Journal of Advances in Computer Research
Quarterly ISSN: 2008-6148
Sari Branch, Islamic Azad University, Sari, I.R.Iran
(Vol. 4, No. 4, November 2013), Pages: 9-20
www.jacr.iausari.ac.ir

Architecture and Performance of Satellite Configurations in Different Orbits

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Received: 2013/06/02; Accepted: 2013/08/16

Abstract

In this paper, new features of satellite configuration, Such as IP network based infrastructure and separated signaling and media are considered to propose a variety of satellite configurations in different orbits. Because of their different altitude in space such as Low Earth Orbit (LEO) and Geostationary orbit (GEO), a test bed used to test call setup delay in a one space link to process the Media Gateway Control protocol calls was reviewed. Furthermore, three different call flows are presented by M/M/1 queuing model that can be used for deploying and evaluating Next Generation Network for satellite configurations. These call flows help to verify Media Gateway Controller protocol and also allow testing and evaluating in various call set up delay time for different satellite configurations. In these simulations, a satellite is a Media Gateway Controller node for receiving and transmitting IP messages in a Space link and a ground station is Media Gateway node.

Keywords: MEGACO, Queuing Model, SLSA, FLSA, HLSA

1. Introduction

The growth in the use of satellite internet services in recent years have led to satellite communication networks to communicate an increasingly large amount of space internet traffic. In feature time, new satellite configurations will be required to transport IP traffic. A case can be made for implementing IP routing directly is a satellite constellation, in order to transport IP traffic well and to provide good support for emerging Quality of Service (QoS). This paper provides different constellations to obtain call setup delay effectively in different orbits with known constraints on the configurations resulting.

Therefore, more and more satellite providers have deemed that next generation satellite constellation would be constructed based on satellite. Considering the forthcoming popularity of satellite configurations, satellite technologies have shown its importance. While current research mainly focuses on satellite interconnection protocols, and corresponding performance analysis.

A signaling protocol can be specifically optimized for the satellite configuration. Such a Media Gateway Control Protocol (MEGACO) can avoid transmitting unnecessary routing information while propagating other useful network -specific information such as internal delay, expected traffic load or instantaneous traffic load.

Internet Engineering Task Force (IETF) and ITU-T standards, have been considered as a promising signaling protocol for the current and future IP services due to its simplicity and flexibility built in its security features. Most of the recent researchers like the true promise of VoIP resides with MEGACO and its ability to create and access innovative IP service applications. If IP service along with MEGACO signaling is the modern day replacement for PSTN, it should meet the same level of Quality of Service and security. There are several ongoing discussions on the QoS of IP services and MEGACO within the IETF and other research communities.

This paper is organized as follows. In section 2, addresses related to the research done in this area. Sections 3 provides a detailed MEGACO protocol history, functions and commands .In section 4, three kinds of satellite constellation are distinctively introduced as well as their applicability and performance. In Sections 5, satellite configurations are presented by queuing models and then in sections 6, Future work and addresses the concluding remarks is proposed.

2. Related Work

Hajipour [1] analyzed and simulated the queuing models for different scenarios such as stateless,stateful, single phase and two phase call setups based on MEGACO with presence Common Open Policy Server (COPS).

Wu et al. [2] analyzed the queuing delay variation using embedded Markov chains in a M/G/1 queuing model.

Lipson [3] proposed a new method to use an queuing delay structure based on markov reward models to analyze properties of a simple signaling network based on IP. He focuses on transient properties related to the number of calls processed before a system failure or system repair. The rewards are expressed as simple rates of incoming requests for each signaling call setup.

V.K.Gurbani, L. Jagadeesan, V.B. Mendiritta, [4] came up with an analytical Session Initial Protocol (SIP) based on reliability model in which they primarily considered two main parameters which include the mean response time and the mean number of calls. They modeled a SIP proxy server as an open feed forward queuing network and they analyze the queuing delay variation using embedded markov chains in a M/M/1 queuing model for Performance and Reliability a peer to peer network such as SIP.Suresh Kumar V. Subramanian, Rudra Dutta [5], analyzed the queuing delay variation using embedded Markov chains in a M/M/1 and M/M/c queuing model of the SIP Proxy Server. Raja opal et al. [6] analyzed and proposed the IP Multimedia Services (IMS) network based on the SIP signaling delay predicted performance of the network, which allowed them to choose the parameter values. Their model was based on a queuing model for the IMS network that characterizes the SIP server workload.

S.V.Subramanian, R.Dutta [7] designed an alternative M/D/1 performance model that enhances the SIP Proxy Server performance.

3. MEGACO Protocol

In traditional circuit switch networks, each call setup is obtained primarily through the backbone of the telephone network. For an example, an old signaling protocol can be used for establishing and deleting connections, simultaneously. In new network based on IP messaging, a new signaling protocol is required for Voice over IP (VoIP) to route through the public network. Different signaling protocols have been provided to control VoIP traffic. In many years, SIP and H.323 which are peer-to-peer protocols have been introduced. However, for large scale deployments, these protocols have scalability problems. For this reason, a new architecture for signaling protocols must be provided. Besides, the control and the media gateway components were redefined using the master/slave architecture. Figure 1 shows the evolution of the MEGACO/H.248 protocol [8, 9].

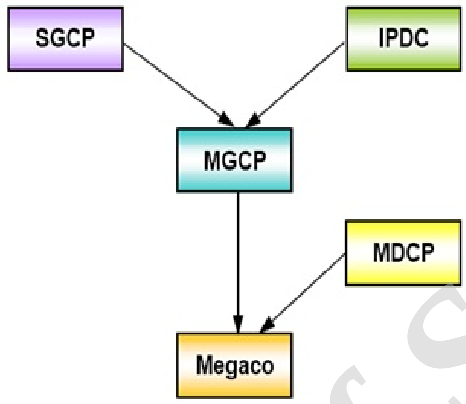

Figure 1: Evolution of the MEGACO/H.248 Protocol

As shown in Figure (2), MEGACO (officially H.248) is an implementation of the MEGACO architecture [10,11] for controlling Media Gateways on the IP networks and the Public Switched Telephone Network (PSTN). The total basic architecture and programming interface was originally described in RFC 2805 and the current specific MEGACO definition is recommendation H.248.1. It is typically used to provide VoIP services (voice and fax) between IP networks and the PSTN, or entirely within IP networks.

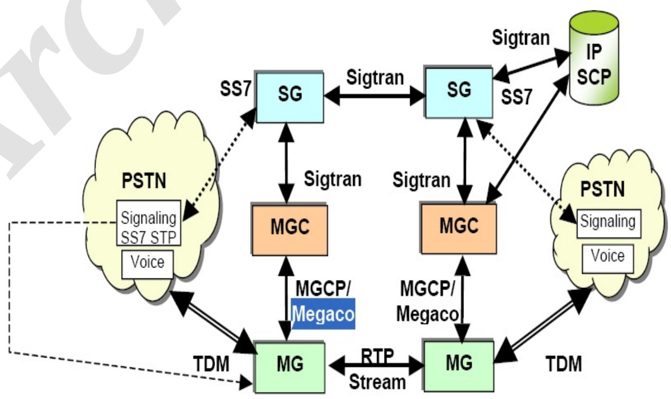

Figure 2: The MEGACO Architecture

4. Satellite Constellation Architectures

Satellite-based networking has developed in complexity over the years, rising up and building upon established work at the various networking layers as described by the Open Systems Interconnection (OSI) reference model [12].

4.1 The Comparison between LEO and GEO satellite constellations

In order to improve the IP packet transfer performance, LEO satellite constellation by orbits much lower than GEO have been proposed. This improvement results in global coverage, more frequency reuse of limited earth-space communication spectrum and as a consequence higher system capacity, reduction in propagation delay in comparison with GEO, although this advantage may not be significant or quantifiable in some special applications.

The use of non-geostationary orbits results in demand for satellite-to-satellite handover even for fixed ground stations. Use of inter-satellite links (ISLs) in the constellation leads to a complex orbiting mesh network topology, where permanent ISLs are established between satellites following each other in the same circular orbital plane. ISLs have added direction to show connection between different orbital planes at the highest latitudes.

The trend toward on-board satellite transponder with complex switching, and the satellite network topologies created by an broadband satellite networks with ISLs, have produced to route IP traffic over multiple satellites between sources and destination in each small cell. Although unicast transmissions, such as those for Transport Control Protocol (TCP), can be supported end-to-end across any proprietary satellite network by tunneling, implementing support for other protocols in the TCP/IP module, particularly multicast, is less straightforward, requiring routing support in the new satellite networks.

For an example, the development of multi-spot beams for each satellite system led to on-board switching, with control of capacity allocated via circuits and a logical link control (LLC) sub layer. Development of ISLs between satellite systems and the design of satellite constellation utilizing ISLs, such as Iridium, Eledesic and Space way has led to different space signaling connection between satellite systems and ground stations[13].

In order to extend the coverage area of the satellite constellation, following three satellite constellations based on IP structures are analyzed:

1) Single Layer Satellite Architecture (SLSA),
2) Fully Layered Satellite Architecture (FLSA),
3) Hybrid Layered Satellite Architecture (HLSA) [14].

4.2 Single Layer Satellite Architecture (SLSA)

In this type of structure, each satellite system in the same orbit can route each IP messaging independently. In this scenario, all of satellite systems can have a management mechanism for each ground station. Based on assumptions, satellite constellation in single layer mode is provided in figure 3.

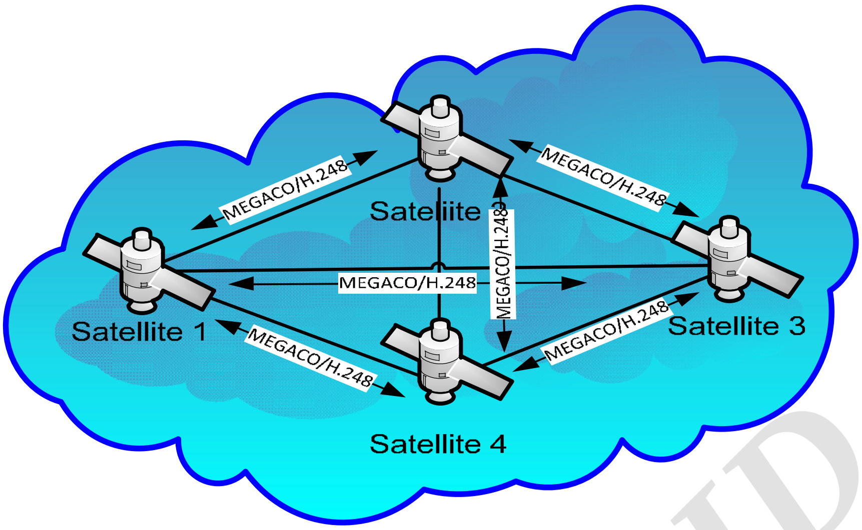

Figure 3: SLSA scenario

Based on [14], SLSA is the simplest architecture to manage signaling messages and ground stations.
In the signaling message section, signaling messages in each call setup scenario obtains in one step.
In this type of architecture, all satellite systems have to peruse each IP messaging for each ground station. When a new ground station request to communicate a satellite constellation, satellite processor-based IP should be updated. In this time, each IP messaging is always, send or receive in a space channel between satellite system and ground station. When the number of satellite systems enhance in this type structure, the number of space channel-based IP will have to increase.
To analyze the performance of satellite configuration, a functional flow chart for each satellite system is provided in figure 4.

Figure 4: Satellite Functional flow chart

In the above figure, flow chart has two main parts as follows:
1. Ground Station Management and Routing (GSMR) will perform authentication, authorization and messaging routing for each ground station.
2. Call control (CC) which is the main part of a satellite processor to control IP messaging. Based on [14], the queuing model for figure 4 can be provided as shown in

figure 5.

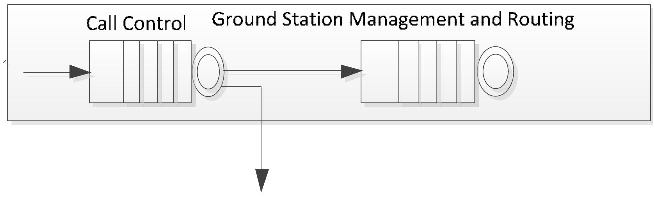

Figure 5: Queuing Model for a satellite system

In figure 5, CC part is provided with an M/M/1 queuing model. The input process of GSMR which is the output process of CC can be modeled with different statistical distributions. In this paper, the Poisson and exponential distributions used. There are different statistical distributions to model in this type of structure. Nevertheless, the Poisson distribution in this type of queuing model can still be used and provides to reliable results [15].

Based on [14], to obtain the call setup delay, the average service time of CC is assumed to be C. This parameter for GSMR is τ. The τ will increase along with the increase of the ground stations managed by each satellite system. Then it can be given than τ=f(m), where m is the number of ground stations. The satellite constellation based on of SLSA is shown in figure 6.

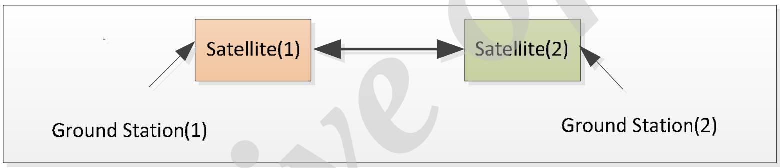

Figure 6: Satellite constellation based on single layer architecture

Based on [14], we have several assumptions as follow:

1) The call setup delay for each satellite system will enhance according to the increasing of the ground stations which directly connected to a satellite system. Also, $\lambda=\alpha\times m$ provide the rate for call setup delay requests. Moreover, α=(Traffic $_{\text{ground station}}$ /Time $_{\text{Call setup}}$), where Traffic $_{\text{ground station}}$ is the traffic of a ground station and Time $_{\text{Call setup}}$ is the average length of time for each call setup[16].
2) R is the ratio of the number of outgoing calls to the total number of calls.
3) The number of ground stations directly connected to both satellite (1) and satellite (2) is m.
4) The propagation delay of signaling messages in each space channel is d.
5) The total number of ground stations in satellite network M.

Based on the description given in this section, the queuing model for the scenario shown in figure 7. In this figure, the dashed line illustrates the path of a call setup delay message between satellite systems and ground stations. Therefore, the call setup delay T is obtained by equation"(1)":

$$T = T_{CC\,1} + T_{GSMR\,1} + T_{CC\,2} + d \qquad (1)$$

Where T_{CC1}, T_{GMSR1}, T_{CC2} are the time delay for each part in this figure.

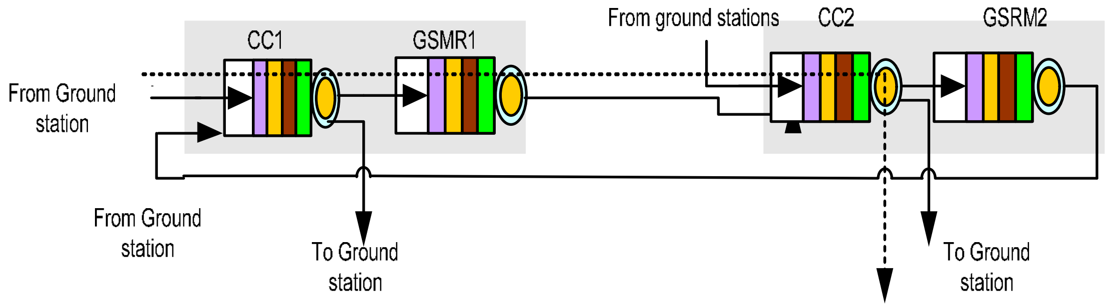

Figure 7: SLSA Queuing Model

The arriving rate and the service rate for SLSA are summarized in table 1 and table 2.

Table1: Arriving rate in SLSA [14]

λ_{CC1}	λ_{GSMR1}	λ_{CC2}	λ_{GSMR2}
$(1+R)\times\lambda$	$R\times\lambda$	$(1+R)\times\lambda$	$R\times\lambda$

Table 2: Service rate in SLSA [14]

μ_{CC1}	μ_{GSMR1}	μ_{CC2}	μ_{GSMR2}
1/C	1/f(M)	1/C	1/f(M)

Based on [17], that the time delay of CC1 as an M/M/1 queuing model can be given by equation"(2)":

$$T_{CC1} = \frac{1}{\frac{1}{C} - (R+1)\frac{\lambda}{C}}. \tag{2}$$

Also, T_{SMR1} and T_{CC2} are provided in equations 3 and 4 [14]:

$$T_{GSMR1} = \frac{f(M)}{1 - R \times \lambda \times f(M)}. \tag{3}$$

$$T_{CC2} = \frac{C}{1 - C \times (1+r) \times \lambda}. \tag{4}$$

4.3 Fully Layered Satellite Architecture call flow

Figure 8 illustrates stages of the FLSA structure for call setup delay between many satellite systems in different orbits.
In FLSA, each satellite system is organized hierarchically based on the priority of ground stations and type of orbit. For example, low orbit satellite manages ground stations directly connecting to it, while high orbit satellite manages all of ground stations. For this reason, high orbit satellite could manage ground stations and IP messaging in a larger value than low orbit satellite system. In FLSA, IP connection between two low orbit satellites will be via their higher orbit satellite as shown in figure

8. FLSA is exactly the same as the architecture of real satellite networks. Although this architecture might lose some advantages of SLSA, such as a single hop IP connection, existing techniques and simple managing solutions, can be inherited into satellite network.

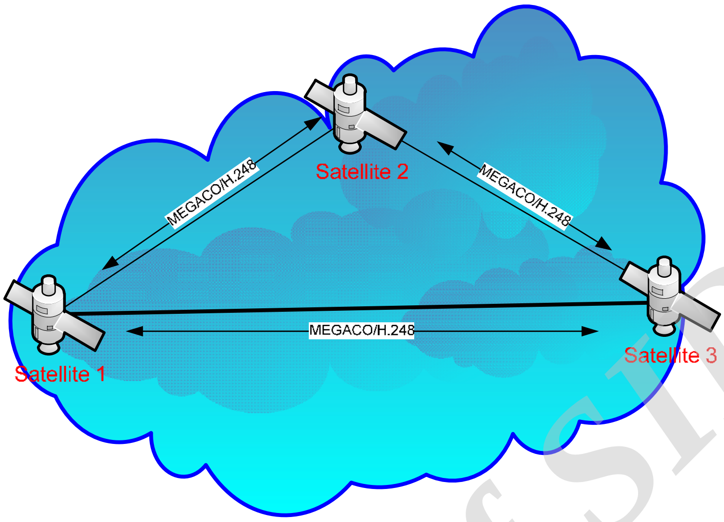

Figure 8: FLSA scenario

In figure 9, satellite (0) insert in a higher orbit, which does not access ground stations directly, but has to perform call setup in this structure.

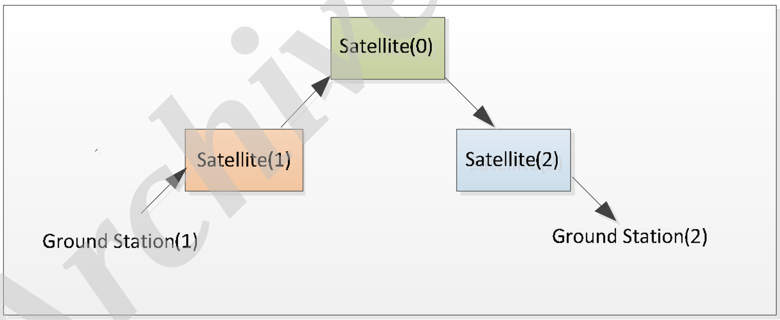

Figure 9: Satellite constellation based on fully layer architecture

Therefore, the queuing model for this scenario is shown in figure 10.

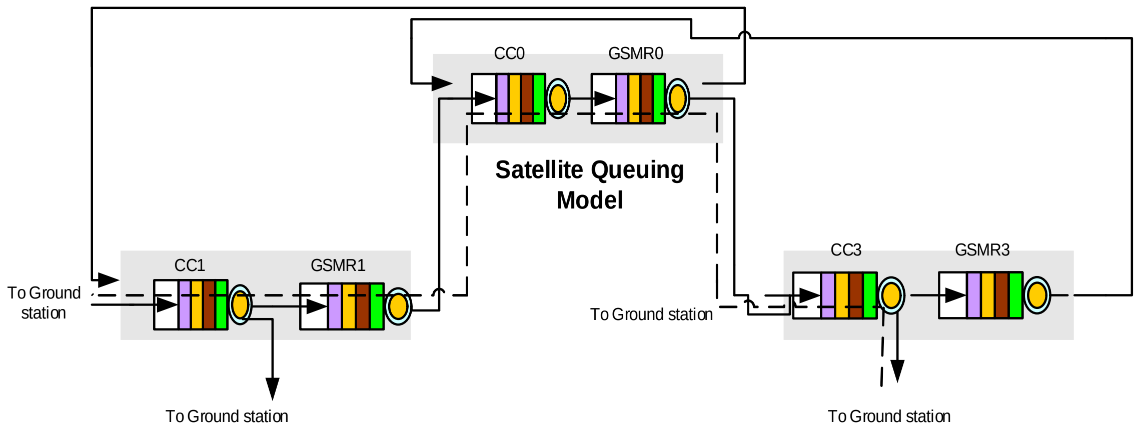

Figure 10: FLSA Queuing Model

In figure 10, the dashed line illustrates the path of a call setup delay message between satellite systems and ground stations. Based on [14], the call setup delay T is given by equation"(5)":

$$T = T_{CC1} + T_{GSMR1} + T_{CC0} + T_{GSMR0} + T_{CC2} + 2d \quad (5)$$

Where T_{CC1}, T_{GSMRI}, T_{CC0}, T_{GSMR0}, T_{CC2}, T_{GSMR} are the time delay of CC1, GSMR1, CC0, SMR0, CC2 and GSMR2. The arriving rate and the service rate for each queue in figure 10 are provided in table 3 and table 4.

Table 3: Arriving rate in FLSA [14]

λ_{CC1}	λ_{GSMR1}	λ_{CC0}	λ_{GSMR0}	λ_{CC2}	λ_{GSMR2}
$(1+R)\times\lambda$	$R\times\lambda$	$2\times R\times\lambda$	$2\times R\times\lambda$	$(1+R)\times\lambda$	$R\times\lambda$

Table 4: Service rate in FLSA [14]

μ_{CC1}	μ_{GSMR1}	μ_{CC0}	μ_{GSMR0}	μ_{CC2}	μ_{GSMR2}
1/C	1/f(m)	1/C	1/f(M,m)	1/C	1/f(m)

Based on [14], the call setup delay for this structure can be given by equation"(6)":

$$T = \frac{2\times C}{1-C\times(R+1)\times\lambda} + \frac{f(m)}{1-R\times\lambda\times f(m)} + \frac{C}{1-2\times C\times R\times\lambda} + \frac{f(M,m)}{1-2\times\lambda\times f(M,m)} + 2d. \quad (6)$$

4.4 Hybrid Layered Satellite Architecture call flow

Figure 11 illustrates the stage of the HLSA scenario for call setup delay between many satellite systems.

Based on [14], we have two main concepts in this architecture which include "domain" and "region". In this type structure, a satellite manages all ground stations and signaling routing in a specific domain. In this structure, a satellite region is composed of many small domains. Two satellite systems residing in the same satellite region, but two different domains will rely on the high orbit satellite system for each call setup scenario based on MEGACO or other signaling protocols.

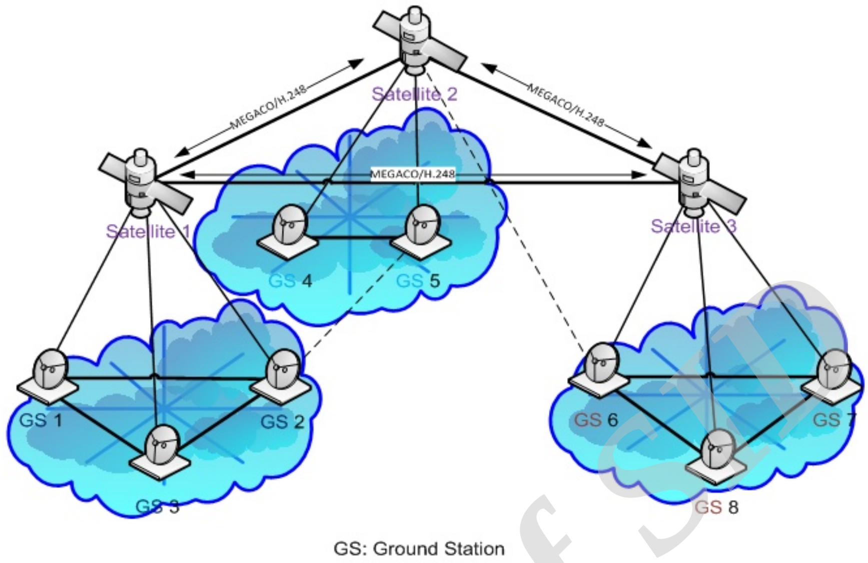

Figure 11: HLSA scenario

Therefore, the queuing model for this scenario is shown in figure 12.

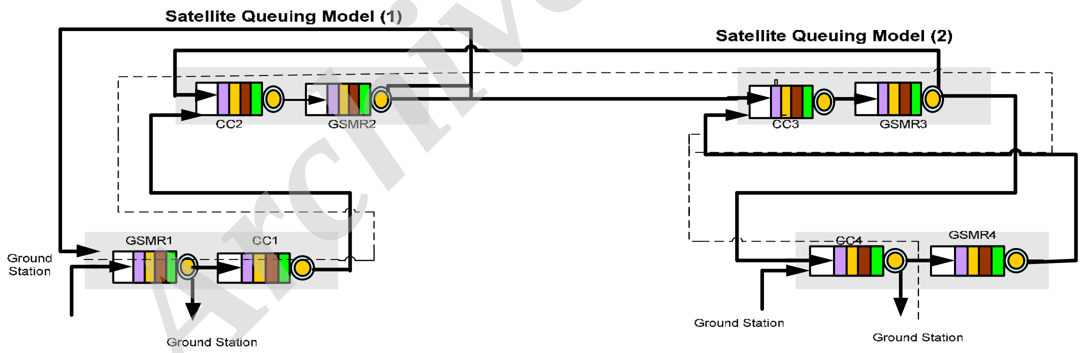

Figure 12: HLSA Queuing Model

5. Numeric Analysis based on different satellite configurations

1. The input and output of Markov processes are one directional and independent to the previous values [1-2]. Call setup delay was analyzed by M/M/1 queuing model. The Call setup delay is based on equation"(7)":

$$T = \frac{1}{m - l}. \qquad (7)$$

Which µ is arrival rate and l is service rate.

2. In queuing model are assumed as 0.5/μ for sending the request followed by reply and modify request and modify reply with 0.3/μ.
3. The number of ground stations could directly connect to a single satellite is 10000.
4. The percent of calls are outgoing calls is 0.2.
5. The average service time for CC is 0.03s.
6. The average time used to add or remove a ground station in a satellite will linearly increase. It means τ=f (m), where $\alpha=4.3\times10^{-8}$.
In order to calculate system's call setup delay and mean number of ground station with propagation delay varying between [0-250] ms (Figures 13,14).
As one can see the call setup delay with variation of number is approximately linear for HLSA, FLSA but SLSA is exponential behavior with increasing the number of ground stations. The results obtained in comparison with ref.[14] show a higher call setup delay due to the high value propagation delay in the satellite constellations.

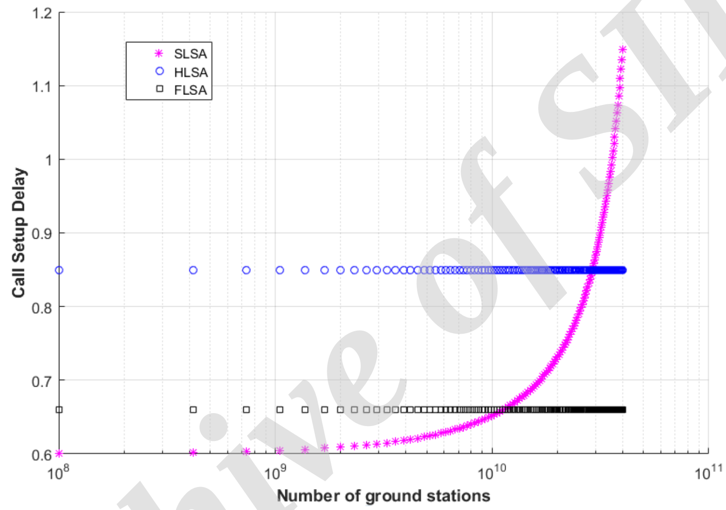

Figure13: Call setup delay based on ground station

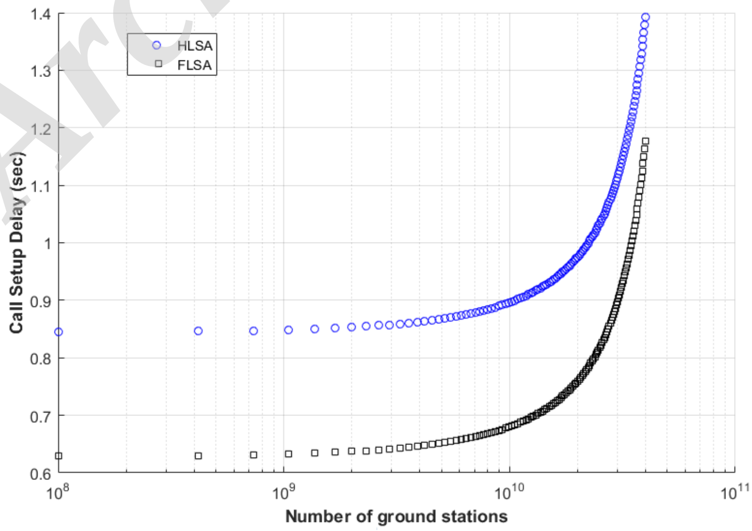

Figure14: Comparative between HLSA and FLSA based the number of ground stations

6. Conclusion and Future works

Based on the measurements and analysis, satellite network architecture was modeled by three different models with the presence of propagation delay in queuing model. Therefore, we understand the call setup delay for SLSA is much smaller than HLSA and FLSA and the HLSA and FLSA models have approximately the same behavior. In the future, we continue to work on redesigning this queuing model based on the multi-threaded program model that is instead of M/M/1 or M/D/1 queuing model we intend to focus on M/M/C or M/D/C or the combination of both. Also intend to expand the study by redesigning the performance model with multiple satellite located in remote locations and factor the network delays.

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