact on the popularity of services of VoIP.

Fifth-generation (5G) systems can be viewed as an ultimate amalgamation of existing and wireless fixed and mobile systems. Satellite systems can be instrumental in this future network infrastructure beyond any doubt, playing a multifaceted role. Consequently, integration of voice and data services is inevitable in satellite links as well.

While the service-related aspects of VoIP are the same in both terrestrial and satellite networks, transport-related issues are quite different. The most important factor that limits the performance of satellite systems is the propagation delay of satellite links that makes the provision of real-time service over these kinds of links easier said than done. The purpose of this work is to demonstrate all the issues that are closely related to the performance of VoIP over different kinds of satellite links along with potential remedies.

II. Main Part

To understand the methods of delay reduction in the use of satellite links, it is necessary to find out the scheme of building the satellite network model. Figure 1 demonstrates the main components of delays on every part of a route. The model presented in this paper can be used to estimate the end-to-end delay of GEO, LEO and MEO satellite networks.

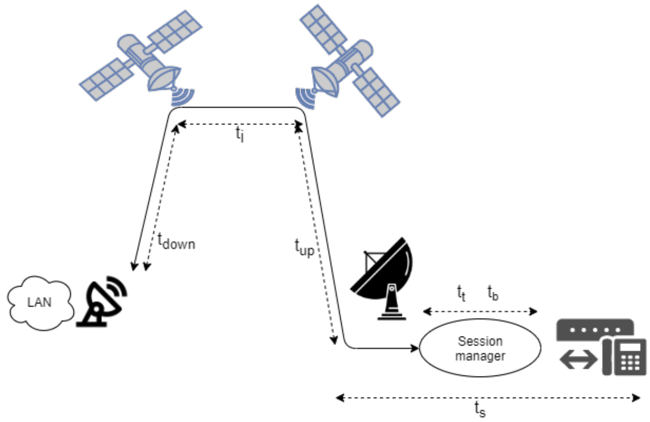

Figure 1. Scheme of end-to-end delay

The end-to-end delay experienced by a data packet traveling through a satellite network is the sum of the transmission delay (t_t), the Earth-to-satellite delay (t_{up}) and the satellite-to-destination delay (t_{down}), the inter-satellite delay (t_i), the built-in switching and processing delay (t_s) and the buffering delay (t_b). The inter-satellite, on-board switching, processing, and buffering delays are summed over the path taken by the connection. In this model, only the satellite component of the delay is considered. The total delay experienced by a packet is the sum of the satellite and ground network delays. The delay variation is caused by orbital dynamics, buffering, adaptive routing (in LEO), and on-board processing. Quantitative analysis of delay jitter in satellite systems is beyond the scope of this study. End-to-end delay (D) is defined as:

$$D = t_t + t_{up} + t_i + t_{down} + t_s + t_b, \qquad (1)$$

where D – is end-to-end delay; t_t – is transmission delay; t_{up} – is uplink delay; t_i – is inter-satellite delay; t_{down} – is downlink delay; t_s – is processing delay; t_b – is buffering delay.

The transmission delay t_t is the time taken to transmit a single data packet at the network data rate and it is equal to packet size divided by data rate. The first operand of (1) can be decreased by two methods: magnification of data rate and reduction of the quantity of data packets, dividing all data by as much as possible quantity of packets.

The uplink delay is the time taken for the signal to travel from the source ground terminal to the first satellite in the network (t_{up}), and the time for the signal to reach the destination ground terminal from the last satellite in the network (t_{down}). There is also delay between satellites(t_i), that is the inter-satellite link delay. This delay is equal to the sum of the propagation delays of the inter-satellite links (ISLs) traversed by the connection divided by the speed of a signal.

There are three main types of satellites – geostationary equatorial orbit (GEO), low Earth orbit (LEO) and medium Earth orbit (MEO). Every type has their advantages and disadvantages.

LEO satellites are much smaller and their orbits are much closer to earth, so the rockets needed to launch them are also smaller and cheaper. The power needed to transmit is about 1 watt. It has least Earth-to-satellite (t_{up}) and satellite-to-Earth (t_{down}) delays (about 10ms each) compare to other orbits due to closeness to the Earth. Due to lower latency, it can be used for critical applications which use real time transport protocol [3]. The feature of using this type is the ability of providing high elevation for the polar region of the Earth. It means that better global coverage can be achieved. Since it is at a shorter distance from the Earth, it covers less of the Earth. Therefore, a large number of satellites are needed to cover the entire region of the Earth. Consequently, the installation of such a LEO-based system is costly. As LEO satellites move constantly, service is handed off from each satellite to the next in the constellation. Hence, a sequence of satellites is required to cover any region on Earth. It means that inter-satellite links delay (t_i) is not convenient. In addition, the ground station is very complex as it requires to handle frequent handoffs between LEO satellites. In LEO constellations, the ISL delays depend on the orbital radius, the number of satellites-per-orbit, and the inter-orbital distance (or the number of orbits). Also, the ISL delays change over the life of a connection due to satellite movement and adaptive routing techniques in LEOs. As a result, LEO systems can exhibit a high variation in ISL delay.

As for MEO satellites, these are launched at higher altitude compared to LEO satellites. This suggests that fewer satellites are needed to cover the entire area of the Earth. The average sum of the Earth-to-satellite delay and satellite-to-Earth delay $(t_{up} + t_{down})$ is about 130 ms. Despite the fact that the number of satellites required to build a MEO system is less than that of LEO systems, the inter-satellite latency (t_i) is not small, which also affects the quality of services that are provided by this type of system.

The third type of satellite system is the use of GEO systems. There is an undeniable advantage that only this type has. As it is at greater height, it covers a larger geographical area. Only 3 satellites are required to cover the entire Earth. In GEO systems, ISL delays can be assumed to be constant over a connection's lifetime because GEO satellites are almost stationary over a given point on the earth, and with respect to one another. But The signal requires considerable time to travel from Earth to satellite and vice versa. The signal travel delay is about 125 ms in one direction. The distance of 35786 Km gives that latency with $3x10^8$ m/sec speed of the signal [4]. Hence it is not suitable for point to point applications requiring time critical applications such as real time voice, video etc. Also this type provides poor coverage at higher latitude places usually greater than 70 degrees. In the North regions of Russia, Norway and Canada there is a problem to have quality of services while using this type of satellites.

The data packets may incur additional delays (t_s) at each satellite hop depending on the amount of on-board switching and processing. For high data rate networks with packet switching, switching and processing delays are negligible compared to the propagation delays.

Buffering delay (t_b) is the sum of the delays that occur at each hop in the network due to cell queuing.

Based on the number of received data on delays for different types of systems it is necessary to get a summarizing table 1, where N – is queuing points. The data in this table was provided for calling between two countries, which are located in Europe and North America or a call that is approximately equal to the distance between these parts of the Earth and are approximately identical degrees [5].

Table 1 – comparing satellite systems.

Delay	GEO (ms)	LEO (ms)	MEO (ms)
Transmission	Negligible	Negligible	Negligible
Propagation	250	60	130
Switching	Negligible	Negligible	Negligible
Processing	Negligible	Negligible	Negligible
Buffering	0 to N · 250	0 to N · 60	0 to N · 100
Total	250 to 500	60 to 360	130 to 390

III. CONCLUSIONS

The paper considers the technology of using a satellite network built on the basic types of satellite systems. The work involved the basic delay formula for any type of satellite system. A basic description of the advantages and disadvantages of LEO, GEO and MEO systems was presented. A comparative characterization of the delays for each type of system studied was performed. Thus it can be said that for calls via satellite communication LEO system is the most suitable. In further research, increasing redundancy, without significantly increasing delays for this type of VoIP construction is a priority.

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