International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Optimizing Quality of Service in LEO Satellite Networks: A Comprehensive Review of Handoff Algorithms and Satellite Diversity Strategies

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Abstract: ***Any robust communication system can be defined as one that can provide ubiquitous connectivity with lower latency periods. Since 1990, Low Earth Orbit (LEO) satellite constellations have proven to be plausible and efficient alternatives to high altitude GEO satellites in delivering seamless voice and data communication services. This is due to some of their important advantages over geo-stationary such as low power requirement, efficient utilization of frequency spectrum and, low propagation delays pertaining to the satellite's closer proximity to the ground station. On the downside, the difference in the mobility speed of a LEO satellite and a user on earth is so high that the user can be considered constant, unless he/she is on a fast-moving vehicle. This calls for strategical user handover mechanisms between LEOs to avoid call drops, as usually the service time for a user tend to be higher than the coverage time of a typical non-stationary LEO. Consequently, it is admissible to claim that the quality of service provided by such a network is limited by the performance of LEO handoff algorithms (generally based on parameters like Probability of call blocking/call termination, Throughput, Delay in transmission). In this paper, we will discuss the LEO handoff algorithms developed over the years and particularly delve into the most commendable satellite handover techniques exploiting the property of satellite diversity, that fall with Acceptable Forced termination of existing calls and dropping of new calls.***

Keywords: Satellite mobile communication, Handover, Satellite diversity

1. Introduction

Future communication networks are focusing on extending reachability to low populated areas and areas that are not covered entirely by terrestrial mobile communication network and an enhanced quality of service can be provided in these areas through satellites. The mindset in the past have been to inculcate most of the complexity to the earth's ground station rather than on the satellite terminal itself. The number of aspects in designing a satellite network has been growing alongside with the advancement in technology and trying to cope up with the need to have robust communication network with global connectivity. With the appearance of serving personal communication devices, it has made more sense to reduce the distance of satellites from earth for low round trip propagation delays and for higher bit rate. Most convenient solution for an efficient mobile communication, would be to make use of the LEO constellation because of their numerous advantages [1] as follows:

1) Due to their low altitudes, the propagation delay of a link from the end-user to the satellite is rather low, less than 5 ms.
2) The low altitude of the orbit translates into lower power requirements. This fact enables communications with handheld terminals.
3) Provide Global coverage.

Distance from earth	In kilometers
GEO	35,800
MEO	5,000-12,000
LEO	500-1,500

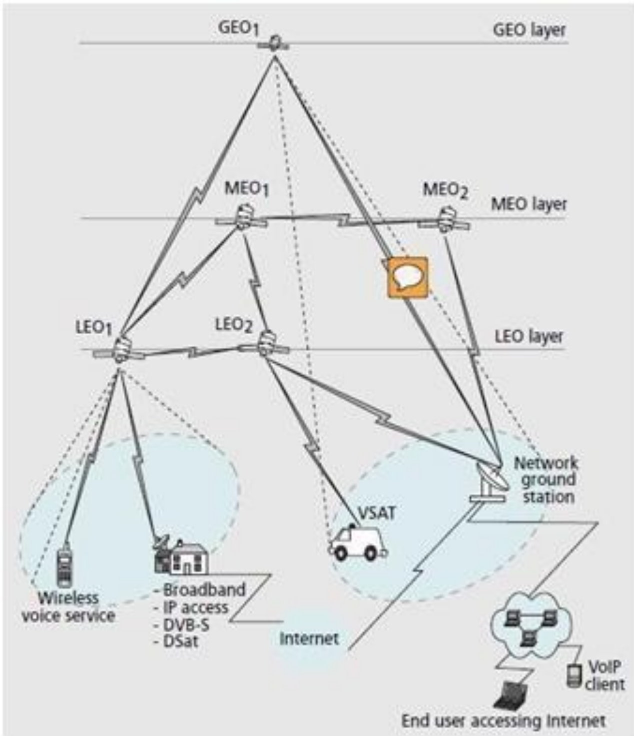

Figure 1: Layout of the different satellite layers and their major applications.
Note: LEO primarily has its applications in mobile and low/high speed data communications

In most satellite networks, Inter satellite links (ISL) between satellites exclude the need to rely on the terrestrial network in routing a connection between two satellite links. In systems that do not employ ISLs at least one satellite should be in view of both the user terminal and a gateway earth station [2]. Nevertheless, to obtain a real time feasible solution we need to overcome the downsides of the LEO satellites that is not present in the other constellations have. One main factor of interest is to arrive at a robust handoff mechanism due to its mobility.

Handover Techniques in Leo Satellites:

To understand the basis and working of each of the handover strategies, it is important for the reader to understand the following terms, related to LEO satellites: footprints, cell, cell/spot beam/intra-satellite handover, satellite/inter-satellite handover.

Footprints refer to the area that can be covered by a LEO and cells are the standard units of a satellite's coverage area that repeat all over the area, making use of frequency re-use to increase the capacity, which is very similar to a terrestrial mobile communication system. Handover in a satellite system can be classified in two broad categories [3]. The first type is the handover of an ongoing call between two adjacent satellites, while the second one accounts for the transfer of an ongoing call from one cell to the next one. The former is usually referred to as satellite or inter- satellite handover, whereas the latter is referred to as spot-beam, beam or cell handover.

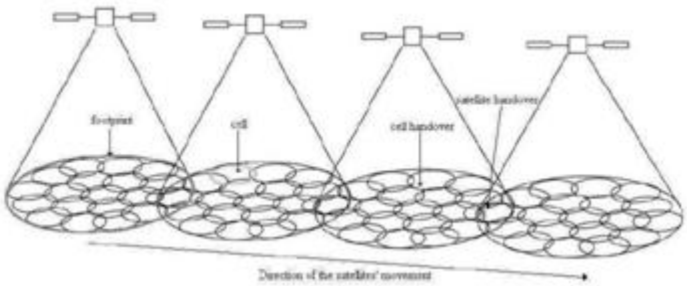

Figure 2: [4] Footprints of a LEO satellite

i) *Handover requests based on Queuing policies:*

Under fixed channel assignment for every satellite beam, all the handover requests are queued for a maximum period of time parameter before they are allocated a channel for service. Two main queuing policies that were adapted in this mechanism are FIFO (First-in-First-out) and LUI (last-update-packet: handover requests are given high priority than any other kind of request in queue irrespective of its residual time) [7].

At the end of the maximum time period, either the ongoing call is subject to termination, or the new call is dropped. According to ITU-U standards, by this method we can achieve a blocking probability of an arriving call (Pb) and the forced termination probability (Pf) of an ongoing call not exceeding 0.0005 and 0.1 respectively [5,6]. Handover queuing by this method is carried out typically when there is no channel resource in the relevant destination MS when at the time of request being sent.

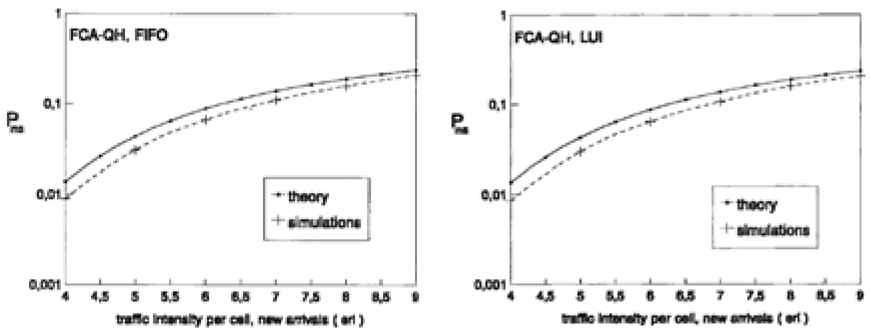

Figure 3: [6] Analytical and simulation graph results for a) Handover queuing FCA technique using FIFO b) using LUI queuing.

The efficiency of the LUI queuing discipline as regards the FIFO one depends on the following parameters: the mobility parameter, the number of channels per cell, and the traffic intensity per cell due to new call arrivals [6]. The results from both the queuing strategies are same and hence FIFO is preferred due to less complexity compared to LUI queuing.

ii) *Guaranteed Handover Service:*

New calls are admitted in the network only if a free channel is available in the current cell and the upcoming future transit cell. [8] In the absence of an open channel in the transit cell, the requests are queued until the next handover. By this mechanism we can avoid the number of forced termination calls. But we need to trade it off with the increasing call drop probability.

Simulation results almost show zero forced termination probability (Pf) but a very high blocking probability of an arriving call (Pb) because of increased restrictions at the entry point of a call into a network.

iii) *Geographical connection admission control (GCAC):*

In the previous methods, spotlight was on the channel allocation policies and queuing and QOS parameters were not given importance. This simple admission control procedure aims at reducing the blocking probability of an arriving call (Pb) by smart use of the limited LEO resources and providing a connection level quality of service in the network.

According to GCAC algorithm a call is admitted under two conditions:

Condition 1: The target handover call blocking probability (PQoS) is guaranteed for the newly arriving call.

Condition 2: The handover blocking probability of the existing call (Pb) does not exceed the target handover blocking probability.

Mathematically, if the following [9] condition holds calls are admitted,

$$P_b = \frac{E_b}{E_h} \leqslant P_{QoS}$$

PQoS - Target handover call blocking.
Eb- Expected number of blocked handover arrivals
Eh- Expected number of handover arrivals
Eb, Eh are dependent on the probability of active handover calls at that instantaneous moment.

The idea is to derive the estimates of Pb and Pf on the basis that LEO trajectory and positions of the users are deterministic values [9]. The handover algorithm bases its decision to the closest values on comparison of the estimated values with a set of pre- defined values. The GCAC/ADCA algorithm can also be well suited for non-uniform traffic pattern as it uses real-time user location to estimate handoff decisions. The range of handover blocking probability using the GCAC/Adaptive Dynamic Channel Allocation is 0.0001 to 0.001. For more detailed analysis please refer to the simulated graphical results in [9].

iv) Doppler based handover prioritization technique (DDBHP):
The issue of dynamic handover management was addressed in [10], this proposed technique that made use of Doppler effect concept to track the exact time of occurrence of handover requests which are then forwarded just before the occurrence of handover to the destination cell to reserve channels by time threshold.

The term appropriate time is the time interval (*time threshold tTH*), prior to the handover occurrence, during which resource allocation activities should be completed. The instant prior to the handover of the terminal, on which a channel reservation request is sent to the forthcoming satellite, is defined by *tTH*. The scheme was evaluated in both LEO and MEO satellite systems that supported only voice. [10, 11]

Dynamic Doppler Based Handover Prioritization Technique" was extended in [11] for the case of *satellite handovers* in LEO satellite systems with satellite diversity. Moreover, three different satellite selection criteria were proposed, which can be applied to both new and handover calls. The scheme was evaluated in systems that supported only voice service.

v) Foundational Handoff Algorithm:
Acceptable Forced termination of existing calls and dropping of new calls: MODEL SETUP:
Consider a 2D LEO satellite footprints that is valid as long as the following assumptions are met.
- The users are considered to be constant when compared to the velocity of the satellite.
- Rotation of earth is not taken into consideration.
- The overlapping area between successive satellites in the same orbital plane is not taken into account since in that case a user should always be connected to the following satellite in order to avoid an immediate handover. However, the overlapping area between contiguous satellites in different orbital planes is taken into consideration.
- Uniform distribution of terminals over the network.
- Polar Satellite network (Iridium, Teledesic).

System Name	System Parameters				
	P	M	i	h	α
Iridium	6	11	86.4°	780	8.2°
Globalstar	8	6	52°	1414	10°

Number of planes	12
Number of satellites per plane	24
Satellite altitude	1375Km
Inclination	85°
Acceptable minimum elevation angle	40°

Figure 4: [11] Parameters of common BIG LEOs, b) Teledesic system

Principle idea: Call is admitted if the channel is free in the current satellite. This handover mechanism between LEOs to avoid call drops works by keeping in mind that usually the service time for a user tend to be higher than the coverage time of a typical non-stationary LEO and as the elevation angle reaches a minimum point, the user has to be handed off to another satellite. Channel is reserved at the satellite selected for first handoff if it is known from the location of user terminals that the handover will occur at a time less than the time needed to allocate resources. Or the call may be blocked. After admission of a call, as we know that a user can be under the coverage of multiple satellites (as shown in Fig 4) at one instant, satellite diversity property comes into the picture to and is exploited to select a satellite based on three factors as proposed in [4]. –
1) Maximum service time: Satellite having a maximum serving time of a user is given preference thereby reducing the number of handovers
2) Maximum number of free channels: Satellite with higher number of free channels will be serving the satellites thereby avoiding over burdening a busy satellite.
3) Minimum Distance: Closest satellite to user will serve the satellite, decreasing the possibility of physical link failures.

Selection of *tTH* is crucial. *tTH* and Pf are inversely proportional; *tTH* and Pb are directly proportional to each other. Also a small tweak in the time threshold will affect the quality of service in the system.

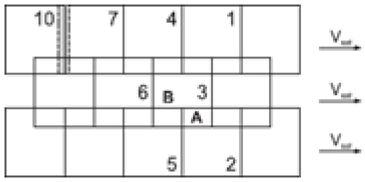

Figure 5: [4] Model setup for mobility

Service scheme	New Calls criterion	Handover criterion
TT scheme	Max service Time	Max service Time
CC scheme	Max number of free Channels	Max number of free Channels
DD scheme	Min Distance	Min Distance
TC scheme	Max service Time	Max number of free Channels
TD scheme	Max service Time	Min Distance
CT scheme	Max number of free Channels	Max service Time
CD scheme	Max number of free Channels	Min Distance
DT scheme	Min Distance	Max service Time
DC scheme	Min Distance	Max number of free Channels

Figure 6: [4] Service schemes based on the satellite selection criterion

Simulation Results:

Each mobile user generates calls that enter as a poisson process¸ with rate lambda (user), while Tcall is the average call duration. tF be the maximum time that a mobile user can stay in a satellite footprint.

Let the mobility model be the one in Fig 5. The common area in the satellite footprints is about 13%

$$\frac{\text{Common coverage area}}{\text{Footpint area}} = 13\%$$

Under a set of satellite network parameters , the algorithm in [11](CT scheme) has Pb = 0:1275 and Pf =0.0098 while the worst scheme (CD scheme) has Pb = 0.1787 and Pf = 0.0165 . For calculation details, refer [11].

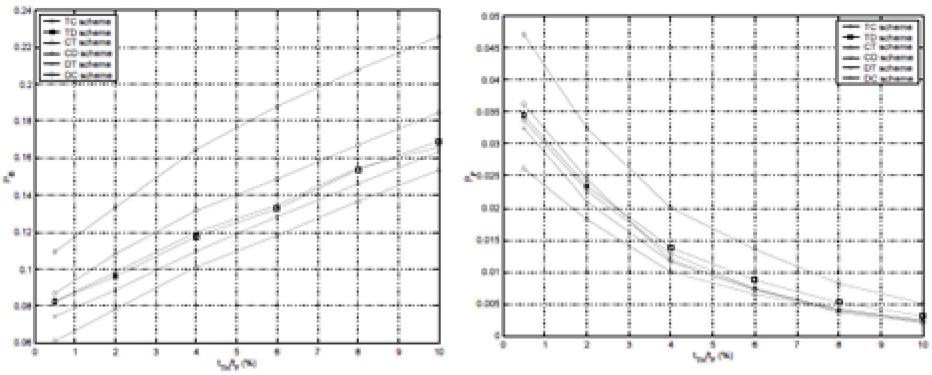

Figure 7: [11] *Pb* for Teledesic if different selection criteria are applied to the access and handover procedure; *Pf* for Teledesic if different selection criteria are applied to the access and handover procedure

2. Conclusion

There had been several handoff algorithms in LEO satellites over the decades for cell handovers of users in LEO. It is difficult to devise an efficient inter-satellite handover but can be realized in a low earth orbiting satellite by analyzing performance of handovers three predefined parameters: Service time, Distance and channels for satellite decision. Conclusively, the performance of the handover procedures in LEO satellites trade-off between the blocking and call termination probabilities. Usage of DDBHP technique for inter satellite handover greatly improved the quality of service of users at the connection level.

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