QoS Handover Management for Multimedia LEO Satellite Networks

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Abstract

Low earth orbit (LEO) satellite systems gained considerable interest towards the end of the previous decade by virtue of some of the appealing features that are endowed with, such as low propagation delay and the ability to communicate with handheld terminals. However, after the limited commercial success of the first networks of this kind, future satellite networks are now conceived as complementary rather than competitive to terrestrial networks. In this paper, we focus on one of the most influential factors in system performance, that is, the handover of a call. First, we provide a succinct review of the handover strategies that have been proposed in the literature. Then we propose two different satellite handover techniques for broadband LEO satellite systems that capitalize upon the satellite diversity that a system may provide. The proposed schemes cater for multimedia traffic and are based on the queuing of handover requests. Moreover, a deallocation scheme is also proposed according to which capacity reservation requests are countermanded when the capacity that they strive to reserve is unlikely to be used. Simulation studies further document and confirm the positive characteristics of the proposed handover schemes.

Keywords: LEO satellite systems, handover management, satellite diversity, multimedia traffic, QoS provisioning

1 Introduction

Satellites have been used for telecommunications, positioning, navigation and remote sensing for years. The interest in satellite systems dates back to the middle of the last century [1]. The mindset of satellite systems designers over the past decades has been to keep most of the system's complexity on the ground segment. However, the growing exigencies for both mobility and ubiquitous access, coupled with advances in technology, have changed the approaches to the design of satellite systems. The advent of personal communications services has led the designers to move satellites closer to the Earth in order to enable low-delay and high bitrate communications services.

The focus of this paper is on low earth orbit (LEO) satellite systems. This type of systems gained considerable interest towards the end of the previous decade [2, 3] by virtue of some

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of their attractive features. The most important advantages that LEO satellite systems are endowed with are as follows:

- Due to the fact that LEO satellites orbit the Earth at an altitude between 500 and 1500 km, the propagation delay of the link from the end-user to the satellite is rather low, less than 5 ms.
- The low altitude of the orbit translates into lower power requirements. This fact enables communications with handheld terminals.
- Polar (*Walker star*) LEO satellite systems provide global coverage[1].

Notwithstanding the aforementioned advantages, due to the movement of the satellites with respect to the Earth's surface a call should be handed over between contiguous satellites. Hereafter we consider LEO satellite systems with inter-satellite links (ISLs), hence at least one satellite needs to be visible to the source terminal. 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 [4]. In recent satellite systems, the coverage area of a satellite, which is referred to as its footprint, is divided into several cells in order to increase the capacity of the network. This is realized by equipping the satellite with multispot-beam antennas. Therefore, two types of handovers can be distinguished [5]. The first one refers to 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*[2]. Moreover, this study deals with *fixed cell/footprint* systems. In this kind of systems cells/footprints move along with the satellites' ground tracks.

Fourth generation (4G) networks, often dubbed beyond third generation (3G) networks, will include all existing and emerging fixed and mobile networks. With the advent of this kind of networks new applications are expected to thrive. In this context, LEO satellite systems can be a major asset to wireless infrastructure operators to provide complementary services to the ones provided by terrestrial systems. Moreover, LEO satellite networks can be employed for the provision of telecommunications services to areas where there is no substantial terrestrial infrastructure. However, as is the case with terrestrial cellular networks, the case of service interruption due to an unsuccessful handover arises in LEO satellite systems as well. In this

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[1] Albeit rosette (*Walker delta*) LEO satellite constellations do not provide global coverage (there is no coverage in the vicinity of the poles), they provide their best coverage at the mid-latitudes where most human population lies.

[2] Hereinafter the term *satellite handover* is used to describe the handover of a call between two neighboring satellites and the term *cell handover* refers to the handover of a call between two contiguous cells.

paper we propose and evaluate two different *satellite handover* schemes which are tailored for broadband LEO satellite systems that support multimedia services. After the limited commercial success of the first two LEO satellite networks, namely Iridium and Globalstar, which mainly provide voice services, it has become evident that future networks should support a broad spectrum of services, and this has been the main drive behind this work.

The proposed schemes aim at providing an infallible handover technique for multimedia services, without unacceptably increasing the blocking probability of new calls, that is, the probability of rejecting a new call. The main mechanism behind the proposed schemes is the queuing of handover requests. Moreover, different strategies are applied to calls that belong to different service classes. Additionally, the proposed techniques can capitalize upon the partial or full satellite diversity that a system may provide in order to enhance system performance. By the term satellite diversity we simply mean that a terminal has a choice of multiple visible satellites with which it can communicate. After opting for one of them, the terminal establishes a single duplex radio link with that satellite. This kind of satellite diversity is also referred to as switched diversity [6]. The performance of the schemes is also enhanced by a novel deallocation technique according to which capacity reservation requests, that is, handover requests, are countermanded when the capacity that they strive to reserve is unlikely to be used.

The remainder of the paper is structured as follows. Section 2 constitutes a concise review of call admission control (CAC) and handover schemes that have been proposed in the literature. In section 3 the mobility model that is used in our study is described. The proposed techniques are delineated in section 4, while section 5 deals with simulation results. Finally, concluding remarks are drawn in section 6.

2 Review of CAC and Handover schemes

The handover of a call constitutes a daunting challenge in LEO satellite systems and many studies have grappled with it. In this section we provide a succinct review of CAC techniques as well as handover schemes that have been proposed for non-geostationary orbit (non-GEO) satellite systems. The aim of CAC is to decide whether to accept or reject a new call. The call is admitted into the network provided that the QoS (quality of service) requirements of the new call are met and that it will not impact on the QoS of existing calls. On the other hand, handover techniques aim to ensure that the service of a connection will not be interrupted as the user moves from one cell (or footprint) to another. The works are referenced on a time-line basis, identifying the seminal works in this field on the one hand, and works that primarily extended previous studies on the other hand.

In [7] two dynamic channel allocation techniques for LEO satellite systems were studied and compared to a classical fixed channel allocation scheme. Furthermore, the queuing of handover requests was proposed to reduce the forced termination probability, namely the probability of dropping an ongoing call. According to the proposed technique when a channel is not available in the next cell the handover request is queued up for a specific time interval which is a function of the overlapping area between contiguous cells. The queuing of handover requests was based on the well-known *first in, first out* (FIFO) policy. Del Re *et al* extended that work and studied another queuing policy in [8]. In that queuing policy, which was named LUI (*last useful instant*), handover requests are served on the basis of the remaining time interval in the cell until the handover occurrence. The performance disparity between the FIFO and LUI queuing policies was also accentuated in [9], where these queuing policies were assessed under the assumption of a fixed channel allocation scheme.

The study in [10] was focused on the impact of different mobility conditions on the performance of radio resource management strategies. To be more precise, a mobility model was proposed and the impact of user mobility on both blocking probability and forced termination probability of a fixed channel allocation scheme was evaluated.

Maral *et al* studied a *"guaranteed handover"* scheme in [11]. That scheme holds considerable appeal for high class users, i.e., business users, and can be implemented in conjunction with a simple handover scheme for regular users. According to the *"guaranteed handover"* scheme a new call is admitted into the network provided that a channel is available both in the current cell and in the first transit cell, otherwise it is blocked. Concerning subsequent handovers, a channel reservation request is sent to the next transit cell as soon as a handover takes places. This request should be served within the terminal's sojourn time in the serving cell. The requests are queued on a FIFO basis.

The study in [4] assessed the *"guaranteed handover"* scheme as a *satellite handover* technique for LEO constellations that require at least one satellite to be visible to both the user terminal and the gateway earth station. Moreover, different satellite selection criteria were described which can be used for both new and handover calls. It should also be noted that, in both [11] and [4], the scheme was tested for voice traffic.

In [12, 13] a scheme similar to the *"guaranteed handover"* technique was proposed. That scheme aimed at achieving a better channel utilization than the *"guaranteed handover"* algorithm. Towards this end, the channels in that scheme are reserved only for the time interval that are expected to be in use. Thus the name *time-based channel reservation* algorithm that was given to it. It is apparent that the algorithm necessitates satellites with integrated positioning facilities. In [12] another version of that algorithm was proposed for constellations where a positioning system is not available.

In [14], a CAC strategy was proposed, along with a *cell handover* scheme. A metric, called *mobility reservation status*, was introduced that aimed to provide the information about the bandwidth that is required by all the active calls in each cell as well as to predict the potential bandwidth requirements by calls in adjacent cells. Upon a new or a handover request, the aforementioned metric was compared to predefined thresholds. The scheme was evaluated for two different mobility models. In addition, a fixed channel allocation scheme was employed and constant bit rate traffic was assumed.

A dynamic channel reservation technique was proposed in [15]. The proposed strategy was predicated upon the view that the longer a call has lasted, the less likely will it require a handover to the next cell. A parameter, referred to as *channel reservation number*, was introduced with the aim of predicting the number of channels that should be reserved in each cell.

The issue of dynamic handover management was addressed in [16, 17]. The proposed technique, which was called *"Dynamic Doppler Based Handover Prioritization Technique"*, capitalizes upon Doppler measurements in order to derive the time instant of the handover occurrence and the destination cell. Then, a channel reservation request is sent to the destination cell at a specific time instant prior to the handover occurrence. The scheme was evaluated in both LEO and MEO satellite systems that supported only voice traffic. In addition to the simulation results given in [16, 17], an analytical study of the performance of this scheme was provided in [18].

In [19, 20], the *"Dynamic Doppler Based Handover Prioritization Technique"* was extended 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.

A combination of the *"Dynamic Doppler Based Handover Prioritization Technique"* with the *Guard Channels* scheme was studied in [21]. The scheme was evaluated in LEO satellite systems with different percentages of overlapping between contiguous satellite footprints. To this end, a novel mobility model was proposed which takes account of the Earth's rotation. Furthermore, all the systems were considered to provide three different constant bitrate services.

In [22], an adaptive dynamic channel allocation scheme was proposed. That scheme relies upon the concept of guard channels. The number of channels that are reserved in each cell for handover requests is dynamically adapted based on the estimation of the future handover events. The studies in [23, 24] extended that scheme and proposed a *geographical connection admission* *control* algorithm. That algorithm aims to guarantee that the forced termination probability is always below a predefined threshold. Upon the arrival of a new call the algorithm estimates the future forced termination probabilities of both the new call and ongoing calls. The call is admitted into the network as long as these probabilities are below the predefined threshold.

Another scheme that aims at reducing the forced termination probability was proposed in [25]. That scheme makes use of the *channel sharing scheme* according to which channels can be shared between neighboring cells. A pair of successive cells was called metacell in that study. When a new call arrives in a cell, it is accepted provided that a channel is available in the metacell that consists of the current cell and the next one. Thus, this technique assures a successful first handover. After the first handover the call tries to reserve a channel that belongs to the next metacell. If there is no channel available the request is placed in a FIFO queue.

In [26] a predictive *cell handover* management and admission control strategy that is tailored for LEO satellite networks that support multimedia services was proposed. The supported traffic was classified into two classes. One that corresponded to real-time multimedia traffic and another that characterized non-real-time data traffic. The scheme aimed to predict and reserve for each accepted real-time call a certain amount of bandwidth in the cells to which the call might be handed over.

In [27], a resource reservation strategy for multimedia LEO satellite networks was proposed. This strategy was combined with a CAC technique that handles calls of different service classes differently. Furthermore, a mobility model that takes the Earth's rotation into account was proposed. Simulations results showed that the rotation of the Earth profoundly affects the performance of any scheme and hence it should not be disregarded.

Another call admission and *cell handover* scheme tailored for multimedia LEO satellite systems was proposed in [28]. According to that scheme handover requests are stored in four different queues. The management of the queues is such as to give priority to real-time multimedia calls over non-real-time data calls. Additionally, for each accepted real-time multimedia call the scheme tries to reserve a sufficient amount of bandwidth in the next two cells. The study in [29] extended the previous scheme and combined it with the concept of multiple virtual windows. The rationale behind the use of multiple virtual windows is to predict the amount of bandwidth that will be available at the time instant of the handover occurrence.

In [30] a *satellite handover* scheme for multimedia LEO satellite systems was proposed. In that study the supported traffic was categorized into two classes, one that accounted for real-time multimedia calls and another that accounted for non-real-time data services. The technique that was used for real-time services was similar to the one that was proposed in [4], whereas the strategy that was employed for non-real-time calls was similar to the one that was applied to data calls in [28].

The study in [6] showed how the geometry that inclined rosette non-GEO satellite systems have can be exploited to provide varying classes of service and thus, support QoS. In rosette constellations a user can communicate either with an ascending or a descending satellite. In that study, a controlled handover management was proposed according to which the user is able to control whether the handover will take place to the ascending or the descending satellite with the aim of reducing end-to-end delay.

In [31], a combined *satellite handover* algorithm was proposed. In any cellular wireless system a handover is usually initiated when the power of the received signal is below a predefined threshold, while a call may be forced into termination if the received signal power is below the minimum required signal power. In that study, in order to diminish the probability of such a call termination, the handover decision was made based on both signal power measurements and the terminal's position.

A *satellite handover* scheme that is suited to the satellite component of UMTS was proposed in [32]. The proposed scheme is tailored for non-GEO satellite diversity based systems. It uses two different power thresholds in order to reserve or release a satellite channel. This scheme was extended and a hybrid handover algorithm was presented in [32, 33]. According to that algorithm under critical channel conditions a terminal can communicate simultaneously with the two satellites that are seen under the highest elevation angles.

In [34] the problem of carrying voice calls over a LEO satellite network was studied and an analytical model for computing blocking probabilities was devised. That model can be applied to a single orbit of a LEO constellation that comprises five satellites at most. Moreover, a decomposition algorithm was developed for orbits that consist of a greater number of satellites.

3 Mobility Model

It is evident that the movement of the satellite footprints with respect to the Earth's surface profoundly impacts on system performance. Several mobility models can be found in the literature that aim at describing the movement of the satellite footprints on the Earth's surface. Usually, such a model comprises a set of rules that permit one to estimate the user's sojourn time in a cell or a satellite as well as to predict the time instant and the location of the upcoming handover.

Most of the proposed mobility models consider only the movement of satellites and neglect both the rotation of the Earth and user mobility [7]-[13], [15]-[20], [22]-[26], [28, 29]. These models are usually referred to as one-dimensional mobility models because they assume that users move on a straight line and therefore they are always handed over to the next cell or satellite in the direction of the satellite's motion. Although these assumptions make for a simple model to work with, they are not realistic. Some studies proposed more realistic mobility models that take the rotation of the Earth into account [14, 21, 27]. These models are referred to as two-dimensional mobility models since the movement of users is considered to be the combined effect of the satellite's motion and the Earth's rotation. As was shown in [27], the rotation of the Earth profoundly affects the performance of any scheme.

In this study the mobility model that was proposed in [21] is employed, which is depicted in figure 1. This model applies to polar constellations and consists of the following set of rules:

- The footprint of a satellite is considered to have a rectangular shape. This assumption is valid for polar constellations [11], [19]-[21].
- A handover is performed only when the serving satellite is seen by the user terminal under the minimum elevation angle, that is, the power received by the user terminal from the serving satellite is at the minimum acceptable level. 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 (the gray area in figure 1).
- Users move with a speed which is the combination of the satellite's speed and the Earth's rotation. The velocity of users in fast vehicles is disregarded since it is negligible compared to the satellite's speed and the Earth's rotation (note that users in fast vehicles move with a velocity of 80 m/sec at most, while the ground track speed of LEO satellites is over 5700 m/sec and the speed that corresponds to the rotation of the Earth at the equatorial level is around 460 m/sec). The rotation of the Earth is considered to correspond to a velocity V_{rot} which is set equal to the velocity at the equatorial level. Since only a part of the entire system is modeled which is not considered to be over the poles, this assumption is valid. Moreover, the fact that most of the human population lies at mid- and low-latitudes reinforces the validity of that assumption.
- The terminals are uniformly distributed over the network.

figure 1 should appear here

It becomes evident from figure 1 that due to the rotation of the Earth the satellite to which a call will be handed over is not always the next one in the same orbital plane, but it can be a satellite of the contiguous orbital plane. Moreover, satellite selection criteria should be defined for users that are located in overlapping areas. Satellite selection criteria have been proposed in [4],[19]-[21]. These criteria can be applied to either new calls or handover calls. For the sake of completeness, they are described in brief below:

Maximum capacity criterion: According to this criterion the satellite with the maximum available capacity (i.e., the least loaded satellite) is selected. This criterion aims to attain a uniform distribution of the traffic load over the celestial network.

Maximum service period criterion: According to this criterion the satellite that offers the maximum visibility period is selected. The aim of this criterion is to minimize the number of handovers per call.

Minimum distance criterion: According to this criterion the closest satellite (i.e., the satellite that is seen under the highest elevation angle) is selected. This criterion aims to mitigate channel impairments. However, the impact of propagation impairments on the handover mechanism is beyond the scope of this study and we will not dwell upon it.

4 Resource and Handover Management

4.1 Motivation

Call handover is indisputably an issue of paramount importance in LEO satellite systems. Most of the studies on this topic focused on narrowband networks that supported only voice calls. Nevertheless, the valuable experience gained by the two LEO satellite networks that are currently in operation, namely Iridium and Globalstar, showed that this kind of networks is unlikely to come to fruition. New requirements for flexible network access have emerged within the telecommunications community, spurred by the vision for optimal connectivity anywhere, anytime. In this context, LEO satellite systems can fulfil this vision and satisfy the growing exigencies for both mobility and ubiquitous access, and this has been the main drive behind this work.

In this paper we focus on broadband LEO satellite systems that support a host of services and propose two satellite handover techniques that are geared towards the QoS requirements of multimedia services. The proposed schemes aim to keep forced termination probability to a minimum, while keeping blocking probability at acceptable levels at the same time. At this point it is worth noting that the geometry of many commercial proposals of LEO satellite systems provides partial or full double surface coverage, that is, satellite diversity, such as Celestri, Globalstar and Teledesic. However, only a handful of studies has taken account of this fact [4, 19, 21, 30, 33], albeit satellite diversity can prove beneficial to system performance. Towards this end, the proposed schemes can capitalize upon the geometry of LEO satellite diversity based systems in order to enhance network performance.

4.2 Description of the schemes

In this subsection the details of the proposed handover techniques are spelled out. However, before setting out the delineation of the schemes, we shall lay out some details about the services that the LEO satellite system is considered to provide. Hereinafter, it is considered that the system provides multimedia and data services which are categorized into two classes, namely *class 1* and *class 2*. *Class 1* accounts for real-time multimedia services that have stringent QoS requirements, whereas *class 2* comprises non-real-time data services with looser QoS constraints. Each type of service is characterized by the minimum capacity that is required by the source in order to maintain an acceptable quality (e.g. the lowest encoding rate of its codec), the maximum capacity that is required for this service and the mean duration of the call. Moreover, it is considered that each satellite has two queues where handover requests, namely capacity reservation requests, are stored. The first queue contains requests of *class 1* calls and is called *Queue-1*, while the second queue contains requests of *class 2* calls and is named *Queue-2*.

The main mechanism behind the two techniques that are proposed in this paper is based on dynamic bandwidth deallocation. According to the proposed mechanism capacity reservation requests are countermanded when the capacity that they try to reserve is unlikely to be used. First, the first handover scheme is delineated and then the disparities between this scheme and the second scheme are accentuated. For the sake of presentation, the first scheme is called *non-persevering bandwidth allocation*, while the second one is named *persevering bandwidth allocation*. The reasons for giving these names will become apparent below. The description of the two scheme follows.

4.2.1 Non-persevering bandwidth allocation

For *class 1* calls, a new call is admitted into the network only if the minimum capacity that is required by the source is available in the visible satellite. Users covered by two satellites first check the available capacity in the satellite that is indicated by the satellite selection criterion that is employed for new calls. If the available capacity is higher than the minimum capacity that is required for the specific type of service, then the call will be admitted into the network and will be served by this satellite. Otherwise the available capacity of second satellite will be checked. A call will be blocked when the available capacity in both satellites is lower than the minimum required capacity. In light of the above it becomes evident that users that are located in the overlapping area stand a greater chance of being admitted into the network than users that are covered only by one satellite. Hereafter, the technique will be described for the case of a terminal that is located in the overlapping area and therefore, it is covered by two satellites, since this constitutes the most complex case.

As soon as a new *class 1* call is accepted the serving satellite derives the time instant of the first handover occurrence as well as the satellites to which the call may be handed over. A handover request, that is, a capacity reservation request, is thereupon sent to them through ISLs. The request is stored in the *Queue-1* of each satellite and should be served within the remaining time interval till the handover occurrence. If one of these two requests is served, then the capacity reservation request that has been sent to the other satellite is countermanded by means of a cancelation request that is sent through ISLs. Hence, the proposed scheme does not waste the limited bandwidth of the satellite channel compared to schemes that reserve capacity in both satellites and make the decision regarding the satellite to which the call will be handed over at the time instant of the handover occurrence [4, 19, 21, 30].

As far as handover calls are concerned, the proposed scheme does not employ a satellite selection criterion when there exist two candidate satellites for serving the call owing to the fact that it is most unlikely that capacity will be available at the same time instant in both visible satellites if the system is not unloaded. Besides, it is quite difficult to calculate the serving period that each candidate satellite offers, namely the time interval during which each satellite will be visible to the user terminal, or to estimate the closest satellite while these satellites are not visible to the user terminal. Therefore, in our study in the rare case that capacity is available in both candidate satellites for relaying the call, the satellite to which the call will be handed over is the following one in the same orbital plane. Upon a successful handover, the serving satellite calculates both the time instant of the next handover occurrence and the satellites to which the call may be handed over and immediately sends them a handover request. Then, the same procedure is followed. A call is forced into termination only if these two requests have not been served until the time instant of the handover occurrence. In that case, the requests are removed from the queues after the call is dropped.

Concerning the technique that applies to *class 2* calls, it shares many similarities to the procedure that is used for *class 1* calls. The only difference between them lies in the amount of bandwidth that is required so that a *class 2* call will not be blocked or forced into termination. A new *class 2* call will be admitted into the network as long as there is some residual capacity in one of the visible satellites, that is, any value greater than zero. It should be noted that the lower the bandwidth that is allocated to a terminal, the longer the transmission delay and queuing delay (recall that the transmission delay is equal to the allocated capacity divided by the packet's size in bits). Hence, a lower bandwidth allocation translates into longer end-to-end delay. Similarly, a handover request, which is stored in *Queue-2* in this case, is considered to be served if some residual capacity has been reserved in one of the visible satellites. Evidently, when capacity has been reserved in one satellite, then the handover request that is stored in the other satellite is deleted. It should be pointed out that each call, irrespective of the class it belongs to, reserves the maximum capacity that is required by the specific service when the available capacity in the visible satellite is equal to or higher than it.

At this point we should stress the importance that the estimation of the terminal's location has to the proposed technique. The satellite should be aware of the terminal's location in order to be able to calculate the time instant of the handover occurrence as well as to derive the candidate satellites for relaying the call. To this end, several techniques have been proposed. The most simple one is to consider that the location of the terminal is derived through a positioning satellite system such as GPS. This necessitates user terminals that are equipped with GPS receivers. The terminal can send its location to the satellite via a packet. A more appealing solution is based on the Doppler effect. The application of Doppler-based techniques proved to be an efficient and low-complexity method for the estimation of the location of a user terminal and the prediction of the time instant of the handover occurrence [16, 17, 35, 36]. Doppler-based techniques necessitate satellites with on-board processing capabilities. Nevertheless, this constitutes a requirement that should be met by most of the future satellite networks.

4.2.2 Persevering bandwidth allocation

Now it may have become clear why we gave the name *non-persevering bandwidth allocation* to the aforementioned scheme. This name was given on account of the fact that *class 2* calls are considered to be satisfied even with a capacity lower than the minimum capacity that is required by the source. Concerning *class 1* calls, the *persevering bandwidth allocation* scheme and the *non-persevering bandwidth allocation* scheme are alike. However, they differ in regard to the technique that applies to *class 2* calls. The *persevering bandwidth allocation* scheme requires each satellite to have one more queue, which is called *Persevering Queue-2*. This queue contains capacity reservation requests of *class 2* calls that are currently being served with a capacity lower than the minimum capacity that is required by the source.

Let us assume a new *class 2* call. The call will be accepted as long as there is some residual capacity in one of the visible satellites and a handover request will be sent to the candidate satellites for relaying the call. Nevertheless, if the allocated capacity is lower than the minimum amount of bandwidth that is required by the source, then a capacity reservation request is stored in the *Persevering Queue-2* of the serving satellite. The aim of this request is to increase the amount of bandwidth that is allocated to the respective call. The request is cast aside if the capacity that is allocated to the call is equal to or greater than the minimum capacity that is required for the specific service or if the call has been handed over to another satellite. A call is successfully handed over to a satellite provided that there exists some available capacity in this satellite. Then, a handover request is sent to the satellites to which the call may be handed over. If the capacity that is allocated to this call is less than the minimum amount of capacity that is required by the source, a capacity reservation request is stored in the *Persevering Queue-2* of the serving satellite.

4.2.3 Management of Queues

The aim of the proposed schemes is to attain a judicious priority-based bandwidth allocation strategy. Thus, the management of the aforementioned queues becomes a matter of paramount importance. According to the *non-persevering bandwidth allocation* scheme, each satellite has two queues. Priority is given to *Queue-1* over *Queue-2* since *Queue-1* contains the capacity reservation requests of real-time multimedia calls. In the case of the *persevering bandwidth allocation* scheme, the satellite has one more queue, the *Persevering Queue-2*. This queue is given the lowest priority.

Concerning the management of the requests in *Queue-1* and *Queue-2*, in this study two different queuing policies are examined. The first is the well-known FIFO (first in, first out) policy. In this strategy the requests are queued according to their arrival time. The second queuing policy is called LUI (last useful instant). In this policy the requests are queued based on the remaining time interval till the handover occurrence. Hence, a request is placed ahead of all the other requests in the queue that have a greater remaining queuing time interval. We examine the proposed handover schemes for each one of these two policies.

The management of the requests in the *Persevering Queue-2* is based on the value of a parameter, hereafter referred to as C_p, which aims to indicate how well a call is served. C_p is given by

$$C_p = \frac{C_{alloc}}{C_{req_{min}}} \tag{1}$$

where C_{alloc} denotes the amount of capacity that is currently allocated to the call, while $C_{req_{min}}$ denotes the minimum capacity that is required by the source. The higher the value of C_p, the lower in the queue the request is placed. The requests in the queue are reordered every time that there has been a change in the value of one of them. Taking into account that a change may occur only when some capacity has been released, namely after a call termination or the handover of a call, as well as that call termination and call handover occurrences are not fairly frequent, the aforementioned mechanism is not considered cumbersome.

5 Performance Evaluation

5.1 Simulation Environment

The experiments conducted in this work aim at evaluating the performance of the proposed handover techniques as well as comparing them with the scheme that was proposed in [30]. The simulation tool that was used for these experiments was custom coded by the authors in C++. In the experiments conducted in this work, the performance of the proposed schemes was evaluated in five systems with different overlapping percentages. Except for the overlapping percentage, all the other parameters were the same in all systems. The term overlapping percentage is used to describe the percentage of the footprint's area that is overlapped by contiguous satellites. An increase in the overlapping percentage can be achieved either by adding an additional orbital plane or by decreasing the minimum elevation angle. However, once the system is deployed, it is impossible to increase or decrease the overlapping percentage. For the needs of these experiments we took some of the features of the proposed Boeing design of the Teledesic system with 288 satellites as our base [37, 38]. This selection can be ascribed to the fact that the proposal of this system represented a broadband LEO satellite system with well-defined specifications. Notwithstanding, it should be pointed out that the conclusions that will be drawn concerning the qualitative performance disparities among the schemes hold true for any polar LEO constellation. The satellites of that system orbit the Earth at an altitude of 1375 km, thus the ground track speed of satellites was set to 5.89 km/sec. Moreover, in all the systems the footprint of a satellite was approximated by a rectangle whose dimensions were 1790 km × 1790 km [21, 30], whereas the satellite capacity was considered to be 32 Mbps.

For the set of comparisons four orbital planes with four satellites in each one were simulated. A wrap-around technique was employed in order to avoid boundary effects. The simulated satellite footprints' layout is illustrated in figure 2. The velocity of the Earth's rotation was considered to be 0.46 km/sec, which is approximately equal to the velocity at the equatorial level. In addition, we considered six different types of services; three for each class. Each one of these services is subject to different QoS requirements. Table 1 summarizes the QoS requirements of each type of service as well as the simulation parameters. Users were uniformly distributed over the simulated area and generated calls according to a Poisson distribution with arrival rate λ, while the connection duration was exponentially distributed with mean value T_{call}.

It should be mentioned that the number of users was sufficiently high so that the approximation of a Poisson arrival process for new call attempts be valid. Furthermore, the call arrival rates were high in order that the system is heavily loaded and the performance disparities among the schemes are apparent.

Figure 2 should appear here

Table 1: Service and Simulation Parameters

	Class 1			*Class 2*		
Parameters	Type 1	Type 2	Type 3	Type 1	Type 2	Type 3
Maximum bandwidth (kbps)	30	256	6000	20	512	10000
Minimum bandwidth (kbps)	30	256	1000	5	64	1000
Mean call duration T_{call} (sec)	180	300	600	30	180	120
λ (arrival rate in calls/min/footprint)	50	3	0.001	90	8	0.1
Mean number of users per footprint	1000	300	100	1000	400	150
Typical Applications	voice	interact. audio	interact. video	email	stream. audio/ video/data	

Performance indicators were blocking probability P_B, that is the probability of not admitting a new call into the network, forced termination probability P_F, namely the probability of dropping an ongoing call, as well as mean bitrate B_R, which is the mean capacity that is allocated to a user terminal during a call. In order to eliminate the statistical errors, the results of three independent simulation runs were averaged out. In each run, a time interval equal to 350,000 sec was simulated.

As mentioned earlier, the performance of the proposed handover schemes was examined for two different queuing policies, namely the FIFO policy and the LUI policy. Moreover, these schemes were compared to the scheme that was proposed in [30]. Recall that concerning *class 1* calls, the scheme that was proposed in [30] is similar to the one presented in [4], while regarding *class 2* calls it is similar to the one proposed in [28]. Further, in [30] it was shown that the best combination of the satellite selection criteria is the one that relies upon the maximum capacity criterion for both new and handover calls. We conducted several simulation runs in order to investigate the impact of the three satellite selection criteria on the performance of the proposed handover techniques. Simulation results showed that the best performance is attained when the maximum capacity criterion is employed. Therefore, due to space limitations, we provide results only for this criterion. In conclusion, six different handover schemes were assessed, which, for the sake of clarity, are described in Table 2.

Table 2: Examined Handover Schemes

Handover scheme	Employed Technique	Queuing Policy
FNPBA scheme	Non-Persevering Bandwidth Allocation	FIFO
LNPBA scheme	Non-Persevering Bandwidth Allocation	LUI
FPBA scheme	Persevering Bandwidth Allocation	FIFO
LPBA scheme	Persevering Bandwidth Allocation	LUI
FCC scheme	The technique proposed in [30] - the maximum capacity criterion is used for both new and handover calls	FIFO
LCC scheme	The technique proposed in [30] - the maximum capacity criterion is used for both new and handover calls	LUI

5.2 Simulation Results

Figure 3 depicts the blocking P_B and forced termination P_F probabilities of *"class 1 - Type 1"* calls versus overlapping percentage. The capacity that is allocated to this type of calls is constant and equal to 30 kbps. From this figure it becomes clear that the *non-persevering bandwidth allocation* scheme exhibits the best overall performance regardless of the overlapping percentage and the employed queuing policy. Its performance, as well as the performance of the *persevering bandwidth allocation* scheme, improves as the overlapping percentage increases. The reason for this behavior is that as the overlapping percentage increases, the percentage of users that are covered by two satellites increases as well. Hence, these users stand a chance of reserving capacity in the second satellite when there does not exist sufficient capacity in the first satellite. Moreover, both schemes outperform the scheme that was proposed in [30]. It is interesting to note that that scheme cannot take fully advantage of the overlapping area between contiguous satellites when the latter is below 50 %. This behavior can be attributed to the fact that users that are located in the overlapping area reserve capacity in both visible satellites. Therefore, users that are covered only by one satellite may not be served owing to the deficiency in available capacity. Nonetheless, an increase in the overlapping percentage over 50 % ameliorates the performance of the scheme because most of the users are covered by two satellites in that case. Thus, it is highly likely that they will manage to reserve capacity in one of the two visible satellites. Regarding the performance disparities between the two examined queuing policies, the LUI policy attains lower forced termination probabilities than the FIFO strategy since it gives priority to calls that are in imminent danger of being dropped. However, the cost is a slight increase in blocking probabilities compared to the ones that the FIFO policy attains. However, it should be pointed out that irrespective of the employed queuing policy the forced termination probabilities are extremely low even when the system is heavy loaded.

Figure 3 should appear here

In figure 4 the blocking and dropping probabilities of *"class 1 - Type 2"* calls are illustrated. The capacity that is allocated to calls of this type of service is fixed to 256 kbps. Concerning P_B, some interesting conclusions can be drawn. The handover schemes that are proposed in this study take advantage of the overlapping area between contiguous satellites in order to ameliorate network performance. The FCC and LCC schemes, nevertheless, cannot capitalize upon this overlapping area. Rather, their performance regarding blocking probability worsens as the overlapping percentage increases due to the fact that more capacity is reserved without being used. In addition to this, this kind of users requires a greater amount of capacity compared to *"class 1 - Type 1"* users; this fact translates into higher blocking probabilities. As regards queuing policies, the performance disparities are apparent only in the graph that presents P_F. The LUI policy outperforms the FIFO policy as expected, the gains in the performance are not significant though. It should be mentioned that the performance of the FCC and LCC schemes seems to slightly deteriorate as the overlapping percentage increases, as was the case with P_B. Nevertheless, their best performance is attained for 100% overlapping because in that case every user is always covered by two satellites, therefore it is more likely that one of the two capacity reservation requests will be served. Finally, the best overall performance is attained by the LNPBA scheme.

Figure 4 should appear here

The next set of figures presents the performance indicators regarding *"class 1 - Type 3"* calls. Figure 5 depicts the blocking and forced termination probabilities versus overlapping percentage. It should be noted that due to the extremely low arrival rate of this type of calls it was not feasible to eliminate the statistical errors in the results that present the forced termination probabilities, which in turn impacted on the results that illustrate the mean bitrate. Nonetheless, the results are indicative of the qualitative performance of each scheme. Regarding P_B, the performance of the FCC and LCC schemes significantly degenerates as the overlapping percentage increases. This behavior can be ascribed to the fact that as the overlapping percentage increases, more and more capacity is reserved without being used. On the contrary, the proposed schemes are barely affected by an increase in the overlapping percentage since capacity reservation requests are countermanded when the capacity that they strive to reserve is unlikely to be used. As far as forced termination probabilities are concerned, the proposed schemes perform similarly and outperform the FCC and LCC schemes. In figure 6 the mean bitrate that is allocated to this type of calls is illustrated. Evidently, it is always greater than the minimum capacity that is required by this type of service, regardless of the employed handover scheme and queuing policy. The maximum bitrate is achieved by the LNPBA and FNPBA schemes, as expected.

Figure 5 should appear here

Figure 6 should appear here

Figure 7 presents the blocking and forced termination probabilities of *"class 2 - Type 1"* calls. The performance of the examined schemes is similar to the one presented for *"class 1 - Type 1"* calls and the comments that were made on the performance of the schemes regarding that type of service hold true for this type of service as well. Namely the FNPBA, LNPBA, FPBA and LPBA schemes outperform the FCC and LCC schemes. Concerning the examined queuing disciplines, on a first observation it seems that the LUI policy outperforms the FIFO policy since it provides significant gains regarding P_F. However, under further scrutiny it becomes clear that P_F is always below 10^{-4} while P_B is much higher. Therefore, blocking probabilities determine the best queuing policy. In this context, the FIFO policy performs better than the LUI policy. In figure 8 the mean bitrate of *"class 2 - Type 1"* calls is depicted. As can be seen in that figure, the proposed schemes accomplish higher bitrates than the FCC and LCC schemes on account of their more efficient exploitation of satellite capacity. Moreover, they can take advantage of an increase in the overlapping area in order to increase B_R, whereas the mean bitrate of the FCC and LCC schemes decreases as the overlapping percentage increases. The main reason for this trend is that less capacity is available in each satellite because calls that are located in the overlapping areas reserve capacity in both visible satellites. It should also be noted that the mean bitrate that each scheme attains is really close to the maximum bitrate that calls of this type of service require and that the examined queuing policies present similar performance. Furthermore, the best performance is achieved by the *non-persevering bandwidth allocation* scheme and not by the *persevering bandwidth allocation* scheme. The latter scheme manages to allocate a greater amount of capacity to calls of the other two *class 2* types of service than the former scheme does. Therefore, the residual capacity in the satellites is lower when the *persevering bandwidth allocation* scheme is employed, and *"class 2- Type 1"* calls, which require a very small amount of capacity, take advantage of this fact.

Figure 7 should appear here

Figure 8 should appear here

The performance metrics of *"class 2 - Type 2"* calls are illustrated in the next set of figures. Figure 9 illustrates the blocking and forced termination probabilities. It is evident that the performance disparities among the schemes are like the ones in figures 3 and 7, thus we are not going to further accentuate them. Concerning figure 10 which illustrates the mean bitrate, the LPBA and FPBA schemes exhibit the best performance. Notwithstanding, the performance of the LNPBA and FNPBA schemes is good as well. It should be noted that, unlike figure 6, this time the mean bitrate of these schemes decreases as the overlapping percentage increases. This is owing to the fact that calls of this kind of service require a greater amount of capacity than *"class 2 - Type 1"* calls do. Furthermore, the two examined queuing policies exhibit almost the same performance regarding mean bitrate.

Figure 9 should appear here

Figure 10 should appear here

Similar observations can be made concerning the results that are presented in the next two figures. Figure 11 depicts the blocking and forced termination probabilities of *"class 2 - Type 3"* calls versus overlapping percentage. The best performance regarding these two metrics is attained by the LNPBA scheme. It should be stressed that when the LUI policy is applied, the forced termination probability is zero regardless of the employed handover scheme and the percentage of the overlapping area. As regards the performance of the FPBA scheme in terms of P_F, it is aggravated as the overlapping percentage increases up to 50%. However, it improves for greater percentages. The *persevering bandwidth allocation* scheme tries to increase the amount of bandwidth that is allocated to *class 2* calls that are being served with a lower capacity than the minimum required. This translates into less available capacity for new or handover calls. The LUI policy overcomes this hindrance by giving priority to those calls that have a shorter residual queuing time interval. For overlapping percentages greater than 50 %, the performance of the FPBA scheme is, nonetheless, ameliorated by virtue of the higher percentage of users that are covered by two satellites, which for handover requests translates, in turn, into a greater chance of being served. As regards the mean bitrate, the FPBA and LPBA schemes outperform the other four schemes. In addition, it should be noted that for overlapping percentages greater than 0% the mean bitrate of the other four schemes is below the minimum capacity that is required by this type of service. However, the decrease in B_R for the *non-persevering bandwidth allocation* scheme is insignificant.

Figure 11 should appear here

Figure 12 should appear here

In order to decide on the scheme that presents the best overall performance, we have to define a cost function which will account for the overall performance of each scheme. First we define the overall blocking probability P_{OB} which is given by

$$P_{OB} = \frac{\sum_{i=1}^{2}\sum_{j=1}^{3} \mathrm{w}_f \frac{C_{min_{ij}}\lambda_{ij}}{\mu_{ij}} P_{B_{ij}}}{\sum_{i=1}^{2}\sum_{j=1}^{3} \frac{C_{min_{ij}}\lambda_{ij}}{\mu_{ij}}} \tag{2}$$

where $C_{min_{ij}}$ is the minimum capacity that is required for the *"class i - Type j"* service, λ_{ij} denotes the corresponding call arrival rate, μ_{ij} denotes the respective call service rate, $P_{B_{ij}}$ is the blocking probability of the respective type of service, while w_f is a weighting factor which accounts for the mean bitrate that each scheme achieves and is defined as $\mathrm{w}_f = C_{min_{ij}}/B_R$. Recall that B_R denotes the mean bitrate that the scheme achieves. Note that according to this definition, w_f aims at giving an added bonus to the schemes that attain higher mean bitrate (B_R) since it reduces the effect of the respective blocking probability on the overall blocking probability. Similarly, the overall forced termination probability P_{OF} is defined as follows.

$$P_{OF} = \frac{\sum_{i=1}^{2}\sum_{j=1}^{3} \mathrm{w}_f \frac{C_{min_{ij}}\lambda_{ij}}{\mu_{ij}} P_{F_{ij}}}{\sum_{i=1}^{2}\sum_{j=1}^{3} \frac{C_{min_{ij}}\lambda_{ij}}{\mu_{ij}}} \tag{3}$$

where $P_{F_{ij}}$ denotes the forced termination probability of *"class i - Type j"* calls. Then, the cost function that accounts for the overall performance of each scheme, which is called overall *Grade of Service* (*GoS*), can be defined as

$$\text{overall } GoS = 0.09P_{OB} + 0.91P_{OF} \tag{4}$$

The overall *GoS* is a function of P_{OB} and P_{OF}, whose values are given in Tables 3 and 4 respectively. A tenfold greater weighting factor has been given to P_{OF} since the forced termination of a handover call is generally considered more irksome than the blocking of a new call [10]. Apparently, the higher the overall *GoS*, the poorer the performance of the scheme and the QoS provided to users. It should be emphasized that the overall *GoS* is determined by the values of P_{OB} and P_{OF} and that the values given to their weighting factors do not impact on the qualitative performance disparities among the examined schemes. Figure 13 depicts the overall *GoS* versus overlapping percentage. From this figure it becomes evident that the *non-persevering bandwidth allocation* scheme yields the best performance. The performance of the *persevering bandwidth allocation* scheme is fairly good as well. Both these schemes outperform the scheme that was proposed in [30]. In addition, it is obvious that these two schemes capitalize upon the overlapping area between contiguous satellites and enhance network performance commensurate with overlapping percentage. At the other extreme, the performance of the scheme that was

Table 3: P_{OB} of the examined schemes

Overlapping Percentage	FNPBA scheme	LNPBA scheme	FPBA scheme	LPBA scheme	FCC scheme	LCC scheme
0 %	0.1751	0.1753	0.1970	0.1984	0.1742	0.1760
25 %	0.1632	0.1644	0.1855	0.1858	0.1901	0.1919
50 %	0.1464	0.1477	0.1703	0.1715	0.2058	0.2084
75 %	0.1256	0.1259	0.1489	0.1502	0.2217	0.2235
100 %	0.0975	0.0983	0.1200	0.1204	0.2356	0.2387

Table 4: P_{OF} of the examined schemes

Overlapping Percentage	FNPBA scheme	LNPBA scheme	FPBA scheme	LPBA scheme	FCC scheme	LCC scheme
0 %	$10.80 \cdot 10^{-4}$	$8.941 \cdot 10^{-4}$	$11.38 \cdot 10^{-4}$	$9.303 \cdot 10^{-4}$	$10.82 \cdot 10^{-4}$	$9.057 \cdot 10^{-4}$
25 %	$9.018 \cdot 10^{-4}$	$8.284 \cdot 10^{-4}$	$10.44 \cdot 10^{-4}$	$8.955 \cdot 10^{-4}$	$9.934 \cdot 10^{-4}$	$8.421 \cdot 10^{-4}$
50 %	$8.789 \cdot 10^{-4}$	$7.332 \cdot 10^{-4}$	$8.828 \cdot 10^{-4}$	$7.956 \cdot 10^{-4}$	$11.88 \cdot 10^{-4}$	$8.504 \cdot 10^{-4}$
75 %	$7.143 \cdot 10^{-4}$	$6.099 \cdot 10^{-4}$	$7.914 \cdot 10^{-4}$	$7.358 \cdot 10^{-4}$	$12.37 \cdot 10^{-4}$	$10.30 \cdot 10^{-4}$
100 %	$3.219 \cdot 10^{-4}$	$3.021 \cdot 10^{-4}$	$4.244 \cdot 10^{-4}$	$3.825 \cdot 10^{-4}$	$10.81 \cdot 10^{-4}$	$7.125 \cdot 10^{-4}$

proposed in [30] is exacerbated as the overlapping percentage increases. Last but not least, on a first observation it seems that the two queuing policies exhibit similar performance. However, the FIFO policy is generally more appealing than the LUI policy by virtue of its low complexity.

Figure 13 should appear here

6 Conclusions

In this work we proposed and evaluated the performance of two handover techniques tailored for multimedia LEO satellite systems. According to the proposed schemes handover requests are queued when they cannot be immediately served. The mechanism behind the proposed schemes that allows them to achieve better performance relies on the cancelation of capacity reservation requests when the capacity that they strive to reserve is unlikely to be used. Moreover, we examined the impact of two different queuing policies on the performance of the schemes. It was shown that, while being much less complex, the FIFO discipline attained a similar performance to the one of the LUI policy and on this account is considered more appealing than the latter policy. In addition, the effect of the overlapping percentage among satellite footprints on network performance was investigated. It was shown that additional advantages in the performance of the proposed schemes accrue as the overlapping percentage increases. The good characteristics of the proposed schemes were confirmed via simulations and significant gains in performance were witnessed for all the scenarios examined.

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References

[1] G. Maral and M. Bousquet. *Satellite Communications Systems: Systems, Techniques and Technology.* John Wiley & Sons, 2^{nd} edition, 1993.

[2] G. Comparetto and R. Ramirez. Trends in Mobile Satellite Technology. *IEEE Computer*, 51(2):44–52, February 1997.

[3] A. Jamalipour. *Low Earth Orbital Satellites for Personal Communication Networks.* Artech House, Boston-London, 1998.

[4] P. Boedhihartono and G. Maral. Evaluation of the Guaranteed Handover Algorithm in Satellite Constellations Requiring Mutual Visibility. *Int. J. Satell. Commun. Network.*, 21(2):163–182, March/April 2003.

[5] A. Ganz, Y. Gong, and B. Li. Performance Study of Low Earth-Orbit Satellite Systems. *IEEE Trans. Commun.*, 42(2/3/4):1866–1871, February/March/April 1994.

[6] L. Wood, G. Pavlou, and B. Evans. Managing Diversity with Handover to Provide Classes of Service in Satellite Constellation Networks. In *Proc. of the* 19^{th} *AIAA International Communications Satellite Systems Conference (ICSSC'O1)*, Toulouse, France, April 2001.

[7] E. Del Re, R. Fantacci, and G. Giambene. Efficient Dynamic Channel Allocation Techniques with Handover Queuing for Mobile Satellite Networks. *IEEE J. Select. Areas Commun.*, 13(2):397–405, February 1995.

[8] E. Del Re, R. Fantacci, and G. Giambene. Handover Queuing Strategies with Dynamic and Fixed Channel Allocation Techniques in Low Earth Orbit Mobile Satellite Systems. *IEEE Trans. Commun.*, 47(1):89–102, January 1999.

[9] E. Del Re, R. Fantacci, and G. Giambene. Different Queuing Policies for Handover Requests in Low Earth Orbit Mobile Satellite Systems. *IEEE Trans. Veh. Technol.*, 48(2):448–458, March 1999.

[10] E. Del Re, R. Fantacci, and G. Giambene. Characterization of User Mobility in Low Earth Orbit Mobile Satellite Systems. *Wireless Networks*, 6(3):165–179, May 2000.

[11] G. Maral, J. Restrepo, E. Del Re, R. Fantacci, and G. Giambene. Performance Analysis for a Guaranteed Handover Service in an LEO Constellation with a “Satellite-Fixed Cell” System. *IEEE Trans. Veh. Technol.*, 47(4):1200–1214, November 1998.

[12] L. Boukhatem, D. Gaïti, and G. Pujolle. A Channel Reservation Algorithm for Handover Issues in LEO Satellite Systems based on a Satellite-Fixed Cell Coverage. In *Proc. of IEEE VTC 2001*, Rhodes, Greece, 6-9 May 2001.

[13] L. Boukhatem, A. L. Beylot, D. Gaïti, and G. Pujolle. TCRA: A Time-based Channel Reservation Scheme for Handover Requests in LEO Satellite Systems. *Int. J. Satell. Commun. Network.*, 21(2):227–240, March/April 2003.

[14] I. Mertzanis, R. Tafazolli, and B. G. Evans. Connection Admission Control Strategy and Routing Considerations in Multimedia (Non-GEO) Satellite Networks. In *Proc. of IEEE VTC 1997*, pages 431–435, Phoenix, AZ, USA, 4-7 May 1997.

[15] Z. Wang and T. Mathiopoulos. Analysis and Performance Evaluation of Dynamic Channel Reservation Techniques for LEO Mobile Satellite Systems. In *Proc. of IEEE VTC 2001*, Rhodes, Greece, 6-9 May 2001.

[16] E. Papapetrou and F.-N. Pavlidou. QoS Handover Management in LEO/MEO Satellite Systems. *Wireless Personal Communications*, 24(2):89–204, January 2003.

[17] E. Papapetrou, E. Stathopoulou, and F.-N. Pavlidou. Supporting QoS over Handovers in LEO Satellite Systems. In *Proc. of IST Mobile & Wireless Telecommunications Summit 2002*, pages 388–393, Thessaloniki, Greece, 17-19 June 2002.

[18] E. Papapetrou and F.-N. Pavlidou. Analytic Study of Doppler-Based Handover Management in LEO Satellite Systems. *IEEE Trans. Aerosp. Electron. Syst.*, 41(3):830–839, July 2005.

[19] E. Papapetrou, S. Karapantazis, G. Dimitriadis, and F.-N. Pavlidou. Satellite Handover Techniques for LEO Networks. *Int. J. Satell. Commun. Network.*, 22(2):231–245, March/April 2004.

[20] E. Papapetrou, S. Karapantazis, and F.-N. Pavlidou. Handover Policies in LEO Systems with Satellite Diversity. In *Proc. of the First International Conference on Advanced Satellite Mobile Systems - ASMS 2003*, Frascati, Italy, 10-11 July 2003.

[21] S. Karapantazis and F.-N. Pavlidou. Design Issues and QoS Handover Management for Broadband LEO Satellite Systems. *IEE Proc. Commun.*, 152(6):1006–1014, December 2005.

[22] S. Cho. Adaptive Dynamic Channel Allocation Scheme for Spotbeam Handover in LEO Satellite Networks. In *Proc. of IEEE VTC 2000*, pages 1925–1929, Boston, USA, 25-28 September 2000.

[23] S. Cho, I. F. Akyildiz, M. D. Bender, and H. Uzunalioğlu. A New Spotbeam Handover Management Technique for LEO Satellite Networks. In *Proc. of IEEE GLOBECOM 2000*, volume 2, pages 1156–1160, San Francisco, USA, 27 November - 1 December 2000.

[24] S. Cho, I. F. Akyildiz, M. D. Bender, and H. Uzunalioğlu. A New Connection Admission Control for Spotbeam Handover in LEO Satellite Networks. *Wireless Networks*, 8(4):403–415, July 2002.

[25] S. Kalyanasundaram, E. K. P. Chong, and N. B. Shroff. An Efficient Scheme to Reduce Handoff Dropping in LEO Satellite Systems. *Wireless Networks*, 7(1):75–85, January 2001.

[26] M. El-Kadi, S. Olariu, and P. Todorova. Predictive Resource Allocation in Multimedia Satellite Networks. In *Proc. of IEEE GLOBECOM 2001*, volume 4, pages 2735–2739, San Antonio, Texas, USA, 25-29 November 2001.

[27] H. N. Nguyen, S. Olariu, and P. Todorova. A Novel Mobility Model and Resource Reservation Strategy for Multimedia LEO Satellite Networks. In *Proc. of Wireless Communication and Networking Conference (WCNC'02)*, Orlando, Florida, USA, March 2002.

[28] P. Todorova, S. Olariu, and H. N. Nguyen. A Two-Cell-Lookahead Call Admission and Handoff Management Scheme for Multimedia LEO Satellite Networks. In *Proc. of the* 36th *Annual Hawaii International Conference on System Sciences (HICSS-36)*, Big Island of Hawaii, USA, 6-9 January 2003.

[29] S. Olariu, S. R. A. Rizvi, R. Shirhatti, and P. Todorova. Q-Win–A New Admission and Handoff Management Scheme for Multimedia LEO Satellite Networks. *Telecommunication Systems*, 22(1-4):151–168, January-April 2003.

[30] S. Karapantazis, P. Todorova, and F.-N. Pavlidou. On Call Admission Control and Handover Management in Multimedia LEO Satellite Systems. In *Proc. of the* 23rd *AIAA International Communications Satellite Systems Conference (ICSSC 2005)*, Rome, Italy, 25–28 September 2005.

[31] W. Zhao, R. Tafazolli, and B. G. Evans. Combined Handover Algorithm for Dynamic Satellite Constellations. *Electronics Letters*, 32(7):622–624, 28 March 1996.

[32] M. Gkizeli, R. Tafazolli, and B. Evans. Performance Analysis of Handover Mechanisms for Non-Geo Satellite Diversity Based Systems. In *Proc. of IEEE GLOBECOM 2001*, volume 4, pages 2744–2748, San Antonio, Texas, USA, 25-29 November 2001.

[33] M. Gkizeli, R. Tafazolli, and B. G. Evans. Hybrid Channel Adaptive Handover Scheme for Non-GEO Satellite Diversity Based Systems. *IEEE Commun. Letters*, 5(7):284–286, July 2001.

[34] A. H. Zaim, G. N. Rouskas, and H. G. Perros. Computing Call-Blocking Probabilities in LEO Satellite Networks: The Single-Orbit Case. *IEEE Trans. Veh. Technol.*, 51(2):332–347, March 2002.

[35] I. Ali, N. Al-Dhahir, and J. E. Hershey. Doppler Characterization for LEO Satellites. *IEEE Trans. Commun.*, 46(3):309–313, March 1998.

[36] I. Ali, N. Al-Dhahir, and J. E. Hershey. Predicting the Visibility of LEO Satellites. *IEEE Trans. Aerosp. Electron. Syst.*, 35(4):1183–1190, October 1999.

[37] D. J. Bem, T. W. Wieckowski, and R. J. Zielinski. Broadband Satellite Systems. *IEEE Communications Surveys & Tutorials*, 3(1):2–16, First Quarter 2000. [Online]. Available: http://www.comsoc.org/livepubs/surveys.

[38] http://www.spaceandtech.com/spacedata/constellations/teledesic_specs.shtml.

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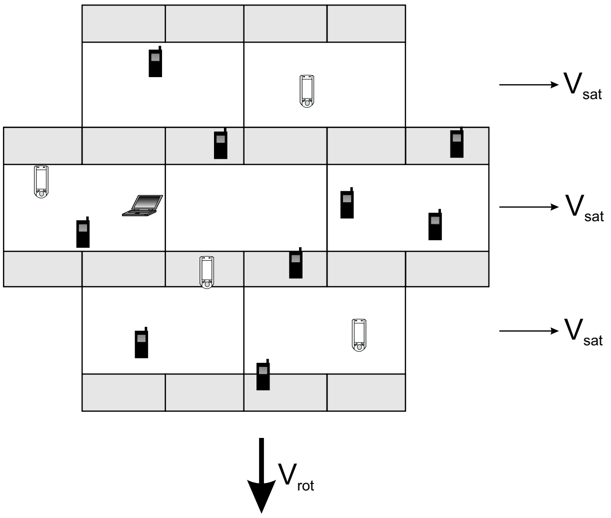


Figure 1: Mobility Model

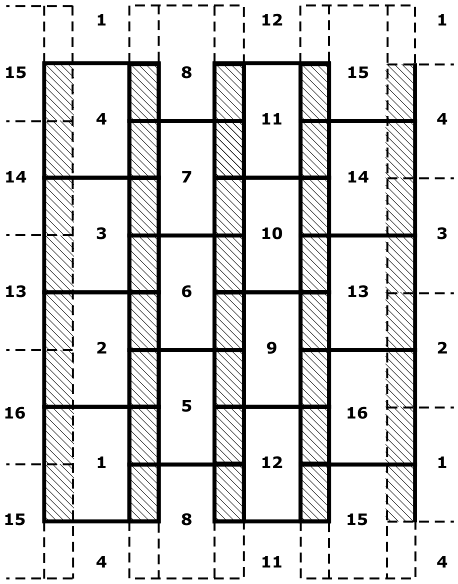


Figure 2: The simulated satellite footprints' layout

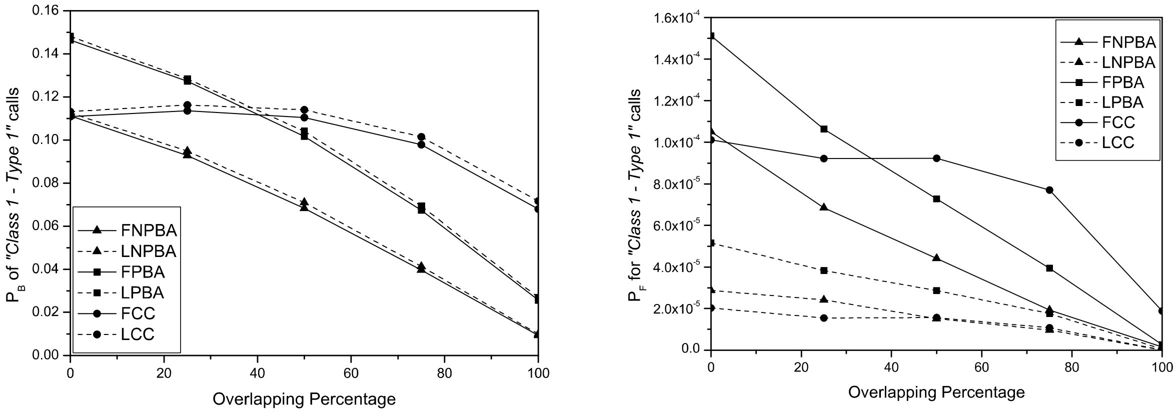


Figure 3: P_B and P_F of *"class 1 - Type 1"* calls vs overlapping percentage

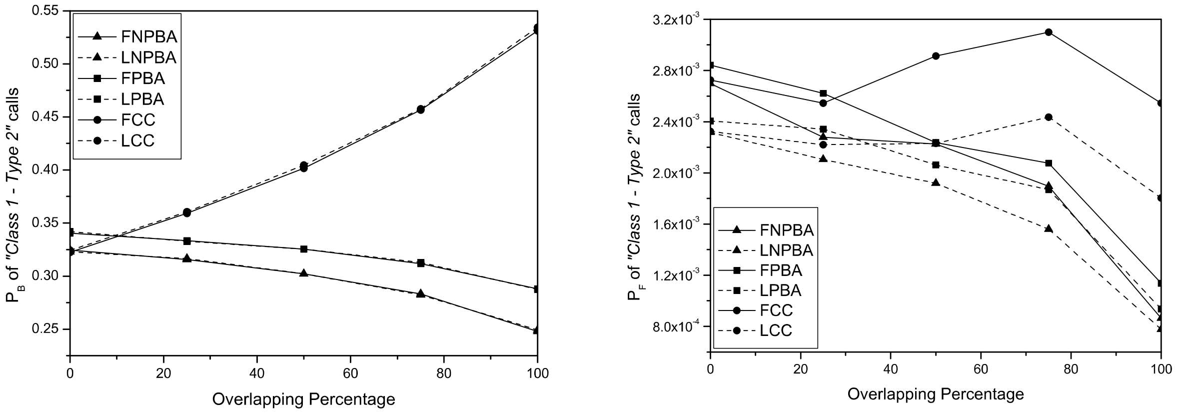
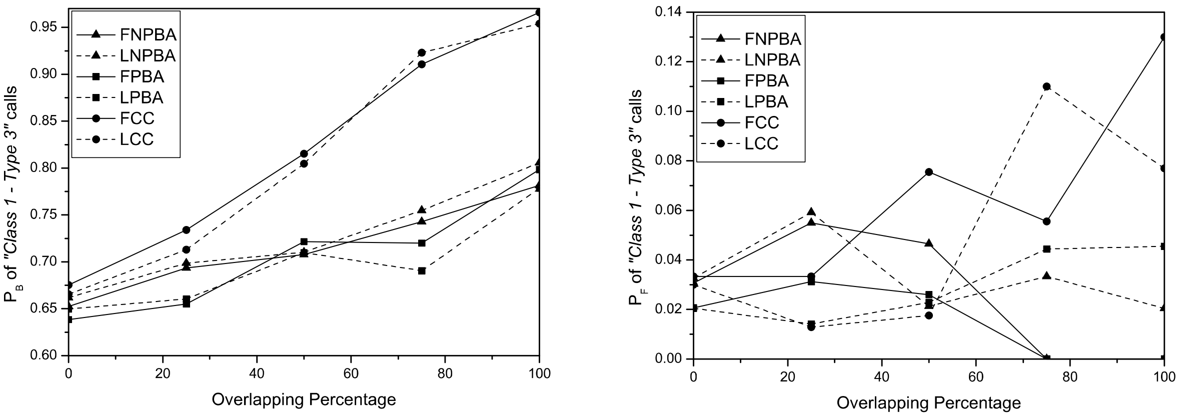


Figure 4: P_B and P_F of *"class 1 - Type 2"* calls vs overlapping percentage



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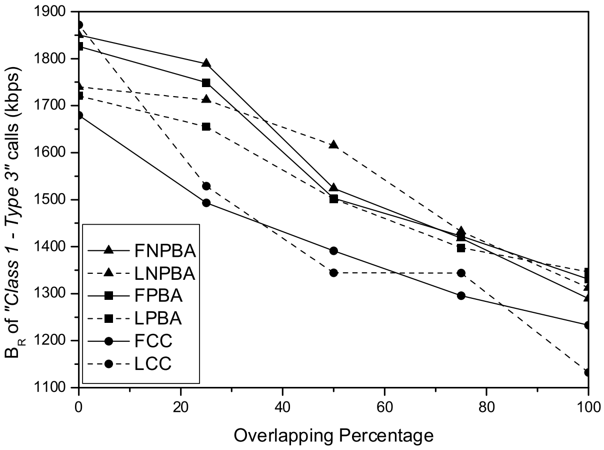

Figure 6: B_R of *“class 1 - Type 3”* calls vs overlapping percentage

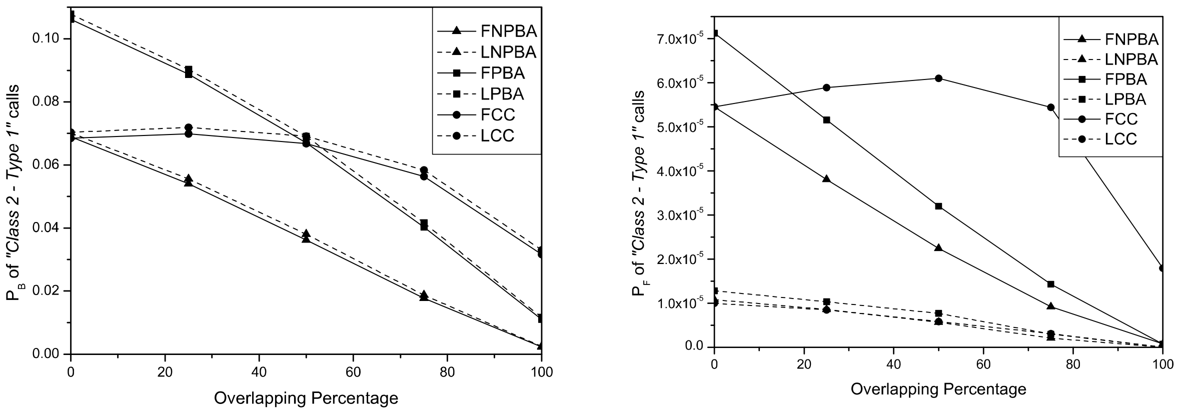

Figure 7: P_B and P_F of *"class 2 - Type 1"* calls vs overlapping percentage

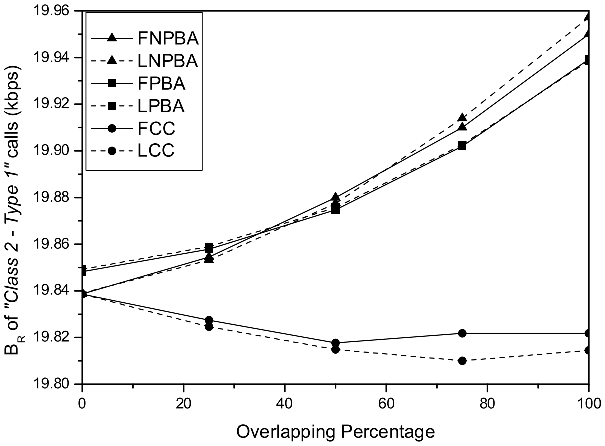

Figure 8: B_R of *"class 2 - Type 1"* calls vs overlapping percentage

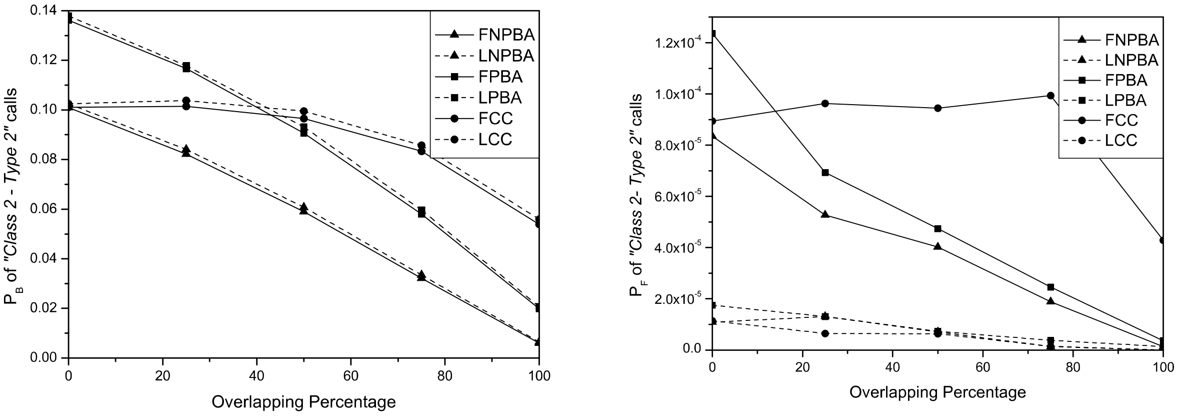

Figure 9: P_B and P_F of *"class 2 - Type 2"* calls vs overlapping percentage

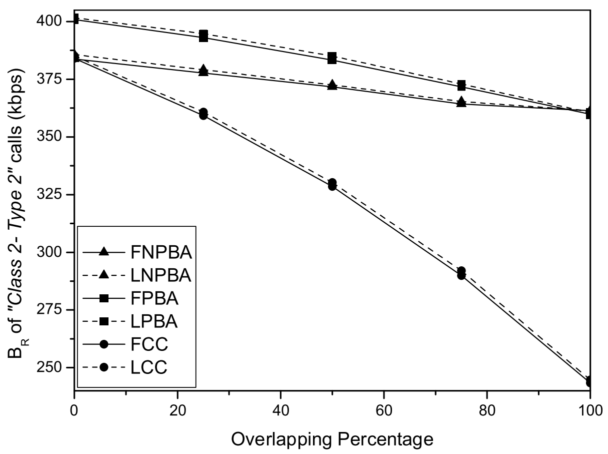

Figure 10: B_R of *"class 2 - Type 2"* calls vs overlapping percentage

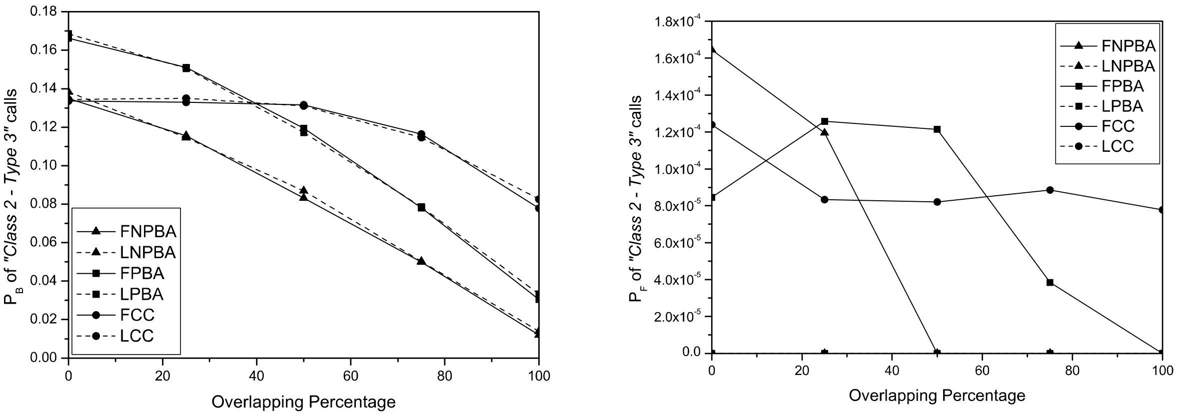

Figure 11: P_B and P_F of *"class 2 - Type 3"* calls vs overlapping percentage

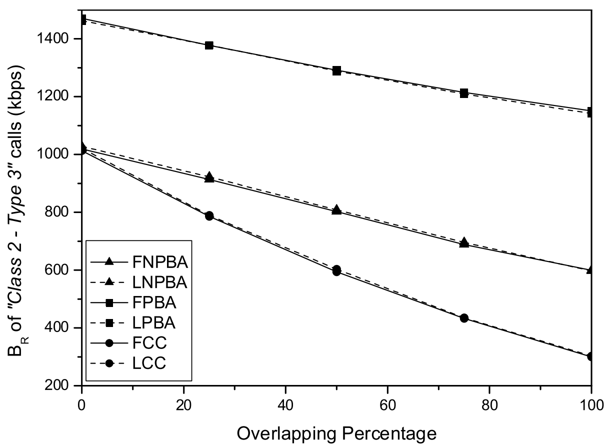

Figure 12: B_R of *"class 2 - Type 3"* calls vs overlapping percentage

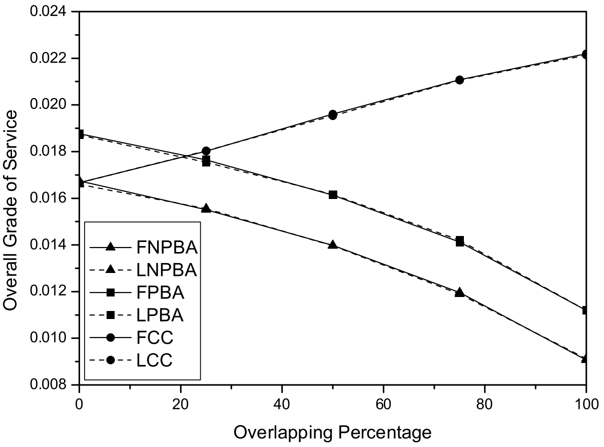

Figure 13: Overall Grade of Service vs overlapping percentage