QoS Handover Management in LEO/MEO Satellite Systems

E. Papapetrou and F.-N. Pavlidou

Abstract

Low Earth Orbit (LEO) satellite networks are foreseen to complement terrestrial networks in future global mobile networks. Although space segment topology of a LEO network is characterized by periodic variations, connections of mobile stations (MSs) to the satellite backbone network alter stochastically. As a result the quality of service delivered to users may degrade. Different procedures have been proposed either as part of a resource allocation mechanism or as part of an end-to-end routing protocol to manage transitions of MSs from one satellite to another (handover). All of these techniques are based on the prioritization of requested handovers to ease network operation and therefore enhance provision of service. This paper proposes a new handover procedure that exploits all geometric characteristics of a satellite-to-MS connection to provide an equable handover in systems incorporating onboard processing satellites. Its performance is evaluated by simulations for a variety of satellite constellations to prove its general applicability.

Keywords: handover management, LEO, MEO, satellite, QoS

1 Introduction

Modern communication networks point at providing ubiquitous high quality services. To this effect they are foreseen to utilize a satellite component able to serve high quality user demands. Low Earth Orbit (LEO) satellite systems [1] emerge as the most convenient solution because they provide low propagation delays relative to geostationary systems. This is an essential advantage for real-time and interactive services dominating nowadays markets. Nevertheless the rapidly moving satellites in such systems call for a special network management to provide users with services insusceptible of this immanent mobility. The more frequent a satellite which is over a region changes the more difficult is to achieve this goal. This situation is encumbered by the fact that in order to increase frequency reuse many satellite systems divide satellite footprint into cells. Due to the relatively small size of cells a user with a call in progress will need to switch from a cell to another (*handover*) more times during this call. Indeed there are two types of handovers the *satellite* and *beam* handover. While the former refers to the switching of a user from a satellite to another, the later refers to the switching between cells.

Handovers may degrade system performance in many ways depending on the managing technique employed by the satellite system. Examples of performance degradation, as experienced by the user point of view, are forced termination of calls, queueing delay, e.t.c. On the other hand from the system point of view performance degradation relates to inefficient use of resources. This paper is concerned with the formation of an appropriate mechanism for managing satellite and beam handovers. Its target is to provide users with high quality of service in terms of forced termination probability and at the same time utilize efficiently network resources.

Various studies have addressed the issue of handover management. One proposed approach is to handle handover upon its occurrence. Queuing of handovers [2],[3],[4] is foreseen if resources are not available. This technique avoids early reservation of resources and favors low blocking probability. Nevertheless introduces delay and relatively high forced termination probability if the maximum acceptable queuing time is low. In [2] E. Del Re et al. proposed a handover prioritization scheme for different channel allocation techniques. This scheme proposes the queuing of handover requests (QH) for a predefined time interval in case there is no channel available in the destination cell. The call will be forced into termination if no channel is made available within the proposed interval. A second approach is to reserve resources before handover occurrence in order to minimize forced termination probability. This reservation may be predetermined (guard channels [4],[5]) or based on a short prediction of handover requests. In this case although no delay is imposed, a cautious planning is needed to efficiently use network resources and avoid an undesirable increase of blocking probability. In [6] Maral et al. proposed a guaranteed handover service (GH) for systems in which channels are fixed allocated to cells. According to the proposed method, calls requesting the guaranteed handover service are admitted in the network only if a free channel exists both in the serving and in the next (in the opposite direction of the satellite movement) cell. When the first handover occurs a channel is requested from the following cell and so on. If a channel does not exist then the request is queued until the next handover occurrence. The procedure is successful only if a channel is found in the meantime. In [7] handover management is considered as part of an end-to-end routing protocol. It takes into account traffic density in a cell to predict the number of handovers and reserve channels.

In this paper a new handover management scheme will be proposed for fixed channel allocation (FCA) systems. The new procedure aims at providing users with a high quality service characterized by practically zero forced termination probability. Provision of different levels of quality of service according to the user request will also be possible. The proposed technique takes advantage of the Doppler effect to derive the location of MSs and therefore perform channel reservations at the appropriate time maximizing channel utilization and bandwidth efficiency. Another feature of the proposed mechanism is that provides a solution for the case that the destination cell of a handover is not the next in the opposite direction of the satellite movement. This is particularly true if earth movement and cells overlapping are taken into account. Finally the case of satellite handover (i.e. when the origin and the destination cells are in a different footprint) is addressed and a solution is provided for cases that the destination satellite is in a different orbital plane.

The rest of the paper is structured as follows. In Section 2 the proposed procedure is presented in detail. Then, in Section 3 we discuss the simulation framework and its implementation for evaluating the new method. In Section 4 the results of our simulation study are presented, leading to useful conclusions in Section 5.

2 Dynamic Doppler Based Handover Prioritization Technique (DDBHP)

Handover management involves always the tradeoff between *blocking* (P_b) (i.e. the probability of blocking a new call) and *forced termination* (P_f) probability (i.e. the probability of blocking an evolving call). Although the minimization of forced terminations is desired from the user point of view blocking probability is also an important parameter of the network operation. In order to overcome the problem of early resource reservation which increases blocking probability and in the same time achieve an infallible handover it is required to somehow introduce a dynamic procedure. The term *dynamic* implies on one hand a short term reservation and on the other a reservation depending on the prediction of the actual handover requests. The proposed procedure relies on Dopplers effect to estimate the handover requests and reserve channels. Each attempt to reserve a channel takes place at a specified time before the handover occurrence. The system must complete resource reservation in the corresponding time interval named *handover threshold*

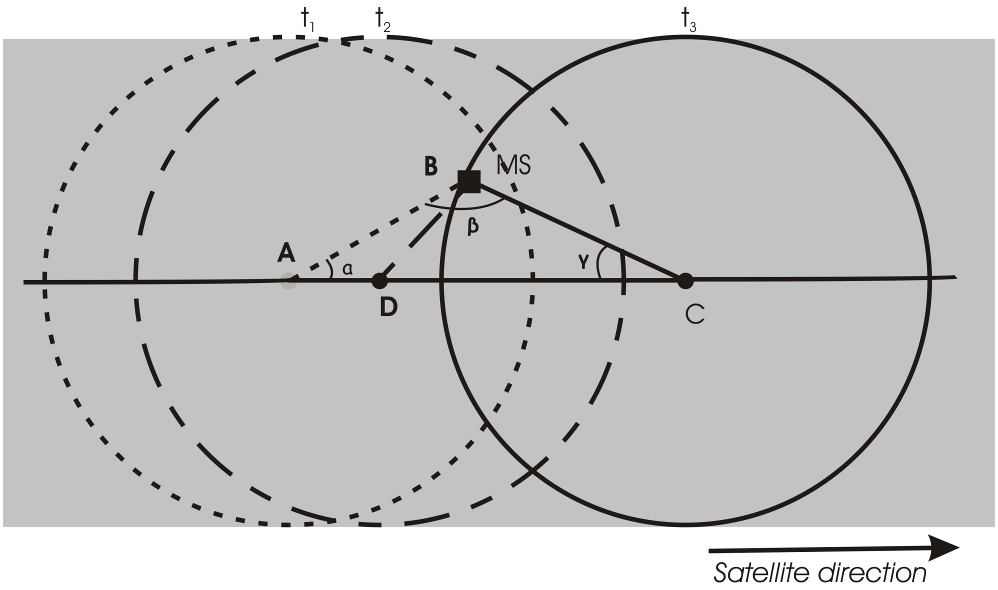

Figure 1: The station monitoring process

(t_{TH}). In this way the quality of service (in terms of forced termination probability) requested by each user is achieved. It is clear that different values of the parameter t_{TH} define different levels of service. DDBHP consists of three mechanisms namely *station monitoring*, *channel reservation* and *reservation cancelation*. New calls are admitted in the network if a free channel is available in the present cell. If the MS position at call setup is such that the remaining time to handover is smaller than t_{TH} (station monitoring which is described below can be used also at call setup to perform this prediction) then a free channel in the following cell is also needed for the call to be admitted in the network. After a new call is admitted in the network the serving satellite activates *station monitoring*.

2.1 Station Monitoring

The serving satellite is able to derive the elevation angle of the communication at any time based on the measured Doppler shift. For this purpose satellites with onboard processing capabilities are required. The measuring of Doppler shift when performed at two different time instances makes possible the calculation of the azimuth angle (α, see Figure 1) between the satellite direction and the MS. Consider the case in Figure 1. At $t_1 = 0$ when a new call is admitted in the network and at $t_2 = t_0$ the satellite measures the Doppler shift and therefore can derive the angular distances AB and DB (Appendix 1):

$$AB = arccos((\frac{R_E}{R_E + h}) \cdot cos(E_1)) - E_1 \tag{1}$$

$$DB = arccos((\frac{R_E}{R_E + h}) \cdot cos(E_2)) - E_2 \tag{2}$$

where R_E is the earth radius, h the satellite altitude and E_1, E_2 are the elevation angles at t_1 and t_2 respectively given by Figure 2 [8]:

$$E_1 = arccos(-\frac{f_{D_1} \cdot \lambda}{2 \cdot v}) \tag{3}$$

$$E_2 = arccos(-\frac{f_{D_2} \cdot \lambda}{2 \cdot v}) \tag{4}$$

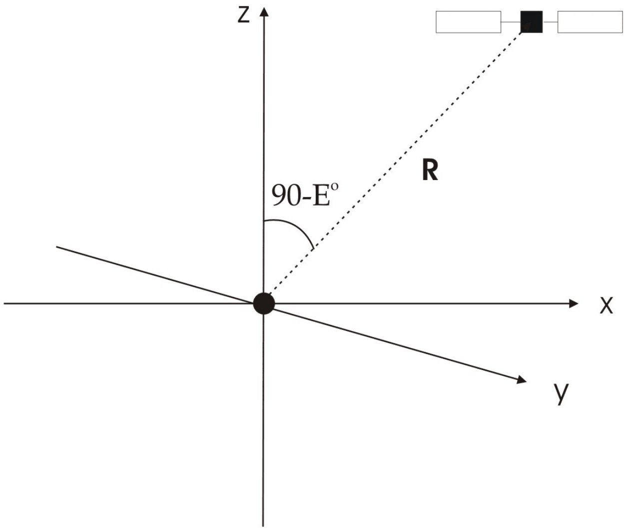

Figure 2: Doppler shift and elevation angle

where f_{D_1} and f_{D_2} are the measured Doppler shifts at t_1 and t_2 respectively, λ is the transmission wavelength and v the satellite velocity. The angular distance AD is calculated by:

$$AD = \frac{2 \cdot \pi}{T_s} \cdot t_0 \tag{5}$$

where T_s is the satellite period. Applying the law of cosines in the spherical triangle ABD the angle α is derived:

$$\alpha = arccos(\frac{cos(DB) - cos(AD) \cdot cos(AB)}{sin(AD) \cdot sin(AB)}) \tag{6}$$

By calculating the azimuth angle α, the satellite is able to derive the time at which a handover will be performed as follows: In spherical triangle ABC (Figure 1) angular distances AB and BC are known and related to E_1 and the minimum elevation angle E respectively. By applying the law of sines we calculate angle γ:

$$\gamma = arcsin(\frac{sin(BC)}{sin(AB) \cdot sin(\alpha)}) \tag{7}$$

Angle β equals:

$$\beta = 180^o - \alpha - \gamma \tag{8}$$

Applying again the law of sines the angular distance AC equals:

$$AC = \omega_F \cdot t_H = arcsin(\frac{sin(\beta) \cdot sin(\alpha)}{sin(BC)}) \tag{9}$$

and

$$t_H = \frac{1}{\omega_F} \cdot arcsin(\frac{sin(\beta) \cdot sin(\alpha)}{sin(BC)})$$

with ω_F given by [8]:

$$\omega_F = \omega_S - \omega_E \cdot cos(i) \tag{10}$$

where ω_S and ω_E are the angular velocities of the satellite and earth respectively and i the inclination of the orbital plane. In Equation 5 only the angular velocity of satellite was taken into account because t_0 is considered to be small therefore $\omega_S \cdot t_0 \simeq (\omega_S - \omega_E \cdot cos(i)) \cdot t_0$.

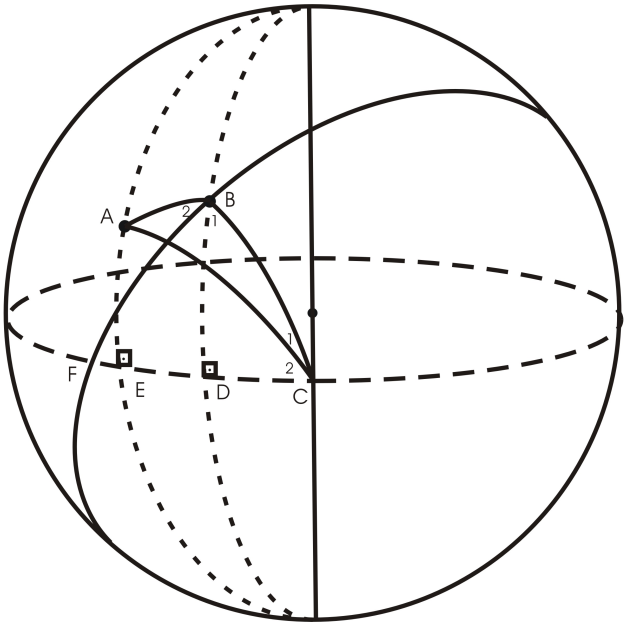

Figure 3: Calculation of point A location

After calculating the time to handover occurrence (t_H) the satellite schedules the channel reservation phase at time $t_H - t_{TH}$ where t_{TH} is a time interval called handover threshold. This threshold is crucial to the performance of the proposed scheme since it is the time in which channel reservation must be completed (i.e. a free channel must be found). The appropriate selection of t_{TH} is explained in the following section.

2.2 Channel Reservation

In order to initiate the channel reservation mechanism the serving satellite must be aware of the destination cell, i.e. the serving cell after the handover. This is possible through the following calculations. In Figure 3 let A be the location of the earth station and B the sub-satellite point at time $t_4 = t_H$, i.e when handover occurs. Applying the law of sines in triangle FBC we calculate angle C:

$$C = arcsin(\frac{sin(FB) \cdot sin(i)}{sin(BC)}) \tag{11}$$

where the angular distance FB depends on the time elapsed since the satellite crossed the equatorial plane, i is the orbit inclination and BC can be calculated by:

$$BC = arccos(cos(AE) \cdot cos(EC)) \tag{12}$$

with AE and EC being the latitude and the longitude of the satellite respectively. Furthermore angle B_1 equals to:

$$B_1 = 180^o - i - C \tag{13}$$

Applying the law of cosines in triangle ABC results in:

$$AC = arccos(cos(AB) \cdot cos(BC) + sin(AB) \cdot sin(BC) \cdot cos(B)) \tag{14}$$

where AB can be computed from the minimum elevation angle according to:

$$AB = arccos((\frac{R_E}{R_E + h}) \cdot cos(E)) - E \tag{15}$$

and

$$B = B_1 + B_2 = B_1 + \gamma \tag{16}$$

with γ given by Equation 7. Angle C_1 is calculated by applying the law of sines in the same triangle:

$$C_1 = arcsin(\frac{sin(AB) \cdot sin(B)}{sin(AC)}) \tag{17}$$

thus:

$$C_2 = C - C_1 \tag{18}$$

Finally by applying the law of sines in spherical triangle AEC:

$$AE = arcsin(sin(C_2) \cdot sin(AC)) \tag{19}$$

$$EC = arcsin(sin(90^o - C_2) \cdot sin(AC)) \tag{20}$$

By calculating the terminal location (EC, AE) the serving satellite is able to derive the destination cell and make the reservation. This is of great importance if cells overlapping and earth rotation are taken into account. In this case the destination cell may be adjacent to the source cell and not the next in the direction of the satellite movement. Furthermore by knowing the position of other satellites the serving satellite is able to decide if the destination cell belongs to a different satellite. Thus the proposed procedure supports cell handovers as well as satellite handovers. If the destination cell belongs to a different satellite, the serving satellite issues a reservation packet towards the destination satellite. The delivery of the reservation packet is managed through ISLs (inter-satellite links) and relies on the routing protocol. Different routing protocols can be used for this purpose [9],[10],[11],[12]. Upon receipt of the reservation packet, the destination satellite performs reservation in the corresponding cell. If a channel is available in the destination cell it is reserved otherwise requests are queued and a channel is reserved the first time one is released. It must be noted that the procedure undertaken when a satellite handover occurs can be supported by regenerative processing satellites. However DDBHP can operate without the need of inter-satellite links supporting only beam handovers which is also the case of other proposed techniques.

The selection of *handover threshold* t_{TH} must be appropriate so there is enough time for a reservation request to be served. On the other hand the *handover threshold* must be small enough to prevent unnecessary reservation of resources. As it will be made clear by simulation results the handover threshold determines the system performance. It will be proved that it is possible to support different levels of service for users depending on the chosen threshold.

2.3 Reservation Cancelation

Referring to the case of Figure 1 it is clear that the reservation takes place at $t_H - t_{TH}$ whereas the handover takes place at $t_4 = t_H$. Meanwhile there is the possibility that the MS terminates the evolving call. In this case the handover request is removed from the queue or if the request does not exist in the queue (the channel has already been reserved) the cell releases the serving channel.

3 Simulation Scenario

DDBHP was tested in three different satellite constellations in order to prove its general applicability. In this paper we adopt the mobility model proposed in [6]. According to this, cells are considered squares. Cell overlapping is not considered as well as movement of mobile users and earth rotation. Satellite velocity V_{sat} is considered the dominant factor causing handovers. Although this assumption is true only for LEO systems, it is adopted in the simulation scenario to provide a fair comparison with the other proposed techniques which do not consider earth rotation. In any case DDBHP can operate efficiently even when the earth rotation is taken into account if Equation 10 is used without any approximation. The parameters for the three constellations are shown in Table 1. The time that a user stays in a cell is denoted as t_{cell}.

Table 1: Simulation parameters

	Iridium-like	Globalstar-like	MEO
Cell length (km)	500	1000	2000
t_{cell} (min)	1.26	2.85	17.54
V_{sat} (km/sec)	6613.75	5847.95	1900
Channels/cell	10	20	40

Within cells, traffic is produced from a population N_{users} of mobile users which are uniformly distributed. Each mobile user generates calls according to a Poisson distribution with a rate ${}_{user}$. The call mean duration is T_{call}. In Table 2 the traffic generation parameters are shown. The traffic parameters were chosen so that the offered load equals 20% to 80% of the cell capacity.

Table 2: Traffic parameters

	Iridium-like	Globalstar-like	MEO
Users/cell	100	200	400
t_{call} (sec)	180	180	180
Load/cell (Erlang)	2-8	4-16	8-32
${}_{user}$ (10^{-4} calls/sec)	1.1 - 4.4	1.1 - 4.4	1.1 - 4.4

4 Simulation Results

As mentioned before the choice of the handover threshold t_{TH} determines the performance of DDBHP. To explore this association we tested different values for t_{TH}. In these simulation tests all users utilize DDBHP. In Figure 4 the forced termination probability with respect to traffic load is depicted for the Iridium-like system.

As illustrated when operating on a relatively high value of t_H DDBHP can provide a guaranteed handover ($P_F = 0$) procedure while for small values of t_{TH} its performance can be considered acceptable for less demanding users. It is clear that if t_{TH} is small P_F increases since some requests may not be served. On the other hand high t_{TH} increases system under-utilization since a user occupies two channels (in the current and next cell) for a longer period of time. Concluding t_{TH} is a parameter that can be set by the system to support different levels of service quality. The advantage of DDBHP is that at the same time manages to support low blocking probability as can been seen in Figure 5. This is the result of performing resource reservations shortly before the handover request.

In Figure 6 the blocking probability of three different handover prioritization schemes in an Iridium-like system is depicted. The QH scheme (with maximum waiting time set to $t_{cell}/10$ [2]) provides low P_B because handover requests are queued and do not reserve resources. Therefore QH presents high P_F , a result confirmed by simulation results (16.57% for 8 Erlang cell load). The GH scheme [6] although providing zero P_F presents high P_B for high traffic load because each user occupies two channels. On the other hand DDBHP ($t_{TH} = 0.6t_{cell}$) minimizes P_B while providing a guaranteed handover.

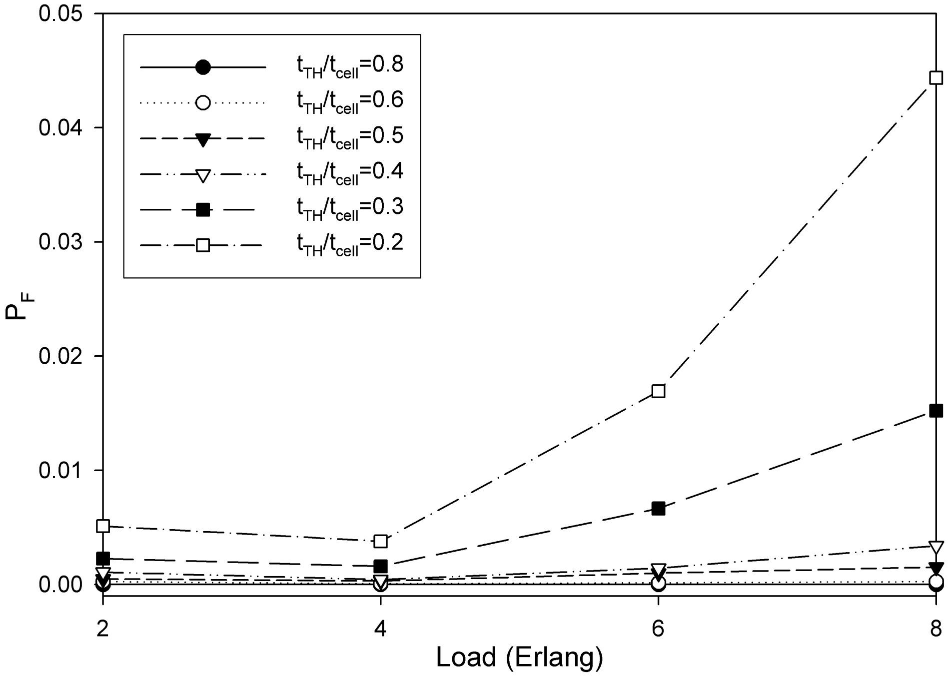

Figure 4: Forced termination probability for different t_{TH} values vs traffic load for the Iridium-like system.

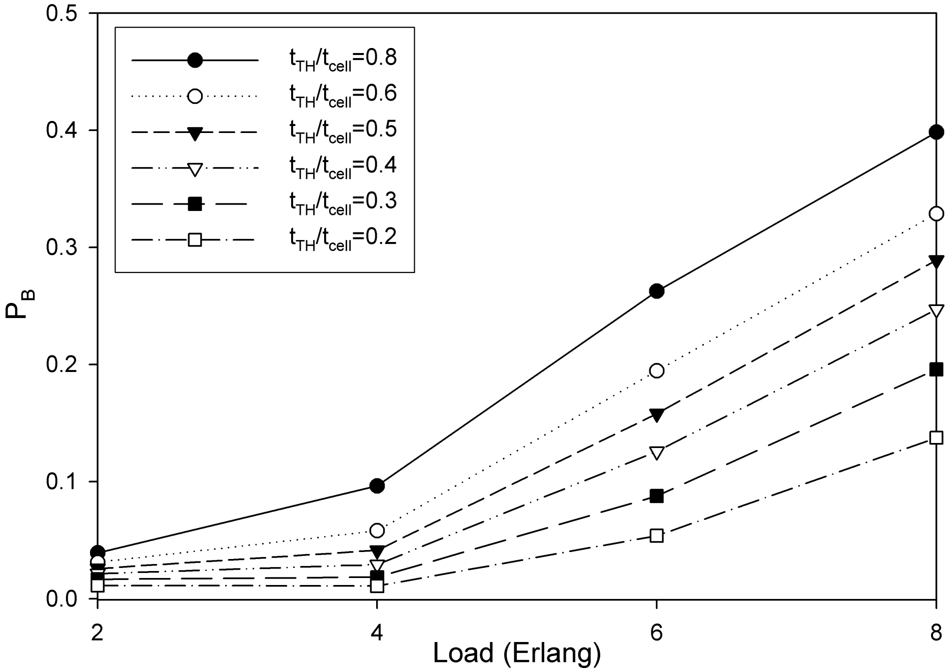

Figure 5: Blocking probability for different t_{TH} values vs traffic load for the Iridium-like system.

Figures 7-9 describe the performance of DDBHP in a Globalstar-like system. This system present lower levels of mobility and as a result DDBHP is able to provide a guaranteed handover even in the case that

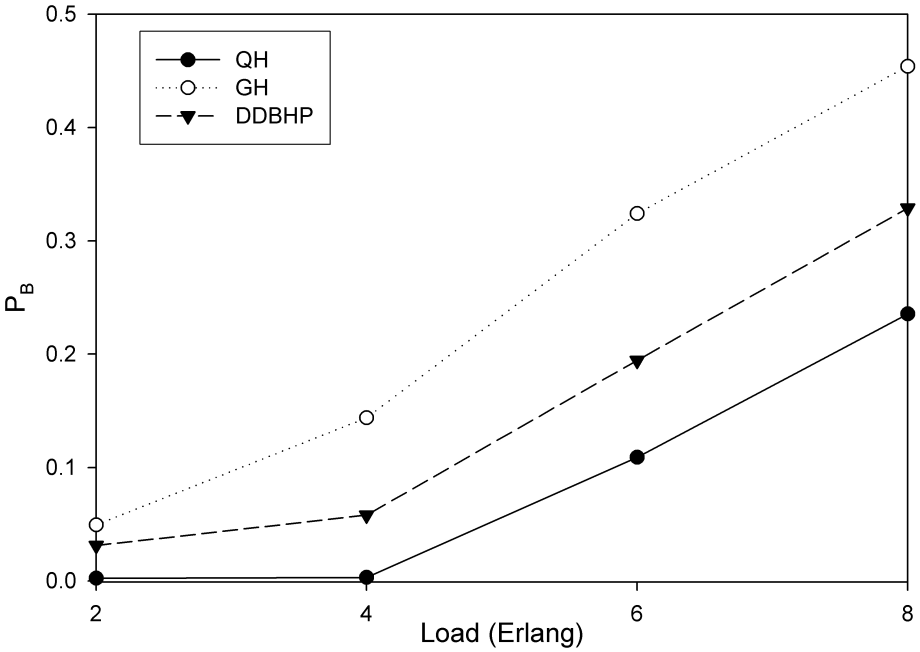

Figure 6: Blocking probability for three different prioritization schemes in an Iridium-like system.

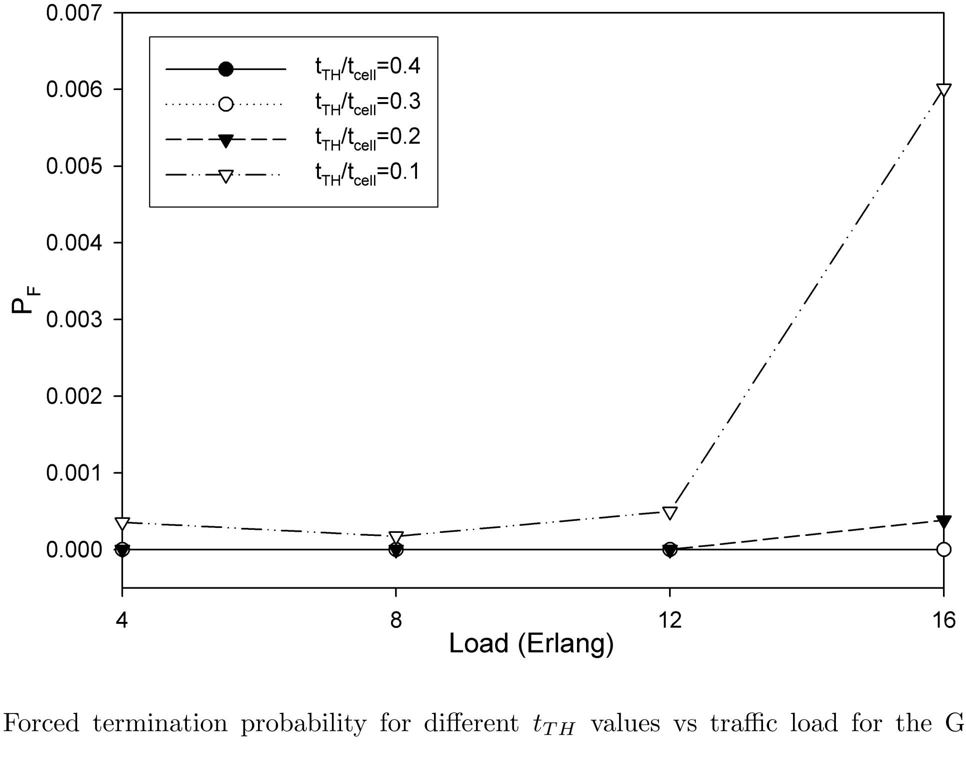

Figure 7: Forced termination probability for different t_{TH} values vs traffic load for the Globalstar-like system.

t_{TH} is only 30% of the time needed by a user to cross a cell. This gives DDBHP the ability to improve its performance in terms of P_B even more. This is illustrated in Figures 8 and 9. In Figure 8, PB is depicted

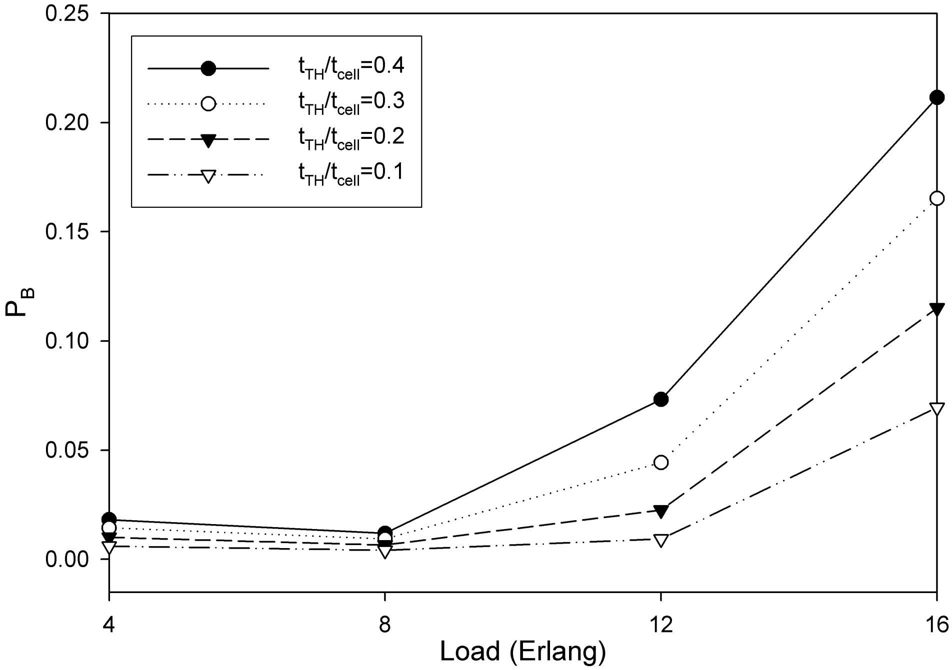

Figure 8: Blocking probability for different t_{TH} values vs traffic load for the Globalstar-like system.

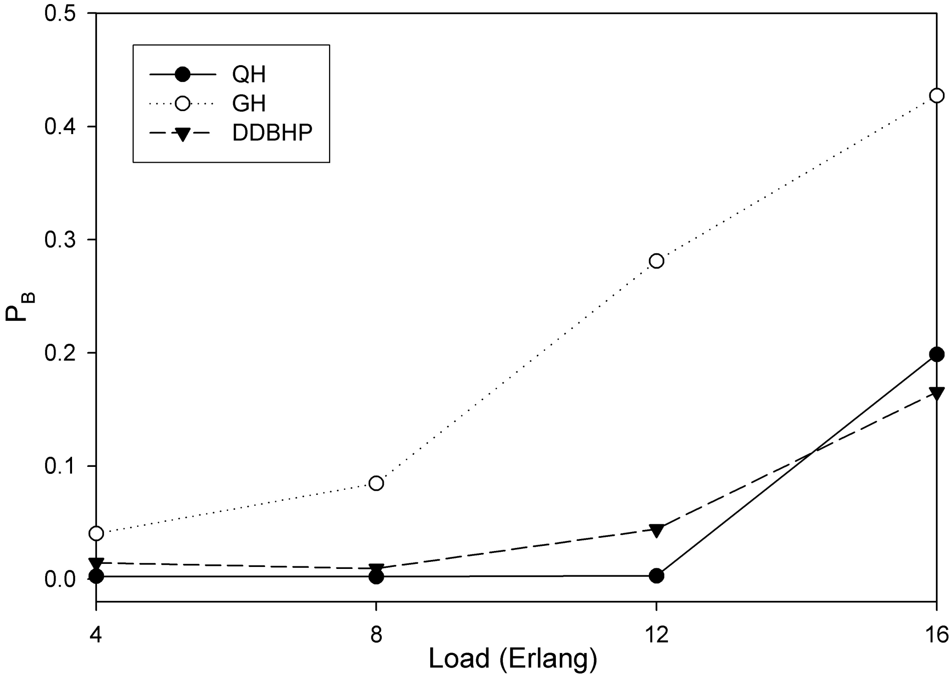

Figure 9: Blocking probability for three different prioritization schemes in a Globalstar-like system.

for different values of t_{TH} over a range of cell load. Even in the case the offered traffic load is 80% of the cell capacity (16 Erlang) DDBHP presents relatively small P_B.

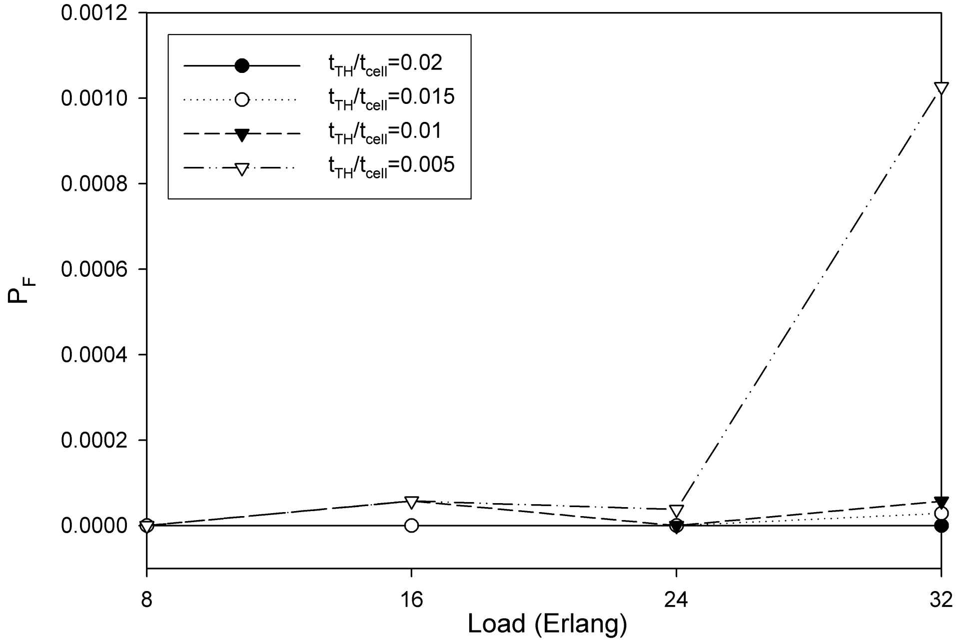

Figure 10: Forced termination probability for different t_{TH} values vs traffic load for a typical MEO system.

In Figure 9 the performance of DDBHP ($t_{TH} = 0.3t_{cell}$) is presented and compared to other proposed schemes. Although QH performs almost in the same manner as far as P_B is concerned, in terms of P_F fails to provide a guaranteed handover procedure ($P_F = 7.16\%$ for 8 Erlang). GH on the other hand fails to utilize the system resources efficiently therefore leading to high P_B.

Finally we tested the proposed method in a system with typical MEO parameters in order to figure out its performance in a relatively low mobility environment. As a confirmation we can see in Figure 10 that only 2% of t_{cell} is required for DDBHP to perform a guaranteed handover. This is combined with a further improvement in P_B depicted in Figure 11. In Figure 12 again the superiority of DDBHP is depicted. Because in this case t_{cell} is high and GH reserves two channels for this time interval it is expected to suffer high P_B. This result is confirmed in Figure 12.

It must be noticed that all presented results do not take into account cells overlapping and earth rotation. If these two factors are taken into account DDBHP would enforce its performance since it provides a mechanism for locating the correct destination cell and therefore suppresses false reservations. Another advantage of the proposed method is that t_{TH} can be chosen by the serving satellite taking into account local traffic measurement. Therefore a system may operate with different values of t_{TH} in different locations and adapt to traffic variations.

5 Conclusions

In this paper a new handover prioritization technique for satellite fixed cell systems, called DDBHP, has been proposed and its performance has been investigated. It takes advantage of Doppler effect to efficiently utilize system resources and support a guaranteed handover procedure. The new technique was tested in three different systems and proved to have an advantage compared to other proposed techniques. Additionally DDBHP provides a solution for cases that the destination cell in a handover is adjacent and not next to the

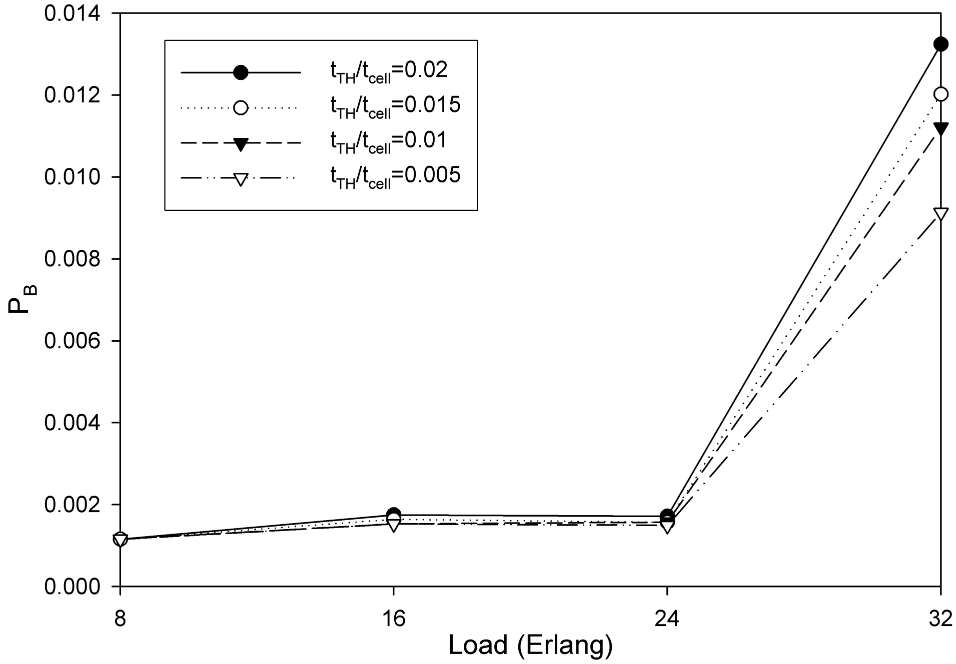

Figure 11: Blocking probability for different t_{TH} values vs traffic load for a typical MEO system.

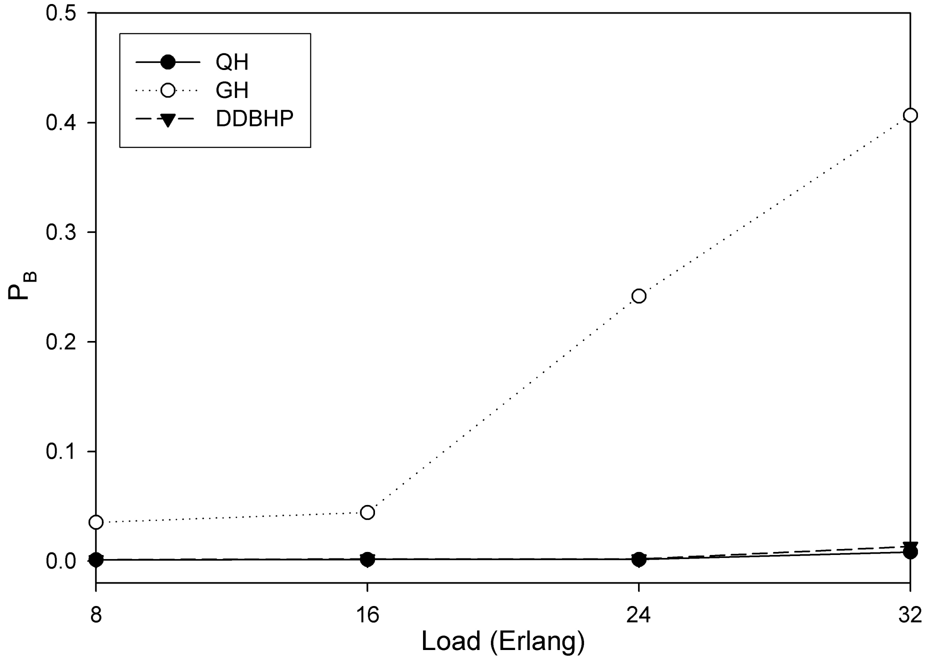

Figure 12: Blocking probability for three different prioritization schemes in a typical MEO system.

origin cell, an issue that has never been addressed so far in the literature. This is particularly true when earth rotation and cell overlapping are taken under consideration. Furthermore DDBHP can be considered

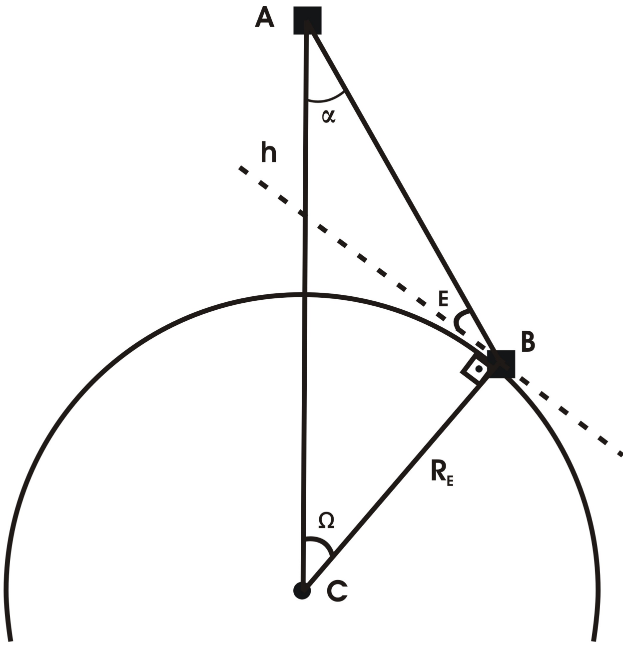

Figure 13: Satellite-terminal geometry

fully distributed in the sense that each satellite is able to use a different value for the handover threshold parameter according to local traffic measurements in order to enhance network operation.

Appendix 1

In order to calculate the elevation angle E as a function of the central angle G we apply the law of sines in triangle ABC shown in Figure 13.

$$\begin{aligned}
\frac{sin(\alpha)}{R_E} &= \frac{sin(90^o + E)}{R_E + h} \\
\frac{sin(90^o - \Omega - E)}{R_E} &= \frac{sin(90^o + E)}{R_E + h} \\
\frac{cos(\Omega + E)}{R_E} &= \frac{cos(E)}{R_E + h} \\
\Omega &= arccos(\frac{R_E}{R_E + h} \cdot cos(E)) - E
\end{aligned}$$

References

[1] G. Maral and M. Bousquet. *Satellite Communications Systems.* John Wiley and Sons Ltd, 2nd edition, 1993.

[2] Enrico Del Re, Romano Fantacci, and Giovanni Giambene. Efficient dynamic channel allocation techniques with handover queuing for mobile satellite networks. *IEEE Journal on Selected Areas in Communications*, 13(2):397–405, 1995.

[3] Sirin Tekinay and Bijan Jabbari. A measurement-based prioritization scheme for handovers in mobile cellular networks. *IEEE Journal on Selected Areas in Communications*, 10(8):1343–1350, 1992.

[4] Daehyoung Hong and S. S. Rappaport. Traffic model and performance analysis for cellular mobile radio telephone systems with prioritized and nonprioritized handoff procedures. *Vehicular Technology, IEEE Transactions on*, 35(3):77–92, 1986.

[5] Sirin Tekinay and Bijan Jabbari. Handover and channel assignment in mobile cellular networks. *IEEE Communications Magazine*, 29(11):42–46, 1991.

[6] G. Maral, J. Restrepo, E. del Re, R. Fantacci, and G. Giambene. Performance analysis for a guaranteed handover service in an LEO constellation with satellite-fixed cell. *IEEE Trans. Veh. Technol.*, 47(4):1200–1214, 1998.

[7] Ozgur Ercetin, etin O"zgu"r Erc, Srikanth Krishnamurthy, Leandros Tassiulas, Son K. Dao, and Ros Tassiulas. A predictive qos routing scheme for broadband low earth orbit satellite networks. In *in Proc. PIMRC 2000*, pages 1064–1074, 2000.

[8] Irfan Ali, Naofal Al-Dhahir, and John E. Hershey. Doppler Characterization for LEO Satellites. *Communications, IEEE Transactions on*, 46(3):309–313, 1998.

[9] Evangelos Papapetrou and Fotini-Niovi Pavlidou. A Proposal of Optimal Routing Techniques for non-GEO Satellite Systems. *International J. of Wireless Inform. Networks*, 8(2):75–83, April 2001.

[10] Markus Werner, Cecilia Delucchi, Hans Jörg Vögel, Gérard Maral, and Jean-Jacques De Ridder. ATM-Based Routing in LEO/MEO Satellite Networks with Intersatellite Links. *IEEE J. Select. Areas Commun.*, 15(1):69–82, January 1997.

[11] I. Gragopoulos, E. Papappetrou, and F.-N. Pavlidou. Performance Study of Adaptive Routing Algorithms for LEO Satellite Constellations under Self-Similar and Poisson Traffic. *Communications, IEEE Transactions on*, 16:15–2, 2000.

[12] H.S. Chang et al. Performance comparison of static routing and dynamic routing in low earth orbit satellite networks. In *VTC'96*, page 12401243, 1996.