Supporting QoS over Handovers in LEO Satellite Systems

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ABSTRACT

Low Earth Orbit (LEO) satellite networks are characterized by topology variations. Although space segment topology varies periodically, connections of mobile stations (MS's) to the satellite 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 MS's from one satellite to another (handover). All of these procedures are based on predictions of the requested handovers to facilitate network operation and therefore enhance quality 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.

I. INTRODUCTION

Modern communication networks point at providing seamlessly high quality services. To this effect they are foreseen to utilize a satellite component able to support high quality service demands. Low Earth Orbit (LEO) satellite systems [1] emerge as the most convenient solution because they provide low propagation delays. This is an essential advantage for real-time and interactive services dominating nowadays markets. Nevertheless rapidly moving satellites call for a cautious system design. The continuous rotation of satellites over an earth region requires 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 latter refers to the switching between cells.

Different studies have addressed the issue of handover management. 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 for a maximum 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 this time limit. In [3] G. Maral et al proposed a "*guaranteed handover service*" in systems where 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 current cell and in the next 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 [4] 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 small forced termination probability and no handover delay. 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 MS's and therefore make 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 II the proposed procedure is presented in detail. Then, in Section III we discuss the simulation framework and the implementation for evaluating the new method. In Section IV the results of our simulation study are presented, leading to useful conclusions in Section V.

II. 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 termination is desired from the user point of view blocking probability is also an important parameter of the network operation. One proposed approach is to handle handover upon its occurrence. Queuing of handovers [2, 5-6] is foreseen if available resources are not present. This technique avoids early reservation of resources and favors low blocking probability. Nevertheless introduces delay and relatively high forced termination probability if the acceptable delay is low. Furthermore depends on the satellite system design (i.e. size of overlap area). A second approach is to reserve resources before handover occurrence in order to minimize forced termination probability. This reservation may be predetermined (guard channels-[6-7]) or based on a prediction of handover requests. In this case although no delay is imposed, a cautious planning is needed to avoid an undesirable increase of blocking probability.

In order to overcome the problem of early resource reservation which increases blocking probability 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 allocation procedure relies on Doppler effect to predict the handover requests and then reserve channels at the appropriate time. The term “appropriate time” defines a time interval (time threshold t_{TH}) prior to handover occurrence in which the system must complete resource reservation and therefore achieve the quality of service (in terms of forced termination probability) requested by each user. It is clear that different values of the time threshold define different quality of service levels.

The proposed technique consists of three mechanisms namely *station monitoring*, *channel reservation* and *reservation countermand*, which produce the described functionality. New calls are admitted in the network if a free channel is available in the present cell. If the MS’s position at call setup indicates (station monitoring which is described below can be used also in the control phase) that a handover will occur in a time interval less than the time threshold then a free channel in the following cell is also needed for the call to be admitted in the network. Since a new call is admitted in the network the serving satellite activates station monitoring.

A. Station Monitoring

The serving satellite is able to derive the elevation angle of the communication at any time based on the measured Doppler shift. The measuring of Doppler shift [8] at two different time instances makes possible the calculation of the azimuth angle 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 :

$$AB = \arccos\left(\frac{R_E}{R_E + h}\cdot\cos(\mathrm{E}_1)\right) - \mathrm{E}_1$$

$$DB = \arccos\left(\frac{R_E}{R_E + h}\cdot\cos(\mathrm{E}_2)\right) - \mathrm{E}_2$$

where R_E is the earth radius, h the satellite altitude and E1, E_2 are elevation angles at t_1 and t_2 respectively calculated by the Doppler shift [8]. The angular distance AD is calculated by :

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

where T_s is the satellite period.

Applying the law of cosines in the spherical triangle ABD the angle α is derived:

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

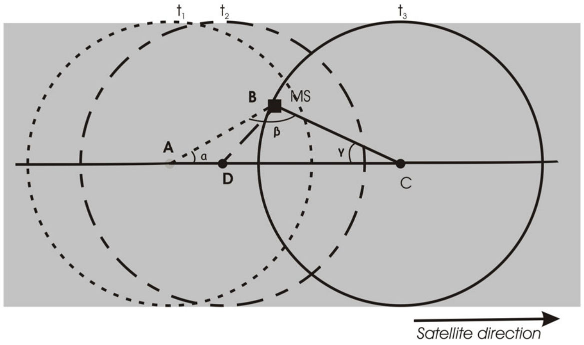

Figure 1. The station monitoring process

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 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 γ :

$$\gamma = \arcsin\left(\frac{\sin(BC)}{\sin(AB)\cdot\sin(\alpha)}\right)$$

Angle β equals:

$$\beta = 180^0 - \alpha - \gamma$$

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

$$AC = \frac{2\cdot\pi}{T_s}\cdot t_H = \arcsin\left(\frac{\sin(\beta)\cdot\sin(\alpha)}{\sin(BC)}\right) \Rightarrow$$

$$t_H = \frac{T_s}{2\cdot\pi}\cdot\arcsin\left(\frac{\sin(\beta)\cdot\sin(\alpha)}{\sin(BC)}\right)$$

After calculating the time to handover occurrence (t_H) the satellite schedules the channel reservation phase at a time $t_3=t_H-t_{TH}$ 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. It must be mentioned that station monitoring can be implemented also if the MS at call setup piggybacks its location on a packet used in the control phase. This overcomes the problem of

Doppler measurement precision that may calculation inaccuracies.

B. 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 2 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 FBO:

$$\hat{O} = \arcsin\left(\frac{\sin(FB)\cdot\sin(i)}{\sin(BO)}\right)$$

where the angular distance FB depends on the time elapsed since the satellite crossed the equatorial plane, *i* is the orbit inclination and BO equals to:

$$BO = \arccos(\cos(DL_2)\cdot\cos(L_2O))$$

with DL_2 and L_2O being the latitude and the longitude of the satellite respectively. Furthermore angle B_1 equals to:

$$\hat{B}_1 = 180^0 - i - \hat{O}$$

Applying the law of cosines in triangle DBO :

$$DO = \arccos(\cos(DB)\cdot\cos(BO) + \sin(DB)\cdot\sin(BO)\cdot\cos(B))$$

where:

$$DB = \arccos\left(\frac{R_E}{R_E + h}\cdot\cos(\mathrm{E})\right) - \mathrm{E}$$

and

$$\hat{B} = \hat{B}_1 + \hat{B}_2 = \hat{B}_1 + \gamma$$

Applying the law of sines in the same triangle:

$$\hat{O}_1 = \arcsin\left(\frac{\sin(DB)\cdot\sin(B)}{\sin(DO)}\right)$$

thus:

$$\hat{O}_2 = \hat{O} - \hat{O}_1$$

Applying the law of sines in spherical triangle DL_2O:

$$DL_2 = \arcsin(\sin(O_2)\cdot\sin(DO))$$

$$L_2O = \arcsin\left(\sin\left(90^0 - O_2\right)\cdot\sin(DO)\right)$$

By calculating the terminal location the serving satellite is able to derive the destination cell and make the reservation. This is of great importance if cells overlap 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 routed through ISLs (inter-satellite links) based on an appropriate routing protocol. Different routing protocols can be used for this purpose [9-12]. Upon receipt of the reservation packet, the destination satellite performs reservation in the corresponding cell.

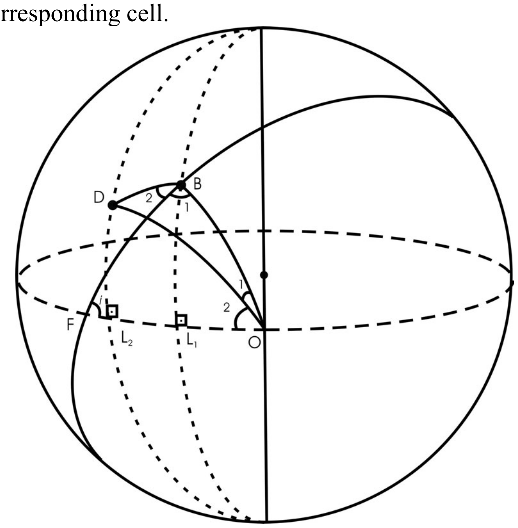

Figure 2. Calculation of point A location.

Upon a handover request 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.

The selection of *handover threshold* t_{TH} must be appropriate so that there is enough time for a channel to be reserved. 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 depending on the chosen threshold.

C. Reservation Cancellation

It is clear that the reservation takes place at $t_3=t_H-t_{TH}$ whereas the handover takes place at $t_4=t_H$. Meanwhile there is the possibility that the earth station 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 reserved channel.

III. SIMULATION SCENARIO

The proposed handover prioritization technique was tested in a typical low earth orbit constellation that resembles the Iridium system. In this paper we adopt the mobility model proposed in [3]. 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. The considered parameters are shown in TABLE I. The time that a user stays in a cell is denoted as t_{cell}.

TABLE I. SIMULATION PARAMETERS

Cell Length (Km)	500
t_{cell} (min)	1.26
V_{sat}(Km/sec)	6613.75
Channels/Cell	10
Users/Cell	100
T_{call} (sec)	180
Load/Cell (Erlang)	2-8
λ_{user} (10^{-4} calls/sec)	1.1-4.4

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 λ_{user}. The call mean duration is T_{call}.

In order to evaluate the performance of the proposed method we conducted two simulation experiments. In the first one all users of the network employ the proposed procedure to undergo handovers. In the second experiment two groups of users are considered. The first one, called "normal" doesn't employ any specific handover prioritization scheme. On the other hand the second group of users called "privileged" utilizes a handover prioritization scheme to eliminate forced termination probability.

IV. SIMULATION RESULTS

As mentioned before the choice of handover threshold t_H determines the performance of DDBHP. To explore this association we tested different values for t_H. In these simulation tests all users utilize DDBHP. In figure 3 the forced termination probability with respect to traffic load offered to a cell is depicted. As illustrated when operating on a relatively high value of t_H, DDBHP can provide a guaranteed handover procedure while for small values of t_H its performance can be considered acceptable for less demanding users. The advantage of DDBHP is that at the same time manages to support low blocking probability as can been seen in figure 4. This is the result of performing resource reservations shortly before the handover request. It is clear that if t_H is small P_F increases since some requests may not be served. On the other hand high t_H increases system underutilization since a user occupies two channels for a longer period of time. In figure 5 the blocking probability of three different handover prioritization schemes is depicted.The QH scheme [2] provides low P_B because handover requests are queued and do not reserve resources. Therefore QH fails to eliminate forced termination of calls (P_F reaches 16.57% for traffic load of 8 Erlang), a result confirmed by simulation results. The GH scheme [3] although it provides zero P_F, presents high P_B for high traffic load. On the other hand DDBHP (when a value of t_H=0.6t_{cell} is chosen) manages to minimize P_B while providing a guaranteed handover.

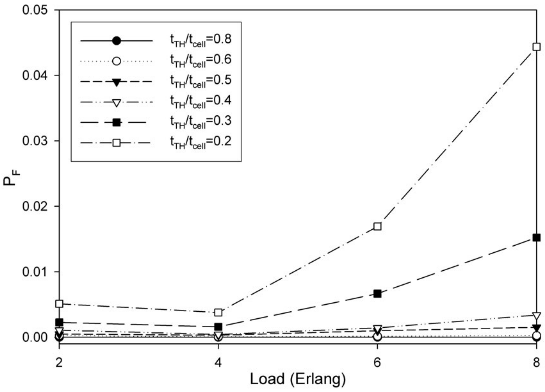

Figure 4. Forced termination probability for DDBHP with different thresholds.

Another interesting metric for the evaluation of a handover prioritization scheme is the number of handovers performed. Figure 6 illustrates the comparison of the three methods. Although the number of handovers rises with the traffic load for all methods only DDBHP preserves this trend for high traffic loads. Actually QH presents a small decrease when the traffic load is 8 Erlang as a result of the increasing forced termination probability. The ascent of both the QH-curve and the GH-curve is smaller than in the case of DDBHP as a result of the smaller number of users admitted into the network. This is a further indication that DDBHP not only manages to support a greater number of handovers but also attains more efficient network utilization.

In our second experiment we considered the situation where the satellite system provides two classes of services namely "normal" and "privileged".

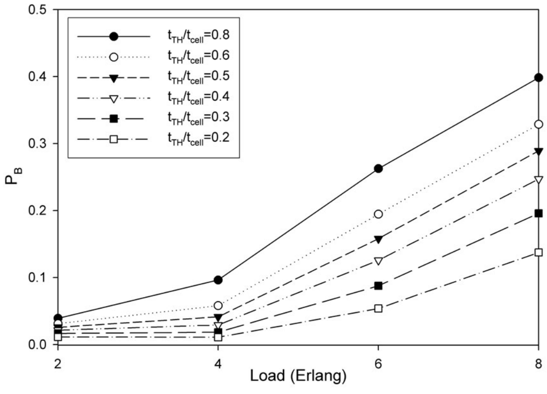

Figure 3. Blocking probability for DDBHP for different thresholds.

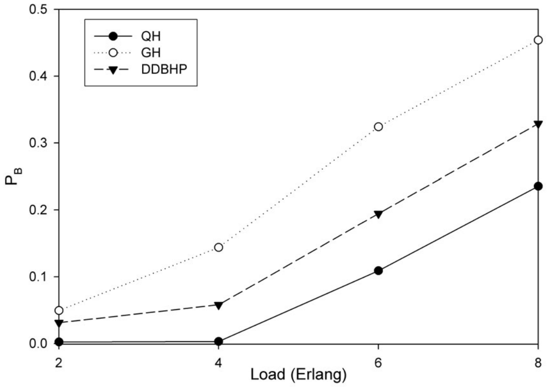

Figure 5. Comparison of blocking probabilities for QH, GH and DDBHP

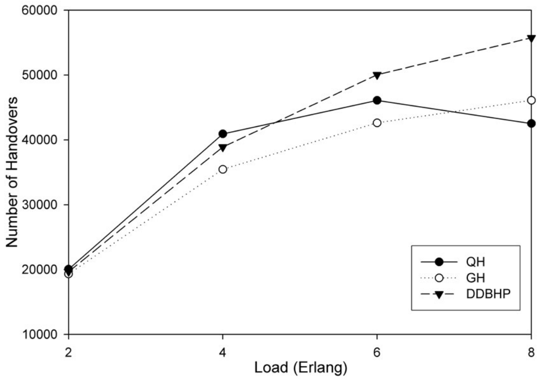

Figure 6. Number of handovers vs traffic load

Users requesting a "privileged" service from the network are supported by a handover prioritization procedure to perform hitless handovers contrary to "normal" users which are not supported by any prioritization scheme. In these sets of simulations the total offered traffic was set to 8 Erlang and the percentage of "privileged" users was between 20% and 100% of the total user population. Figure 7 presents the "optimum" threshold of DDBHP when the percentage of "privileged" users changes. By the term "optimum" we indicate the threshold that provides the best performance in terms of blocking probability and at the same time eliminates forced termination of calls. The variation of the "optimum" threshold is small (approximately 7%) which allows the network to easily and quickly adapt to variations of service type requests.

In figures 8 and 9 the blocking and forced termination probabilities with respect to the percentage of "privileged" users are presented respectively. We tested GH and DDBHP as the prioritization scheme used by the "privileged" users because unlike QH they were proved to eliminate forced termination probability and thus support the "privileged" service. As far as "privileged" users are concerned both methods provide a hitless handover but DDBHP achieves smaller blocking probability. For "normal" users DDBHP provides both smaller P_F and P_B as a result of effective resource management.

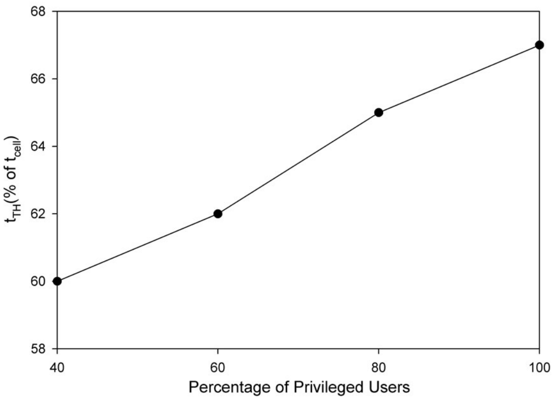

Figure 7. Best threshold for DDBHP when two user categories are considered.

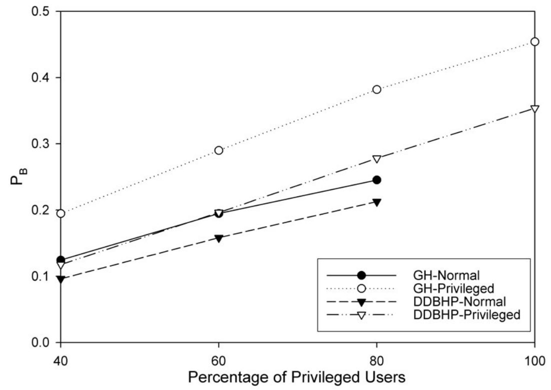

Figure 8. Blocking probability for normal and privileged users for QH, GH and DDBHP.

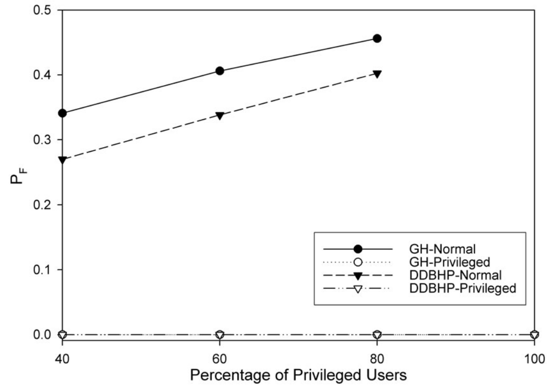

Figure 9. Forced termination probability for normal and privileged users for QH, GH and DDBHP.

IV. 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 QoS over handovers. The new technique was tested in a typical LEO system and proved to have an advantage compared to other proposed techniques. Additionally DDBHP provides a solution for cases that the destination cell in handover is adjacent and not next to the origin cell. This is particularly true when earth rotation is taken under consideration. Furthermore DDBHP can be considered 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.

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