Handover Policies in LEO Systems with Satellite Diversity

E. Papapetrou, S. Karapantazis, F.-N. Pavlidou

Dept. of Electrical & Computer Engineering,
Aristotle University of Thessaloniki,
P.O.Box 1641, 54124, Thessaloniki, Greece
Email: skarap@auth.gr

ABSTRACT

In this paper satellite handover procedures are proposed for investigating the satellite diversity (namely, the existing common coverage area between contiguous satellites) of some satellite constellations in order to provide an efficient handover strategy. Based always on a tradeoff of the blocking and forced termination probabilities three different handover criteria are examined for the appropriate selection of the servicing satellite. Each criterion can be applied either to new or handover calls, therefore we investigate nine different service schemes. Extended simulation results provide a deep insight on the system operation and lead to a beneficiary system architecture.

1. INTRODUCTION

The success of future communication networks is based on providing high quality services with global coverage. Thus, 3G mobile systems worldwide comprise of interworking terrestrial and satellite components (i.e. UMTS, IMT2000). Regarding real-time and interactive services, Low Earth Orbit (LEO) satellite constellations emerge as the most convenient solution because of the low propagation delays they provide [11]. Several LEO constellations have been proposed in the literature (Globalstar, Iridium, Ellipso etc.), while the operation of the Iridium system has offered a very good experience for the study of the critical performance issues of these systems. Last achievements in antenna technology leaded to multibeam LEO systems where the satellite footprint is divided in many cells (using multi-beam arrays), in order to enhance frequency reuse policies (Fig. 1). This leads to a significant probability of service interruption and consequently, the hand-over mechanism becomes of great importance for the overall performance of the system. That is, in LEO in parallel to the classic performance criteria (blocking probability P_B, delay D, throughput T etc) the forced termination probability (P_F) is a crucial parameter, as is the case in land mobile systems. There are two types of handover events, the *cell handover* and the *satellite handover*. The former refers to the transfer of an ongoing call from one cell to the next one in the same satellite footprint while the latter describes the transfer of an ongoing call from a satellite to another one (Fig.1).

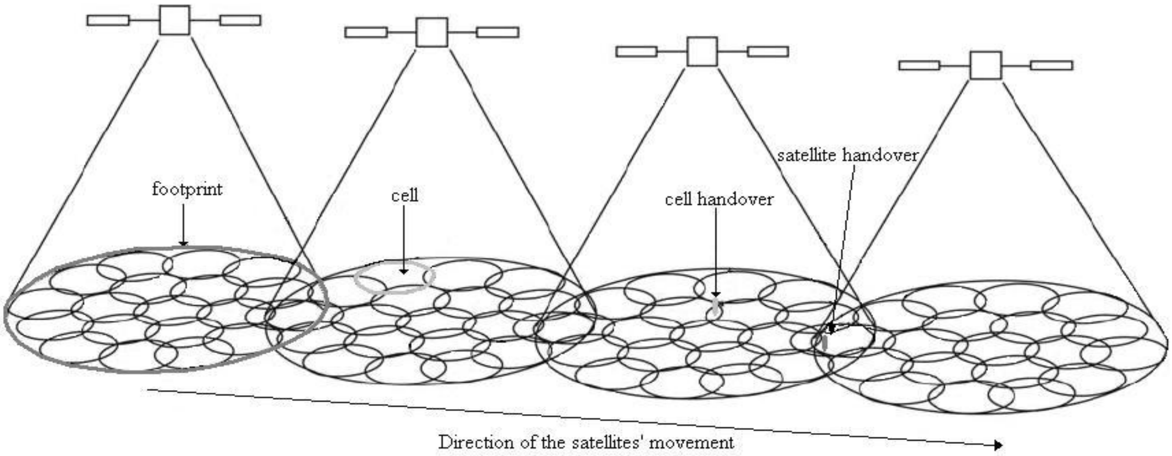

Fig. 1. Footprints of LEO satellites

Quite many studies have been carried out on the issue of cell handover, investigating channel allocation policies for new and handover calls mainly through fixed channel allocation (FCA) techniques. In [1] different queuing policies for handover requests were proposed. The handover requests, queued up to a maximum time interval (which is a function of the overlapping area of contiguous cells), are served in a *first-input-first-output (FIFO)* scheme or in a *last useful instant (LUI)* scheme (that is, a handover request is queued ahead of any other requests already in the queue that have a longer residual queuing time). In [2] a *"guaranteed handover service"* was proposed. This technique provides zero P_F but at the cost of unacceptably high values of P_B due to very early channel reservation. In [3] a connection admission control strategy for cell handover was studied in detail. A *geographical connection admission control (GCAC)* algorithm was introduced in addition to an *adaptive dynamic channel allocation (ADCA)* scheme. According to the *GCAC* algorithm, the future forced termination probability for a new call and for the existing calls is estimated as a function of user location and it is checked if it is below a predefined level. Upon this check the *GCAC* algorithm determines whether the new call is accepted or not. In [4] a *dynamic Doppler based handover prioritization* technique *(DDBHP)* has been proposed. This method takes advantage of the Doppler effect in order to estimate the terminal location and to reserve channels at an "appropriate time" in the servicing and forthcoming satellite. The term "appropriate time" defines a time interval (*time threshold* t_{TH}), prior to the handover occurrence, during which resource allocation activities should be completed. The instant prior to the handover of the terminal, on which a channel reservation request is sent to the forthcoming satellite, is defined by the $t_{TH.}$

Satellite diversity (or partial satellite diversity) can support drastically efficient bandwidth utilization techniques and a very flexible system operation for providing QoS services in future systems. Thus a thorough investigation of constellations with partial satellite diversity is quite beneficiary for an efficient performance of such systems. In this paper the *satellite handover* issue is studied in depth exploiting the partial satellite diversity. In many proposed satellite networks, contiguous satellites share common coverage areas on the surface of the earth (*"partial satellite diversity"*). The term diversity implies that a user is always covered by two satellites at least. However, *"partial satellite diversity"* implies that there are also some users that are covered only by one satellite. The proposed technique aims at handling the satellite handover issue in an optimum way and therefore providing users with high quality of service at quite low forced termination probability. Our analysis is based on the *DDBHP* procedure proposed in [4], as it seems to offer a suitable tradeoff between blocking and forced termination probabilities, modifying it for the case of satellite handover. We focus our study on a network that resembles the Boeing design of the Teledesic system (288 satellites), because the specifications of this design are quite well defined. We also tested our algorithm in a system that resembles the Iridium network. Considering the common area that satellites in different orbital planes share, the user can select between more than one satellites and thus we have to define criteria for that selection. We propose and evaluate three criteria, each of them being applied either to new or handover calls. Consequently, we result in nine different service schemes and we investigate the overall system performance for each one of them. Throughout in our study we neglect the cell handover since we like to focus on the satellite handover. Of course, we should examine the common phenomenon of cell and satellite handover, but for the moment this is out of the scope of our study.

The remaining of the paper is organized as follows. In section 2 we describe the mobility model and the proposed technique in detail. The simulation framework and the performance evaluation of the system for the different service schemes are presented in section 3. Finally, section 4 summarizes the results and concludes.

2. MOBILITY MODELING AND CHANNEL RESERVATION PROCEDURES

In non-GEO satellite constellations the visibility period of a satellite can be rather small. Future satellite networks should be compatible with terrestrial systems (S-UMTS), therefore voice will not be the sole service they will provide. Interactive multimedia IP services are expected to be of utmost importance (and obviously, for this type of services quite many satellite handovers will occur). Teledesic will definitely support IP services. Although this system does not provide always dual satellite coverage, its constellation design presents *"partial satellite diversity*", and therefore, provides the possibility for satellite handover between satellites in *different orbital planes*.

2.1 Mobility model

In Teledesic adjacent satellite footprints share common areas on the earth surface (*partial satellite diversity*) as it is shown in Fig. 2. We consider an approximate two-dimensional design where the satellite footprints have orthogonal shape (Fig. 3). This model is valid as far as the following assumptions are met.

- Users are considered fixed on the earth surface, while satellites move with a constant speed V_{sat}. This is true if we take into account that terminals in very fast vehicles move with a velocity of 80m/sec at most, whereas the satellite velocity (for LEO constellations) is approximately 7400m/sec. Furthermore, we do not take into consideration the rotation of the earth.

- A user can select only between satellites in different orbital planes at call setup. We do not consider the case wherein the user can select between contiguous satellites in the same orbital plane, because in that case the user should always select the following satellite in order to avoid an immediate handover. With regard to Fig.3, the gray area between satellites 7 and 10 presents the common area between contiguous satellites in the same orbital plane.
- Terminals are uniformly distributed on the earth surface and in each satellite footprint.

Fig. 3 illustrates the service procedure of the system. If user B generates a new call, he can be served only by satellite 3 and will be handed-over to satellite 6. However, user A can be served either by satellite 3 or satellite 2. Regarding the first option, he can again select between two satellites (6 or 5). We see thus that there is a quite flexible selection environment in the system.

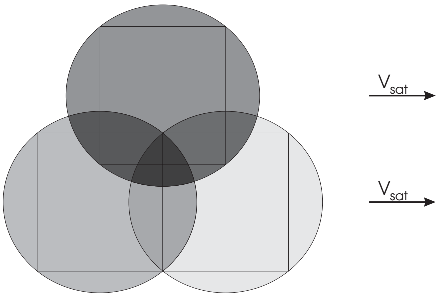

Fig. 2. Partial satellite diversity

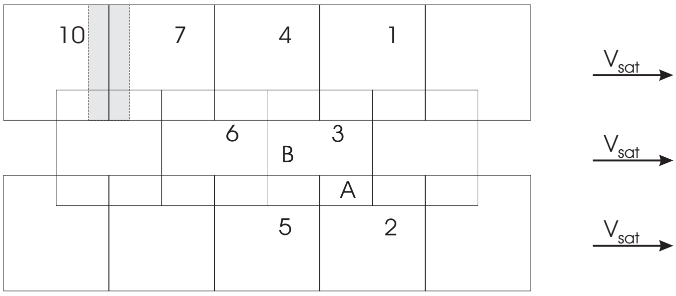

Fig. 3. Mobility model

As previously stated, the proposed algorithm is based on the *DDBHP* technique [4]. This technique makes use of the Doppler effect to avoid early reservation of channels and favors low blocking probability. The application of a Doppler-based positioning technique for users in a footprint has been examined in several proposals in the literature [4, 12, 13] and has been proved to be an efficient and low-complexity method for predicting handover requests and reserving channels into the interval defined by t_{TH}. Describing briefly *DDBHP* we note that by measuring the Doppler shift at two different time instants, it is possible to estimate the location of the user's terminal and the time at which the handover will take place (*station monitoring*). Furthermore, by knowing the position of other satellites, the servicing satellite is able to select the possible forthcoming satellites for relaying the calls. This is an important feature of the *DDBHP* technique since the servicing satellite is not always the following one in the same orbital plane.

2.2 Channel Reservation Procedures

According to the proposed algorithm, a *new call* is admitted in the network if an available channel is found in the current satellite. However, if the location of the user's terminal indicates that a handover will occur in a time interval less than t_{TH} then a channel has to be reserved at the satellite selected for the first handover, otherwise the call is blocked. After the call is admitted in the network, station monitoring is activated by the servicing satellite. The selection of the next servicing satellite is based on three criteria described below.

Regarding subsequent *handovers,* a channel-reservation request is sent to the next satellite at a time defined by the t_{TH} before the handover occurrence. If an available channel is not found in the meantime, then the call is forced into termination. The selection of t_{TH} is crucial. High values of t_{TH} lead to small values of forced termination probabilities compared to forced termination probabilities for small values of t_{TH}, but blocking probabilities are unacceptably high due to early reservation of resources. On the contrary, small values of t_{TH} result to smaller values of blocking probabilities. Apparently, different values of the t_{TH} define different quality of service levels. A study on the determination of the range of t_{TH} is given in the following section.

For the selection of the next servicing satellite we propose the following three criteria.

1. *Maximum service time* ***(T)***
   According to this criterion, the user will be served by the satellite that offers the maximum service period. This criterion aims at minimizing the number of handovers and therefore achieving low forced termination probabilities.
2. *Maximum number of free channels* ***(C)***
   According to this criterion, the user will be served by the satellite with the maximum number of free channels. The aim in this case is to achieve a uniform distribution of the telecommunication traffic in the celestial

network. Thus, new or handover calls experience the same blocking or forced termination probabilities in every satellite regardless their location, avoiding, therefore, overloaded satellites.

3. *Minimum distance* (***D***)
According to this criterion, the user will be served by the closest satellite. This criterion aims at avoiding link failures depending on the distance between the user terminal and the satellite. As far as we know there is no known probability function that describes link failure occurrences. Nevertheless, simulation results will show that it is worth examining this criterion.

Since the criteria can be applied to both new and handover calls, we result in nine different service schemes which are:

- *TT scheme*
- *CC scheme*
- *DD scheme*
- *TC scheme*
- *TD scheme*
- *CT scheme*
- *CD scheme*
- *DT scheme*
- *DC scheme*

The first letter corresponds to the criterion used for new calls while the second letter corresponds to the criterion used for handover calls.

Investigating the reservation techniques in detail we notice that according to the proposed mobility model the number of the possible servicing satellites can be two at most (the case of user A in Fig. 3). The *new call admission procedure* has as follows. A new call will first check if there is an available channel in the satellite indicated by the criterion used for the access procedure (assume that this satellite is satellite number 3). If no free channel is found, then it will check the second satellite (satellite number 2). The *reservation procedure for handover calls* has as follows. At a handover request the servicing satellite decides on the next possible servicing satellite according to the criterion used. We consider again the case of two satellites covering the user area (we assume that user A was initially served by satellite 3). At the time of the handover occurrence, the selected satellite is checked (assume that it will be satellite 6). If a channel has been reserved in the meantime, then the call is handed-over to this satellite and if a channel has also been reserved in satellite 5, it is released; otherwise the request is deleted from the queue. If no channel has been reserved in satellite 6, the request is deleted from the queue and satellite 5 is checked. If a channel has been reserved, the call is handed-over to this satellite, otherwise is forced into termination and the request is deleted from the queue. If a call is terminated in t_{TH}, the reserved channel in each one of the forthcoming satellites is released. If there is no reserved channel in a satellite, the request is just deleted from the queue of this satellite. The messages for channel reservation are sent to the forthcoming satellites through inter-satellite links (ISLs).

3. PERFORMANCE EVALUATION

A simulation tool has been developed in C++ and extended runs for different system configurations provided reliable and interesting information on the system performance. We examined the performance of each one of the nine service schemes proposed in the previous section in a typical low earth orbit constellation that resembles the geometry of the Teledesic system (Boeing design – 288 satellites). According to this design, contiguous satellites in different orbital planes share a common area of about 13% of the footprint's total area (at the equatorial level). For the simulation runs we adopted the mobility model mentioned in section 2. Furthermore, we applied the parameters of *Table I*. t_F defines the maximum time that a mobile user can stay in a satellite footprint. Each mobile user generates calls according to a Poisson distribution function with a rate λ_{user}, while T_{call} is the average call duration.

Table I. Simulation parameters

Footprint Length	1667.6 Km
t_F (time in a footprint)	4.71 min
V_{sat} (Footprint's velocity)	5.8928 Km/sec
Channels per Satellite	10
Users per footprint	100
T_{call} (call duration)	180 sec
Load per footprint	8 Erlang
λ_{user} (arrival rate 10^{-4}calls/sec)	4.44

We first examined different values of the time threshold t_{TH} in order to see its influence on blocking and forced termination probabilities.

As mentioned before, different values of the t_{TH} define different quality of service levels. Fig. 4 and 5 present blocking and forced termination probabilities for service schemes that use the same criterion both for the access and the handover procedure. As we expected, the higher the t_{TH} is, the higher blocking probabilities are. On the contrary, as t_{TH} increases, a drop in forced termination probabilities is observed. We also observe that the CC and the TT scheme perform better than the DD scheme. Moreover, they seem to have a similar performance. The TT scheme presents better blocking probabilities, whereas the CC scheme performs better as far as forced termination probabilities are concerned. However, various simulation runs showed that the CC scheme performs slightly better, because it presents almost the same blocking probabilities with the TT scheme but lower forced termination probabilities. Besides, forced termination calls are less desirable from the user's point of view than blocked calls.

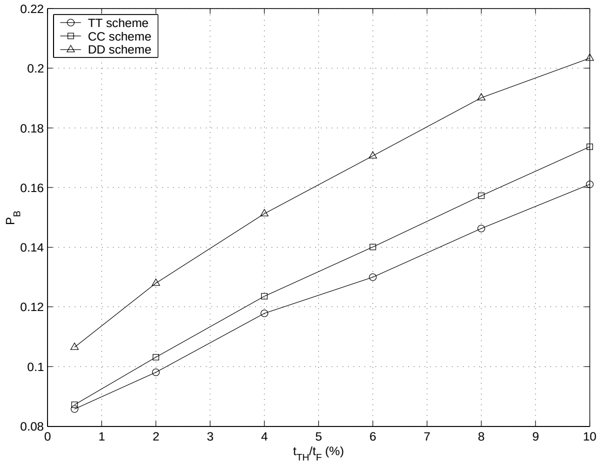

Fig. 4. P_B if the same selection criterion is applied to new and handover calls

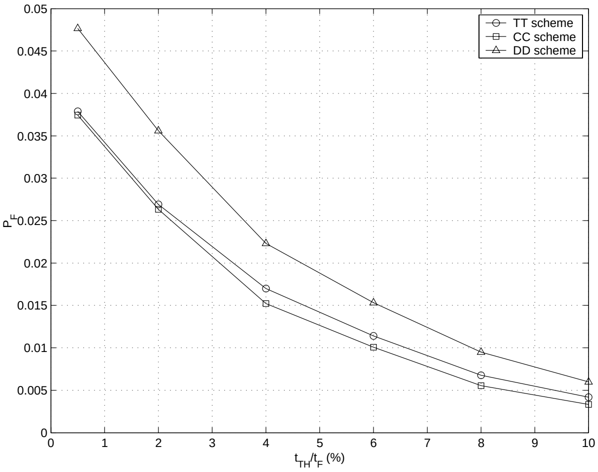

Fig. 5. P_F if the same selection criterion is applied to new and handover calls

Fig. 6 and 7 illustrate the performance of the other six schemes. The results are fairly interesting. The best performance is obtained for the CT scheme, while the worst for the CD scheme, both for new and handover calls. The differences among the schemes are more obvious in blocking probabilities than in forced termination probabilities. At this point, we should say that several simulation runs showed that the DC, the DT and the DD schemes perform better for smaller

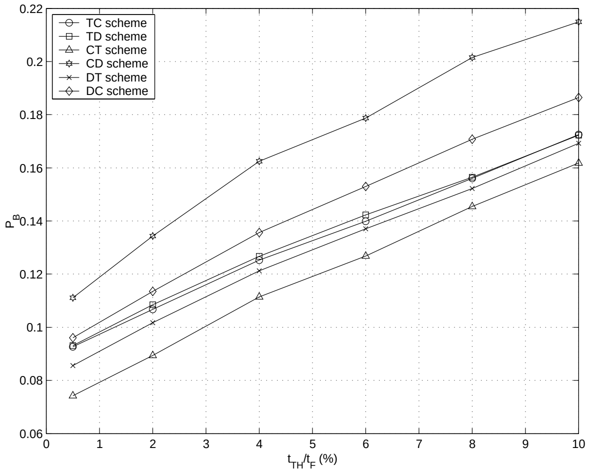

Fig. 6. P_B if different selection criteria are applied to new and handover calls

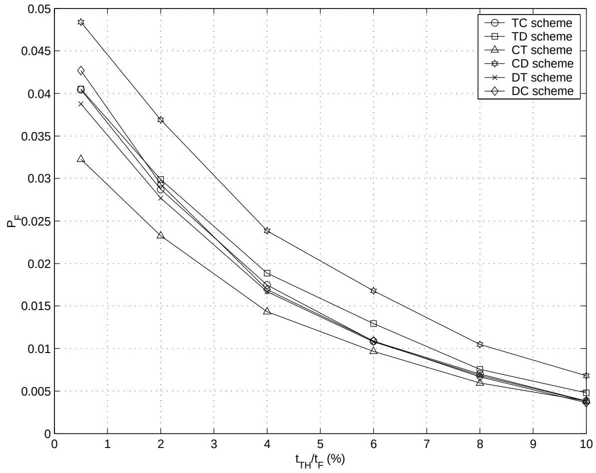

Fig. 7. P_F if different selection criteria are applied to new and handover calls

values of the common coverage area but only regarding blocking probabilities, whilst all the other schemes present lower probabilities for higher values of the common coverage area. We also see that only the CT scheme performs better than the CC and the TT schemes and therefore, CT scheme seems to be the best case among all experiments.

We also tested the performance of the criteria for different values of the telecommunication load. Simulation runs for other values of the telecommunication load (2, 4 and 6 Erlang) showed that the CT scheme performs better than any other scheme for all the different values of load. Considering that each satellite has 10 channels, 2 (4 or 6) Erlang means that all the channels of the satellite are reserved for the 20% (40% or 60%) of the simulation time interval. The t_{TH}/t_F for these simulation runs was set to 5 %. Fig. 8 and Fig. 9 present the P_B and P_F respectively for schemes that depend on the same criterion both for new and handover calls. Obviously, the CC scheme outperforms the TT and DD schemes.

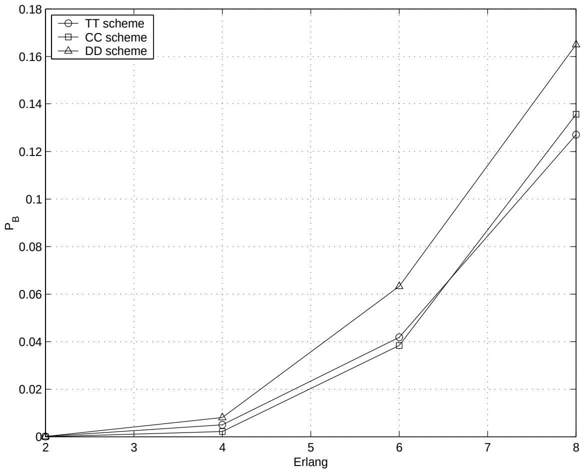

Fig. 8. P_B if the same selection criterion is applied to new and handover calls

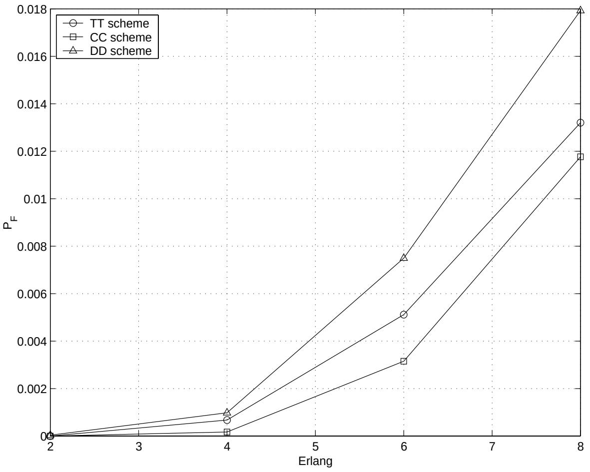

Fig. 9. P_F if the same selection criterion is applied to new and handover calls

Fig. 10 and Fig. 11 show the P_B and P_F respectively for schemes that depend on different criteria for new and handover calls. We observe that the best performance is presented by the CT scheme. Furthermore, the CT scheme outperforms the other eight schemes.

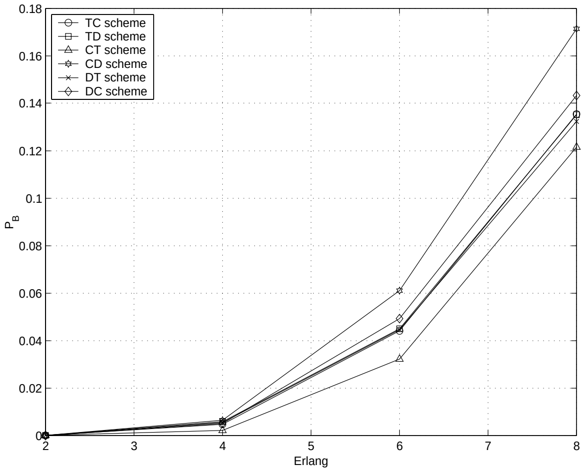

Fig. 10. P_B if different selection criteria are applied to new and handover calls

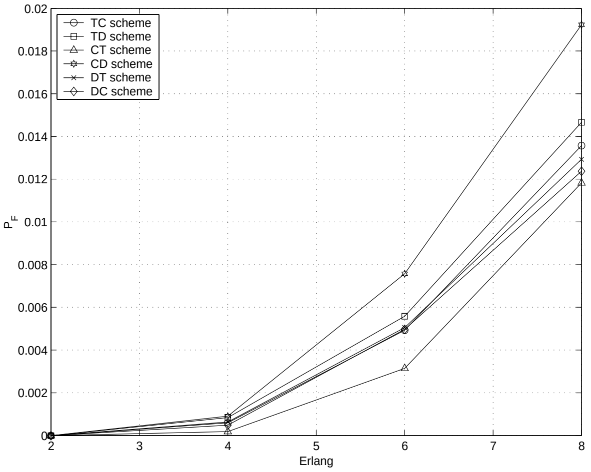

Fig. 11. P_F if different selection criteria are applied to new and handover calls

Moreover, considering the evolution of Teledesic, a vital parameter for the success of a system is the constructive and operation cost, and therefore, future designs of non-GEO satellite systems tend to decrease the number of the satellites by increasing the altitude of the orbits. So, we also checked the schemes on a system with 66 satellites that resembles the geometry of the Iridium network, resulting essentially to an analogous performance for each one of the schemes. Fig. 12 and Fig. 13 present the P_B and P_F respectively for different values of traffic load and for schemes that depend on the same criterion both for new and handover calls, while Fig. 14 and Fig. 15 present the P_B and P_F respectively for schemes that depend on different criteria for new and handover calls. The t_{TH}/t_F for these simulation runs was set again to 5 %, and all the parameters were still the same apart from the following: Footprint length=3638.53 Km , t_F=9.18 min, V_{sat}=6.6058 Km/sec.

We observe that again the CT scheme outperforms the other schemes. Generally, the difference in the performances between the criteria is independent of the geometry of the network.

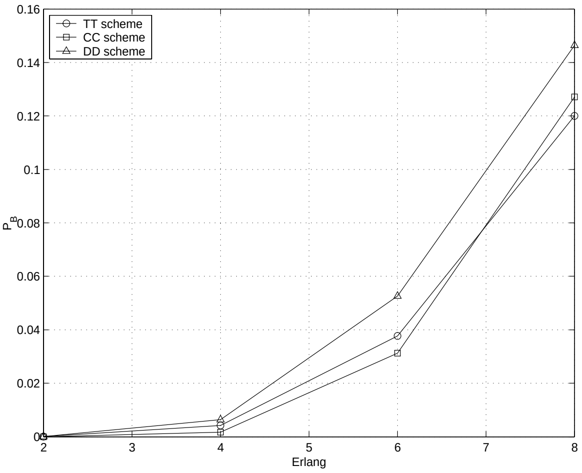

Fig. 12. P_B if the same selection criterion is applied to new and handover calls

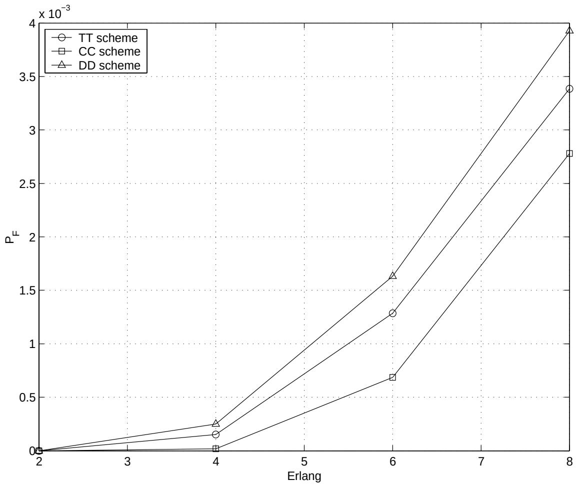

Fig. 13. P_F if the same selection criterion is applied to new and handover calls

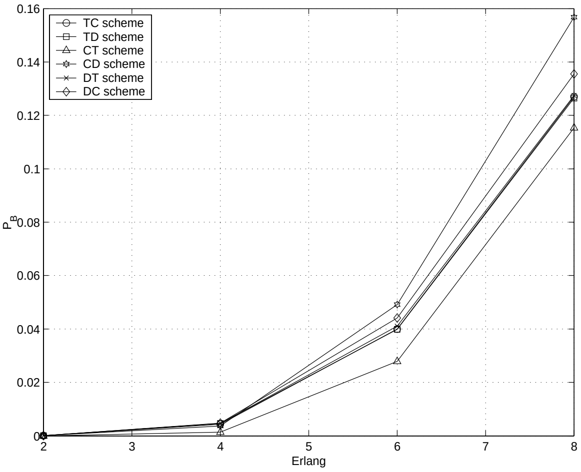

Fig. 14. P_B if different selection criteria are applied to new and handover calls

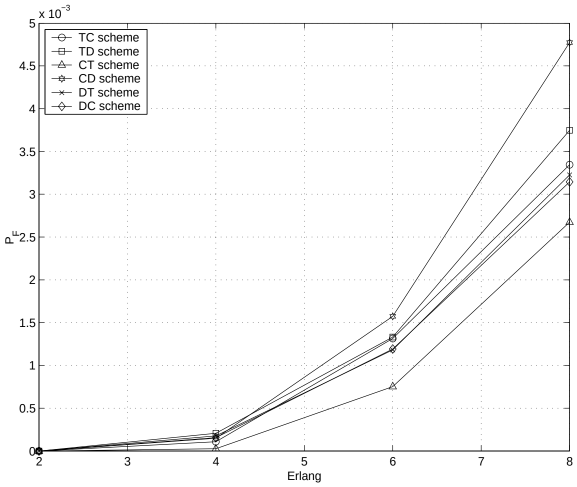

Fig. 15. P_F if different selection criteria are applied to new and handover calls

Of course in a realistic system we have always an overlapping of satellite footprints, something that we try to avoid for interference, waste of bandwidth and economical reasons. But since it exists we examined the influence of different values of overlapping on blocking and forced termination probabilities for the Teledesic-like system applying the parameters of *Table I*. An increment in the common area between contiguous satellites can be achieved either by increasing the altitude of the orbits or by adding another orbital plane. Simulation runs for all the schemes showed that the bigger the common coverage area is, the better the scheme performs. Fig. 16 and Fig. 17 present the P_B and P_F for different values of t_{TH} and for the CT scheme.

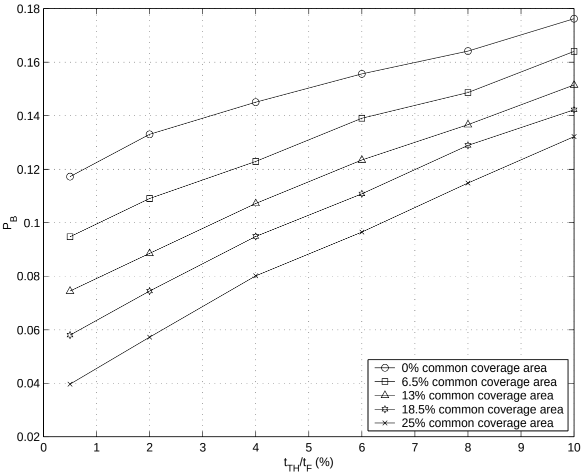

Fig. 16. P_B for different values of the common coverage area

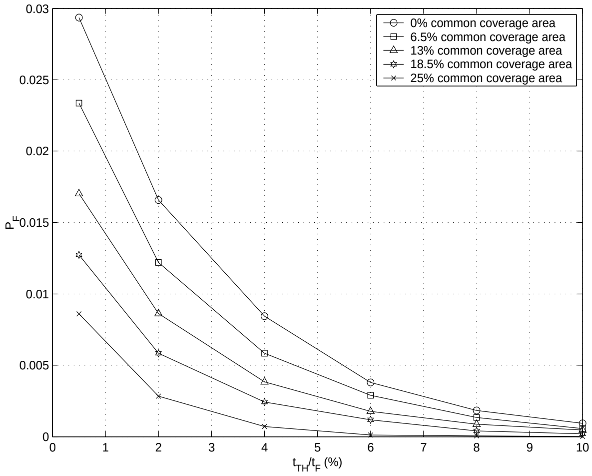

Fig. 17. P_F for different values of the common coverage area

The obtained results are quite promising and illustrate that an effective design of a partial satellite diversity constellation is possible at a low complexity algorithm resulting in a favorable allocation of resources and satisfactory QoS provision.

4. CONCLUSIONS

This paper proposes a prioritization technique that is based upon the *DDBHP* technique for handling the satellite handover issue. It takes into account the partial satellite diversity that future LEO networks will present and it defines three different criteria for the selection of a satellite. The three different criteria resulted in nine different service schemes. We tested these schemes in two different networks, in a Teledesic-like network and in an Iridium-like network, in order to derive the scheme with the best performance. Obviously, different criteria and different values of the time threshold can be used by users in different areas either for the access or the handover procedure, always according to the prospective telecommunication load.

5. REFERENCES

1. Enrico Del Re, Romano Fantacci, Giovanni Giambene, Different Queuing Policies for Handover Requests in Low Earth Orbit Mobile Satellite Systems, *IEEE Transactions on Vehicular Technology*, vol. 48, No. 2, March 1999

2. Gerard Maral, Joaquin Restrepo, Enrico Del Re, Romano Fantacci, Giovanni Giambene, Performance Analysis for a Guaranteed Handover Service in a LEO Constellation with a "Satellite-Fixed Cell" System, *IEEE Transactions on Vehicular Technology*, vol. 47, No. 4, November 1998

3. Sungrae Cho, Ian F. Akyildiz, Michael D. Bender, Huseyin Uzunalioglu, A New Admission Control for Spotbeam Handover Management Technique for LEO Satellite Networks, *Kluwer Academic Publishers, Wireless Networks*, Vol. 8, Issue 4 (July 2002)

4. E. Papapetrou, E. Stathopoulou, F.-N. Pavlidou, Supporting QoS over Handovers in LEO Satellite Systems, *Mobile & Wireless Telecommunications Summit 2002*, 17-19 June 2002/ Thessaloniki – Greece

5. Enrico Del Re, Romano Fantacci, Giovanni Giambene, Characterization of user mobility in low earth orbit mobile satellite systems, *Kluwer Academic Publishers, Wirelless Networks*, Vol. 6, Issue 3 (July 2000)

6. Lloyd Wood, George Pavlou, Barry Evans, Managing diversity with handover to provide classes of service in satellite constellation networks, *Proceedings of the 19th AIAA International Communication Satellite Systems Conference (ICSSC'01)*, Toulouse, France, April 2001

7. Suresh Kalyanasundaram, Edwin K.P. Chong, Ness B. Shrof, An Eficient Scheme to Reduce Handoff Dropping in LEO Satellite Systems, *Kluwer Academic Publishers, Wireless Networks*, Vol. 7, Issue 1, p. 75 - 85 (2001)

8. L, Boukhatem, D. Gaiti, G. Pujolle, A Channel Reservation Algorithm for Handover Issues in LEO Satellite Systems based on a Satellite-Fixed Cell Coverage, *IEEE VTS 53rd Vehicular Technology Conference*, Spring 2001, May 6 -9, 2001 Rhodes - Greece

9. Zhipeng Wang, Takis Mathiopoulos, Analysis and Performance Evaluation of Dynamic Channel Reservation Techniques for LEO Mobile Satellite Systems, *IEEE VTS 53rd Vehicular Technology Conference*, Spring 2001, May 6 - 9, 2001 Rhodes – Greece

10. *http://www.spaceandtech.com/spacedata/constellations/teledesic_specs.shtml*

11. A. Jamalipour, *Low Earth Orbit Satellites for Personal Communications Networks*, Artech House, 1997

12. Irfan Ali, Naofal Al-Dhahir, John E. Hershey, Predicting the Visibility of LEO Satellites, *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 35, No 4, October 1999

13. Irfan Ali, Naofal Al-Dhahir, John E. Hershey, Doppler Characterization for LEO Satellites, *IEEE Transactions on Communications*, Vol. 46, No. 3, March 1998