Satellite Handover Techniques in LEO Systems for Multimedia Services

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

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

ABSTRACT

Specifying

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 and QoS in multimedia applications. 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.

Key words: LEO satellite networks, partial satellite diversity, Doppler effect, multimedia services

1. INTRODUCTION

Multimedia services are enriching day by day every communication system satisfying the demand for Internet connectivity anywhere, anytime. 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

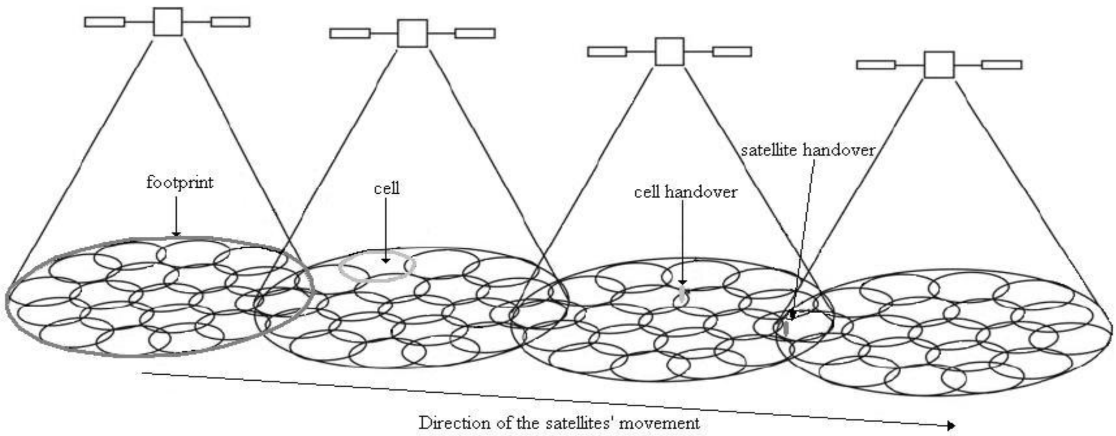

Fig. 1. Footprints of LEO satellites

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).

Quite many studies have been carried out on the issue of cell handover, investigating channel allocation policies for new and handover calls mainly though 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, 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). The maximum queuing time is a function of the overlap area between contiguous cells in the same direction. A new call is always admitted in the network if an available channel exists in the current cell. New calls generated in the overlapping area of adjacent cells are immediately addressed to the destination cell in order to avoid an immediate handover. A call is forced into termination if the handover request is not served within the queuing time in the current cell. *FIFO* policies attain results very close to the results of the *LUI* technique with lower implementation complexity.

In [2] a *"guaranteed handover service"* was proposed. According to this method a new call is admitted in the network only if there is an available channel in the current cell and simultaneously in the first transit cell. When the first handover occurs a channel reservation request is issued to the next candidate transit cell and so on. If all the channels of the next cell are busy, the request is queued in a list in a FIFO discipline until the occurrence of the next handover. This technique provides zero P_F but at the cost of unacceptably high values of P_B due to very early channel reservation. Furthermore, in some cases where the *"guaranteed handover service"* is provided to all the users of the network, an increase in the satellite capacity is required.

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. The performance of the *GCCA* algorithm was investigated using both uniform and non-uniform traffic distribution in the coverage area. The results showed that P_B increased in the case of non-uniform traffic.

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 cell. 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 $t_{TH.}$ This technique favors low P_F, whereas the values of P_B are not unacceptable.

Recently paper [14] proposed a detail investigation of narrowband services applying the satellite diversity possibility in Teledesic-like and Iridium like systems. The results were quite positive but they should be extended for more classes of services since currently the integration of infrastructure and services are pushing for more general results. Satellite diversity (or partial satellite diversity) can support drastically efficient bandwidth utilization techniques and a very flexible system operation for providing QoS in future systems. Thus a thorough investigation of constellations with partial satellite diversity has been proved quite beneficiary for an efficient performance of such systems.

At this point we should mention that in all the above papers only one service is considered, that is voice. However, taking into account that the viability of future satellite networks will be based on their services, multimedia services will definitely be supported by satellite networks. In this paper, in addition to the study of a narrowband network, the *satellite handover* issue is also studied in depth for multimedia services. Various classifications of multimedia services are found in the literature. For satellite mobile systems the UMTS Forum Report 13 has comprehensively addressed the future services and applications. The DiffServ approach is under study within the IETF (Internet Engineering Task Force). The evolving differentiated services framework offers the most promising approach for meeting Internet's QoS requirements. In particular, the most demanding advanced applications would benefit significantly from the family of differentiated services that make well-defined transmission guarantees based on service profiles. The goal of the evolving IETF differentiated services (diffServ) framework is to provide a means of offering a spectrum of services in the Internet without the need for per-flow state and signaling in every router. In LEO satellite networks with ISLs (inter-satellite Links), a satellite can be considered as a router.

And there are always the ATM-based classifications of service (ATM Forum UNI 4.0), which are the constant bit rate (CBR), the variable bit rate-non-real time (VBR-NRT), the variable bit rate-real time (VBR-RT), the available bit rate (ABR) and the unspecified bit rate (UBR).Summarizing the QoS parameters for these services we can say for CBR class that is used for emulating circuit switching. The cell rate is constant with time. Furthermore, CBR applications are sensitive to cell-delay variation. Applications that can use CBR are telephone traffic, television and videoconference. Regarding VBR-NRT class, this class allows users to send traffic at a rate that varies with time depending on the availability of user information. Statistical multiplexing is provided to make optimum use of network resources. Multimedia e-mail is an example of VBR-NRT. VBR-RT class is similar to VBR-NRT but is designed for applications that are sensitive to cell-delay variation. Voice with speed activity detection (SAD) and interactive compressed video could be considered as examples for real-time VBR. As for ABR class, this class provides rate-based flow control and is aimed at data traffic such as file transfer and e-mail. Although the standard does not require the cell transfer delay and cell-loss ratio to be guaranteed or minimized, it is desirable for switches to minimize delay and loss as much as possible. Depending upon the state of congestion in the network, the source is required to control its rate. The users are allowed to declare a minimum cell rate, which is guaranteed to the connection by the network. Last but not least, the UBR class is the catch-all, other class and is widely used for TCP/IP.

As regards multimedia services, our study is focused on the following description. We consider three kinds of traffic sources (service classes), *voice*, *web browsing* and *video*. Each one of these sources is subject to different QoS limitations. *"Voice calls"* should immediately find a free channel at the handover occurrence, otherwise there are forced into termination. However, *"data calls"* such as *web browsing* and *video* can wait in order to reserve the required capacity at the transit satellite. So, "*data calls"* are not forced into termination. Nevertheless, the QoS constraints for these two sources impose that the waiting time should not be higher than 4sec for *web browsing* and 0.5sec for *video*. In our study we consider that from the beginning of a call till the termination its bit rate is constant. The bit rate is assumed to be the same among calls from the same kind of traffic source.

Our approach is the same as in paper [14] so we briefly repeat the procedures applied. 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. We base our analysis 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. Regarding the case of the narrowband system, we focus our study on a network that resembles the Boeing design of the Teledesic system (288 satellites). We also examined our algorithm in a network that resembles the geometry of the Iridium network. We chose these two networks because the specifications of those systems are quite well defined. For the case of the wideband network, we concentrated only on the Teledesic-like network. All the simulations have been based onto a two-dimensional mobility model. However, we also examined the algorithm in a narrowband Teledesic-like network using a three-dimensional mobility model. Considering the common areas 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. Section 2 describes the mobility model and the proposed technique in detail. The simulation framework and the performance evaluation both for the narrowband and the wideband 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.
- The system is a polar network. This is true for Teledesic and Iridium.

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

As previously said, the proposed algorithm is based on the *DDBHP* technique [4], which 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

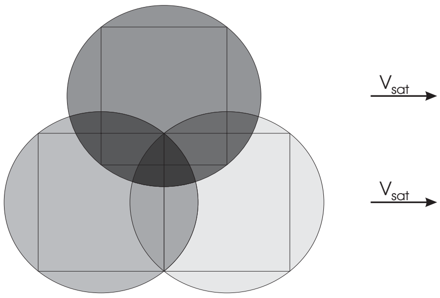

Fig. 2. Partial satellite diversity

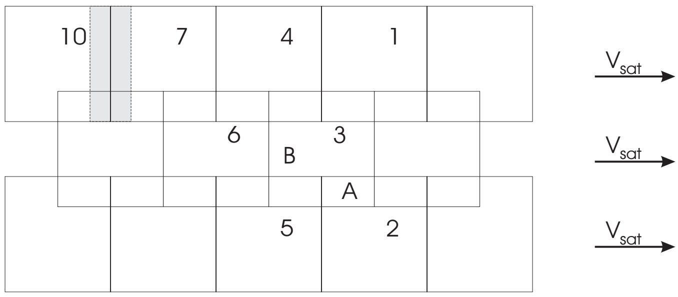

Fig. 3. Mobility model

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 the required capacity 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 the required capacity should simultaneously 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 capacity-reservation request is sent to the next satellite at a time defined by the t_{TH} before the handover occurrence. If the required capacity is not found in the meantime, then the call either is forced into termination if it is a "*voice call*" or waits until the required capacity is reserved if it is a "*data call*". 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*
   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*
   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*
   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 that are shown in *Table I.*

Table I. Service Schemes

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

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 the required capacity available in the satellite indicated by the criterion used for the access procedure (assume that this satellite is satellite number 3). If no, 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 the required capacity has been reserved in the meantime, then the call is handed-over to this satellite and if the required capacity has also been reserved in satellite 5, it is released; otherwise the request is deleted from the queue. If no capacity has been reserved in satellite 6, the request is deleted from the queue and satellite 5 is checked. If the required capacity has been reserved, the call is handed-over to this satellite, otherwise is forced into termination if it is a "*voice call*" and the request is deleted from the queue or waits until the required capacity is reserved in one of the two satellites if it is a "*data call*". If a call is terminated in t_{TH}, the reserved capacity in each one of the forthcoming satellites is released. If there is no reserved capacity in a satellite, the request is just deleted from the queue of this satellite. The messages for capacity reservation are sent to the forthcoming satellites through inter-satellite links (ISLs).

The basic flow chart (implemented for every class of service separately) of the implemented algorithms is presented in Fig. 4.

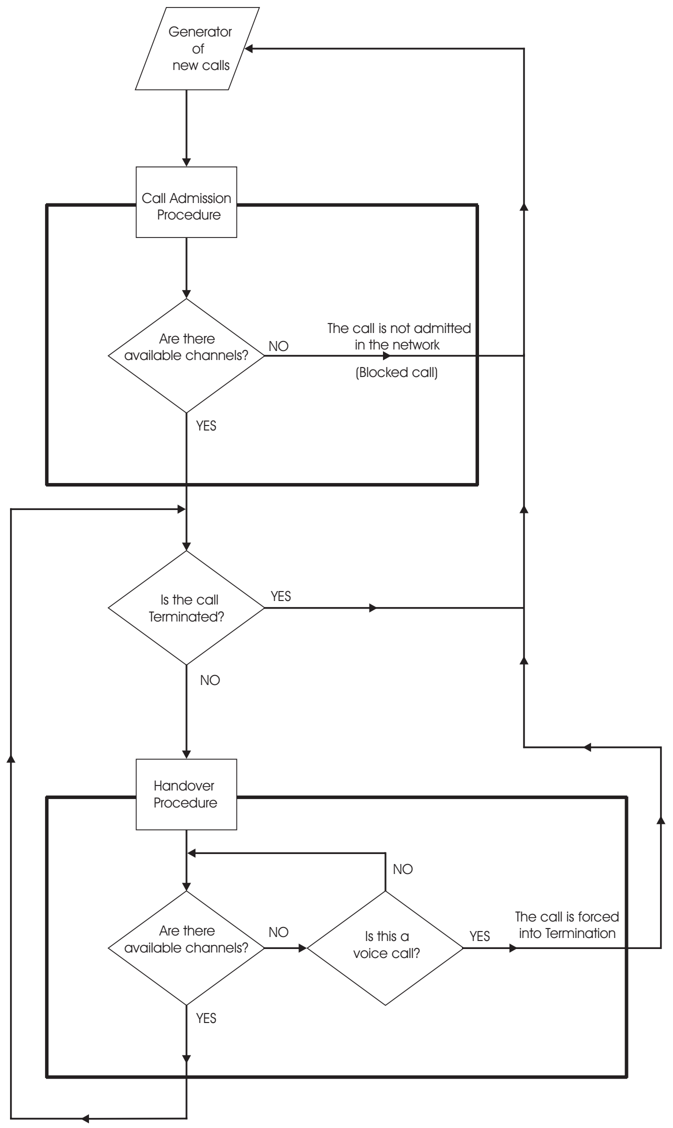

Fig. 4. Flow chart

3. PERFORMANCE EVALUATION

3.1 Narrowband network

First, we examined our algorithm in two narrowband networks, in a Teledesic-like network and in an Iridium-like network, using the two-dimensional mobility model. Furthermore, we simulated a Teledesic-like network using a three dimensional mobility model. The three-dimensional model can be considered to be more accurate, however, due to its complexity the simulations were time-consuming.

3.1.1 Two-dimensional model

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 *Table I* 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. We simulated 4 orbits with 6 satellites in each one. Users from the first satellite could be handed-over to the sixth satellite. Furthermore, we applied the parameters of *Table II*. 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. Moreover, we examined different values of the time threshold t_{TH} in order to see its influence on blocking and forced termination probabilities and. We also tested the performance of the schemes for different values of the load per footprint.

Table II. 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
Simulation time	300000 sec

As mentioned before, different values of the t_{TH} define different quality of service levels. Fig. 5 and 6 present blocking and forced termination probabilities for a network that resembles the Teledesic system and 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 results 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.

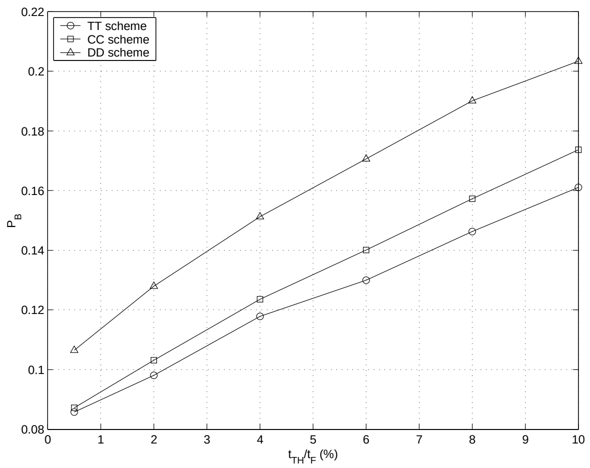

Fig. 5. P_B for Teledesic if the same selection criterion is applied to the access and handover procedure

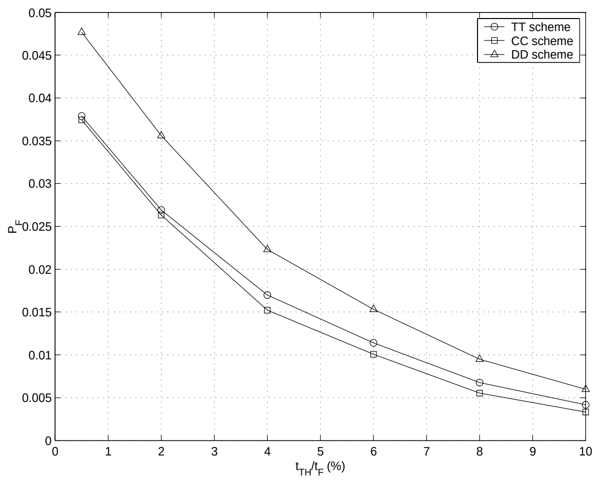

Fig. 6. P_F for Teledesic if the same selection criterion is applied to the access and handover procedure

Fig. 7 and 8 illustrate the performance of the other six schemes of *Table I*, for the same network. 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 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 slightly better than the CC and the TT schemes. However, the differences among these three schemes are so minor that we cannot say which scheme seems to be the best case.

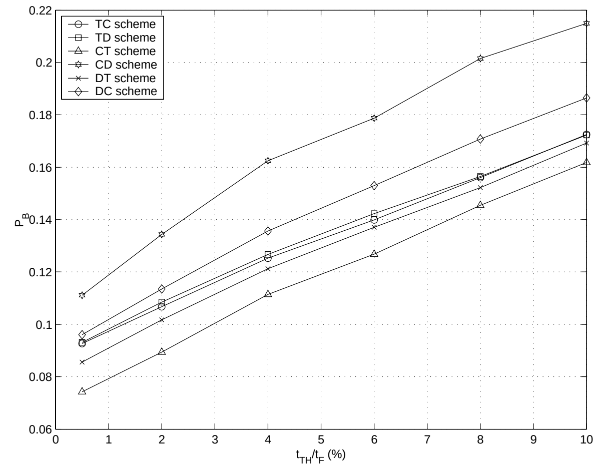

Fig. 7. P_B for Teledesic if different selection criteria are applied to the access and handover procedure

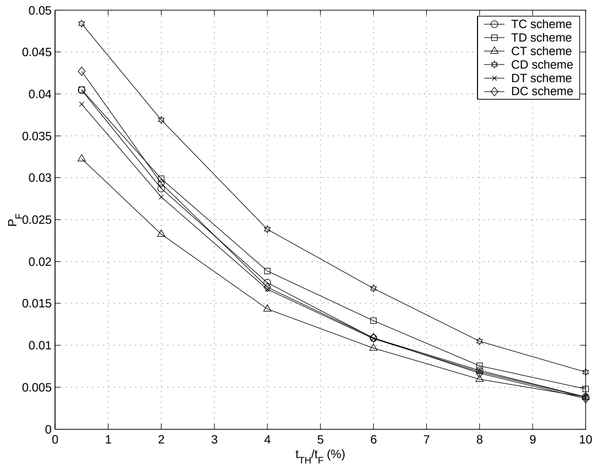

Fig. 8. P_F for Teledesic if different selection criteria are applied to the access and handover procedure

Simulation runs for other values of the telecommunication load (2, 4 and 6 Erlang) showed that the CT scheme outperforms the other eight schemes 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. Also, the performance of the CC scheme seemed to be very close to the performance of the CT scheme. Fig. 9 and 10 present the performance of the schemes that are based on the same criterion both for the access and the handover procedure for different values of load and for $t_{TH}/t_F=5\%$. Fig. 11 and 12 present the performance of the remaining six schemes. For high values of load (6 and 8 Erlang) there is a considerable difference in the performances of the schemes. The differences among the performances are obvious both in P_B and in P_F, that is to say, the best scheme (CT scheme) has P_B=0.121567 and P_F= 0.011833 while the worst scheme (CD scheme) has P_B= 0.171318 and P_F= 0.0192334 (for load=8 Erlang).

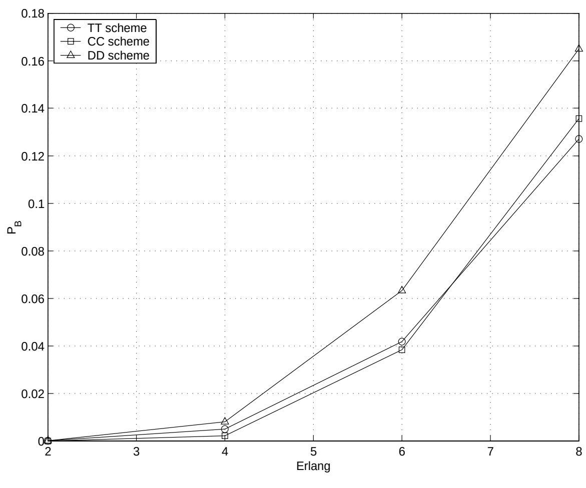

Fig. 9. P_B for Teledesic if the same selection criterion is applied to the access and handover procedure

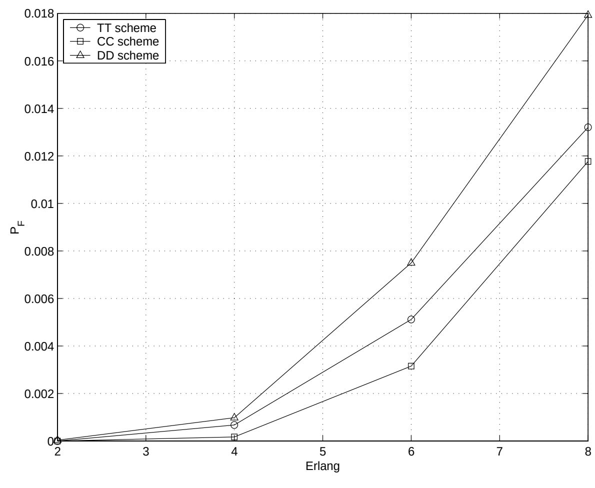

Fig. 10. P_F for Teledesic if the same selection criterion is applied to the access and handover procedure

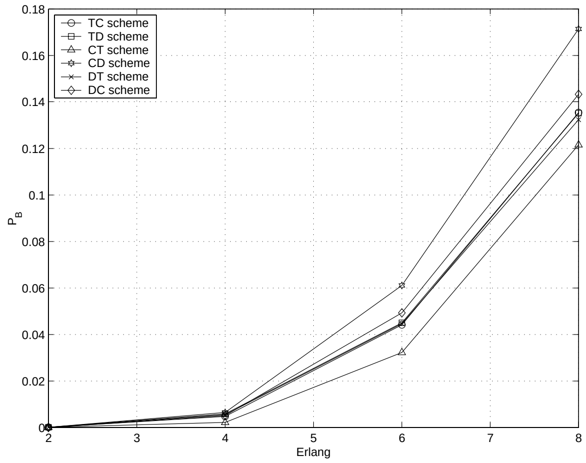

Fig. 11. P_B for Teledesic if different selection criteria are applied to the access and handover procedure

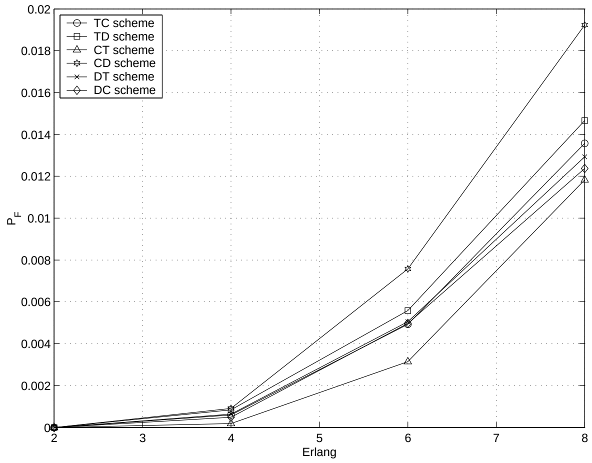

Fig. 12. P_F for Teledesic if different selection criteria are applied to the access and handover procedure

Examining 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 checked the schemes on a system with 66 satellites, namely an Iridium-like system, resulting essentially to an analogous performance for each one of the schemes. Again the CT scheme outperformed all the other schemes, while the performance of the CC and TT schemes were very close to the performance of the CT scheme. Fig. 13, 14, 15 and 16 show the performance of the schemes for this system and for different values of t_{TH}. All the simulation parameters were still the same except for the following: Footprint length = 3638.53 Km , t_F = 9.18 min, V_{sat} = 6.6058 Km/sec

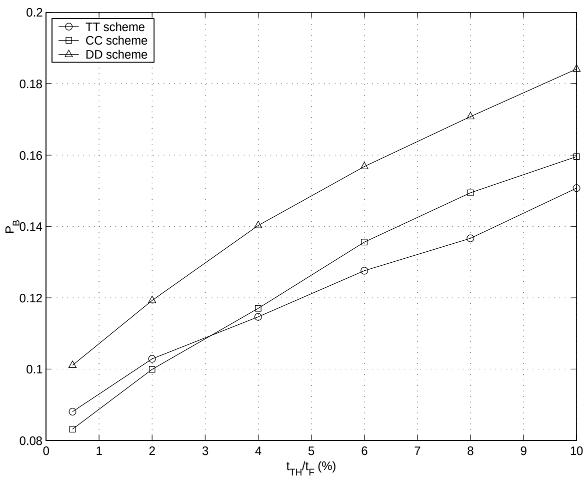

Fig. 13. P_B for Iridium if the same selection criterion is applied to the access and handover procedure

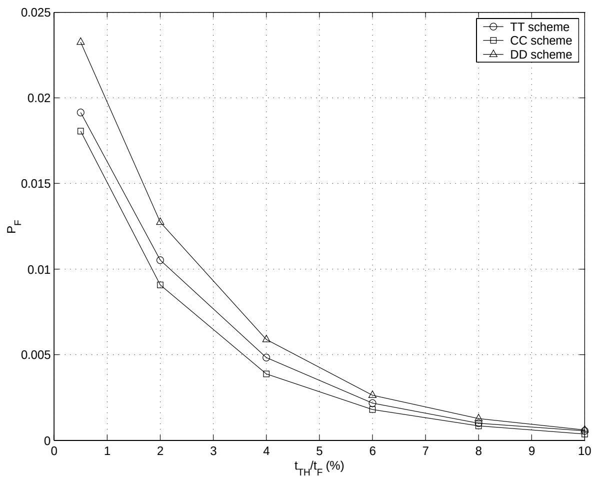

Fig. 14. P_F for Iridium if the same selection criterion is applied to the access and handover procedure

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 provide data in Fig. 17 and 18 on the influence of different values of overlapping on blocking and forced termination probabilities for the Teledesic-like system applying the CT scheme and the parameters of *Table II*. 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. We should notice that the case of 25% common coverage area is the marginal case of satellite diversity, where all users are covered by two satellites.

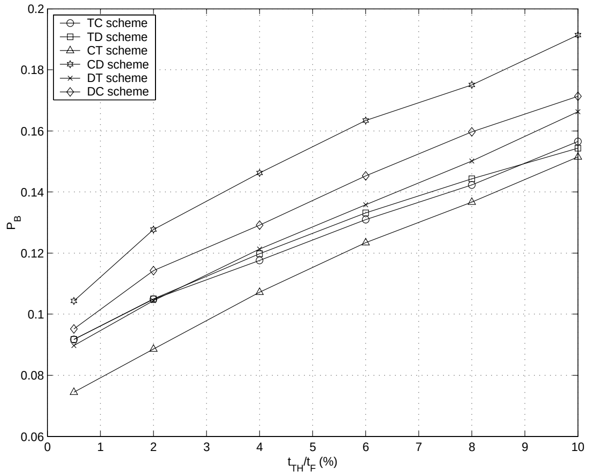

Fig. 15. P_B for Iridium if different selection criteria are applied to the access and handover procedure

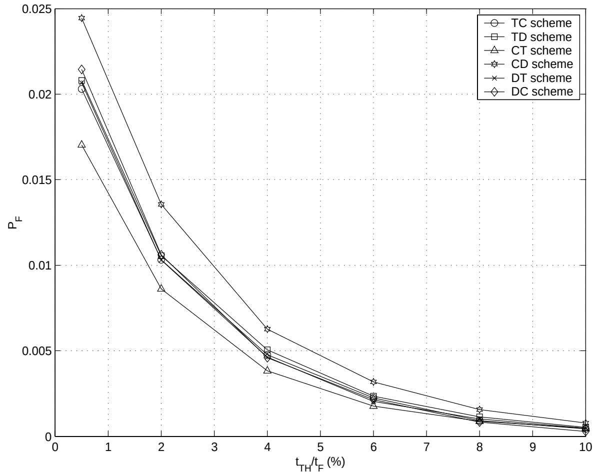

Fig. 16. P_F for Iridium if different selection criteria are applied to the access and handover procedure

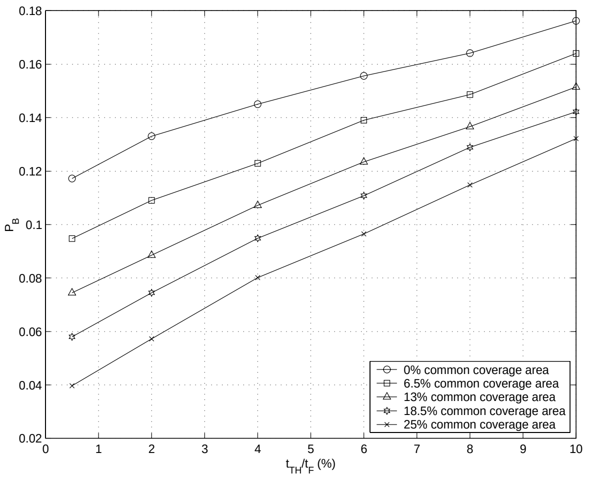

Fig. 17. P_B for the Teledesic-like network and for different values of the common coverage area

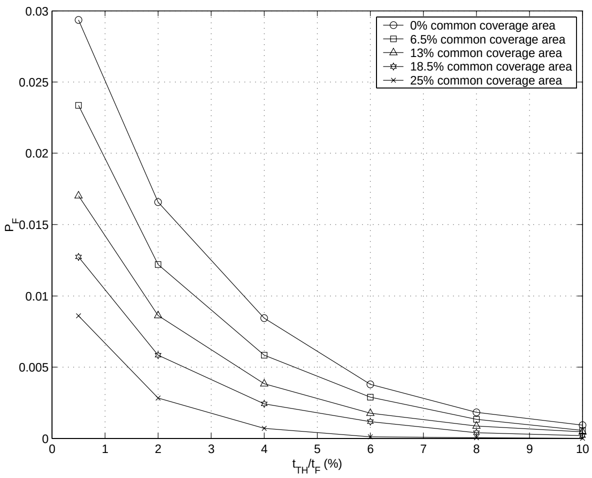

Fig. 18. P_F for the Teledesic-like network and for different values of the common coverage area

3.1.2 Three-dimensional model

Except for the two-dimensional mobility model, we also tested the nine service schemes in a three-dimensional model of a Teledesic-like system. According to this model, the users are fixed on the surface of the earth but the rotation of the earth is taken into consideration. Fig. 19 describes that model.

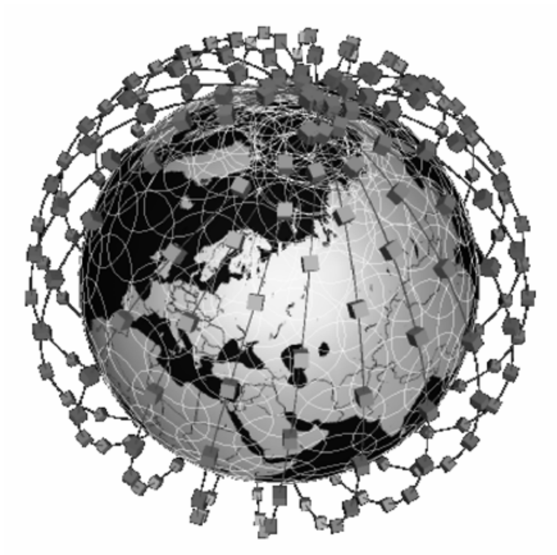

Fig. 19. Three-dimensional mobility model

The simulation parameters are showed in *Table III*. The users are uniformly distributed on the surface of the earth between 60° of latitude.

Table III. Simulation parameters of the three-dimensional model

ω_s (satellite's angular velocity)	$9.2564 \cdot 10^{-4}$ rad/sec
Channels per satellite	20
Users on the surface of the earth	50000
T_{call} (call duration)	180 sec
Load per footprint	4608 Erlang
λ_{user} (arrival rate 10^{-4}calls/sec)	5.12
Simulation time	80000 sec

Fig. 20 presents the values of P_B for all the schemes, whereas the values of P_F are presented in Fig. 21. Fig. 22 presents the mean number of satellite handovers per call.

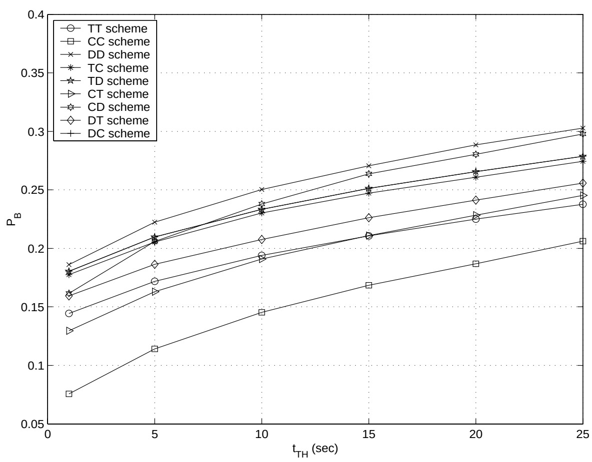

Fig. 20. P_B for Teledesic and for different values of t_{TH}

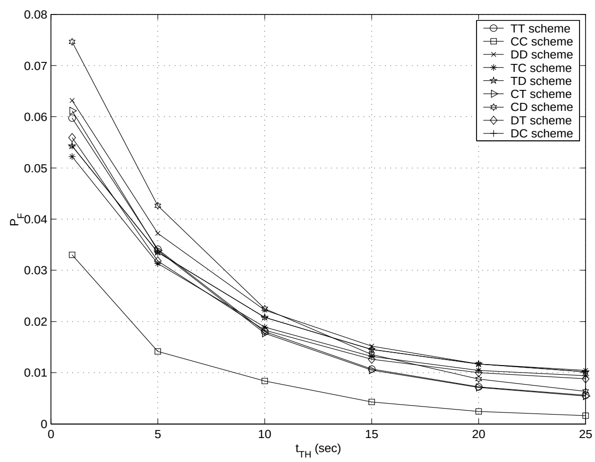

Fig. 21. P_F for Teledesic and for different values of t_{TH}

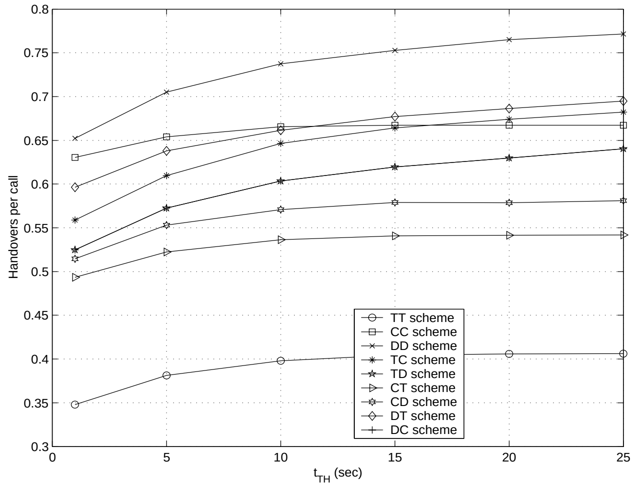

Fig. 22. Mean number of satellite handovers per call

We observe that this time the CC scheme outperforms the other schemes. Also, the CT and TT schemes have a good performance but the CC scheme seems to be the best case. In the two-dimensional model, the CC scheme has a similar performance to the CT and TT schemes. However, in the three dimensional model it performs better than the two other schemes. All the other schemes present an analogous performance to the performance of the two-dimensional model. So, regarding the Teledesic network we can say that the best performance is obtained by the CC scheme.

Regarding the mean number of satellite handovers per call, we observe that the service schemes that apply the maximum service time criterion either to new or handover calls present a diminished number of handovers per call. That is very obvious in the TT scheme. Furthermore, an increase in t_{TH} results to an increase in the number of handovers per call. This happens because the bigger the t_{TH} is, the smaller the P_F is, so, less calls are forced into termination.

3.2 Wideband network

Extending our work, we tested the schemes of *Table I* in a wideband Teledesic-like network using the two-dimensional mobility model. Regarding that the success of future satellite network is based on supporting multimedia services, we consider the three kinds of traffic sources, that is to say *voice*, *web browsing* and *video*. In order to achieve a fair treatment for each one of these three kinds of traffic and especially for *video* (which requires much more capacity than the other two kinds), we combined our technique with the method of guard channels. According to this method, some channels are available only for a specific kind of traffic. Apparently, except for the different number of guard channels, different values of t_{TH} can be applied to each kind of traffic. Furthermore, in our simulations we used the same scheme for *voice*, *web browsing* and *video*. However, different service schemes can be used by different kinds of traffic, resulting in twenty-seven combined schemes. Examining these twenty-seven combined schemes can be considered as a further research work. The parameters of the simulation are presented in *Table III*. V_{sat}, t_F and footprint's length were as in Table II.

Table IV. Simulation parameters

Channels per satellite	264
Channel's capacity	64 Kbps
Voice	
Users per footprint	300
T_{call} (call duration)	180
Bit rate	64
λ_{user} (arrival rate 10^{-4}calls/sec)	6.4814
Guard capacity (G.C.)	0 Kbps
t_{TH}/t_F	2 %
Web Browsing	
Users per footprint	300
T_{call} (call duration)	3600
Bit rate	384
λ_{user} (arrival rate 10^{-4}calls/sec)	1.5555
Guard capacity (G.C.)	0 Kbps
t_{TH}/t_F	2 %
Video	
Users per footprint	30
T_{call} (call duration)	3600
Bit rate	1152
λ_{user} (arrival rate 10^{-5}calls/sec)	5
Guard capacity (G.C.)	4608 Kbps
t_{TH}/t_F	12 %

Fig. 19 presents the P_B for each one of the three kinds of traffic, whereas Fig. 20 presents the P_F for voice calls. The mean delay time per handover for "data calls" is presented in Fig. 21. As we have said in section 1, the QoS limitations impose that the mean delay time should not be higher than 4sec and 0.5sec for web browsing and video respectively.

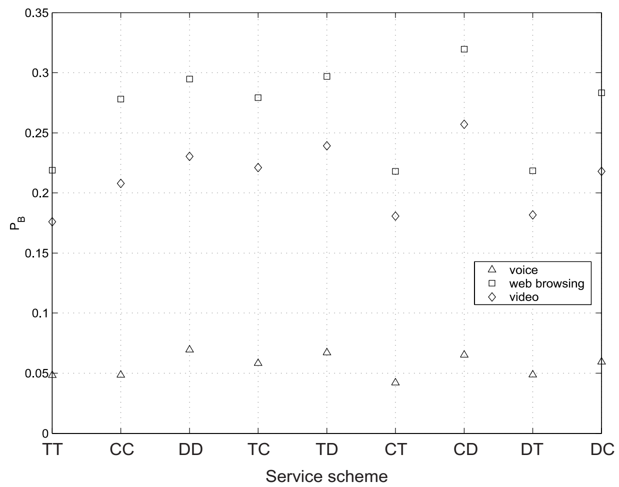

Fig. 19. P_B for different service schemes and for $G.C._{voice}=0Kbps$, $G.C._{w.b.}=0Kbps$, $G.C._{video}=4608Kbps$, $(t_{TH}/t_F)_{voice}=2\%$, $(t_{TH}/t_F)_{w.b.}=2\%$, $(t_{TH}/t_F)_{video}=12\%$

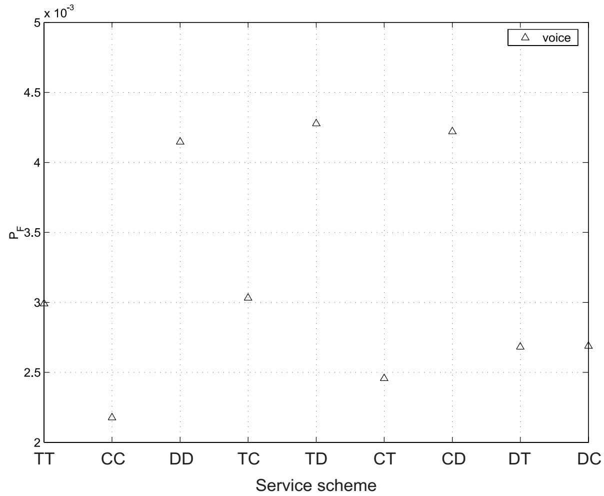

Fig. 20. P_F for different service schemes and for $G.C._{vc}=0Kbps$, $G.C._{dclr}=0Kbps$, $G.C._{dchr}=4608Kbps$, $(t_{TH}/t_F)_{voice}=2\%$, $(t_{TH}/t_F)_{w.b.}=2\%$, $(t_{TH}/t_F)_{video}=12\%$

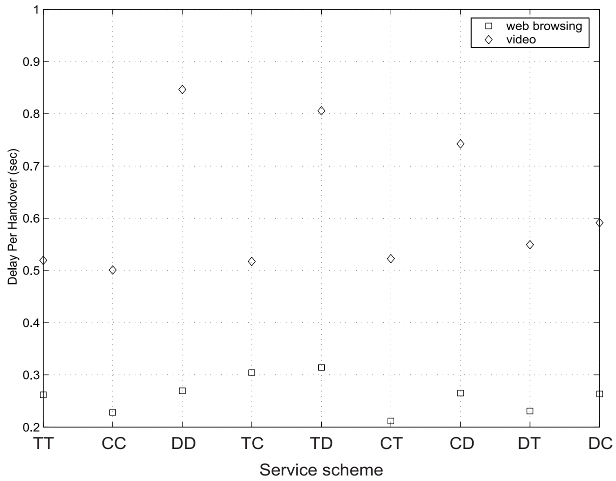

Fig. 21. Mean delay time per handover for different service schemes and for $G.C._{voice}=0Kbps$, $G.C._{w.b.}=0Kbps$, $G.C._{video}=4608Kbps$, $(t_{TH}/t_F)_{voice}=2\%$, $(t_{TH}/t_F)_{w.b.}=2\%$, $(t_{TH}/t_F)_{video}=12\%$

With regard to the mean delay time per handover, the CC scheme seems to present the best performance. We also observe that the delay per handover for *web browsing* is much lower than 4sec, so t_{TH} could be decreased. However, for *"video calls"* only the CC scheme complies with the QoS limitations. Nevertheless, the CT scheme seems to perform better than the other schemes with regard to P_B, whereas, considering the P_F and the mean delay time per handover, its performance is close to the performance of the CC scheme. So, these two schemes present the best performance. A good performance is obtained from the TT and DT schemes too.

In order to decrease the delay time per handover for "*video calls"*, we changed the value of t_{TH} for *web browsing* to 0.5% and increased the value of guard capacity for *"voice calls"* to 640 Kbps. All the other parameters were as in *Table III*. Fig. 22, Fig. 23 and Fig 24 presents the P_B, P_F and the mean delay time per handover respectively.

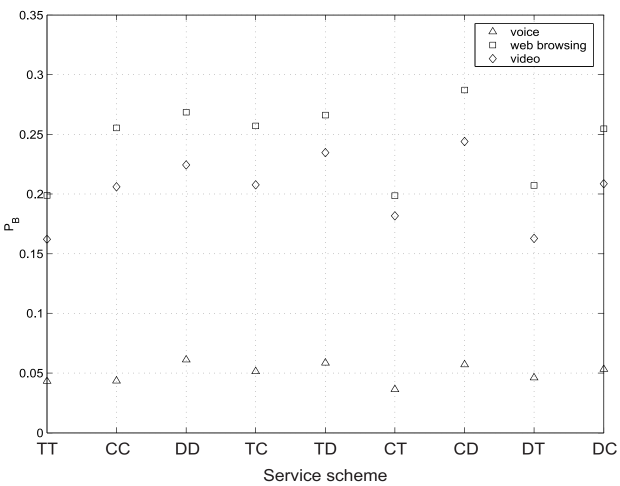

Fig. 22. P_B for different service schemes and for $G.C._{voice}=640Kbps$, $G.C._{w.b.}=0Kbps$, $G.C._{video}=4608Kbps$, $(t_{TH}/t_F)_{voice}=2\%$, $(t_{TH}/t_F)_{w.b.}=0.5\%$, $(t_{TH}/t_F)_{video}=12\%$

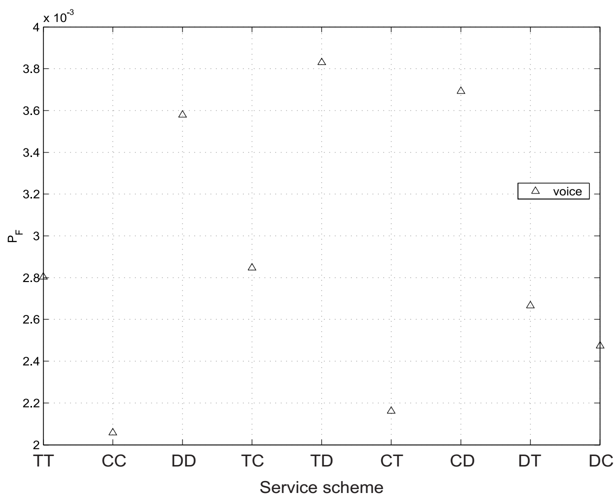

Fig. 23. P_F for different service schemes and for $G.C._{voice}=640Kbps$, $G.C._{w.b.}=0Kbps$, $G.C._{video}=4608Kbps$, $(t_{TH}/t_F)_{voice}=2\%$, $(t_{TH}/t_F)_{w.b.}=0.5\%$, $(t_{TH}/t_F)_{video}=12\%$

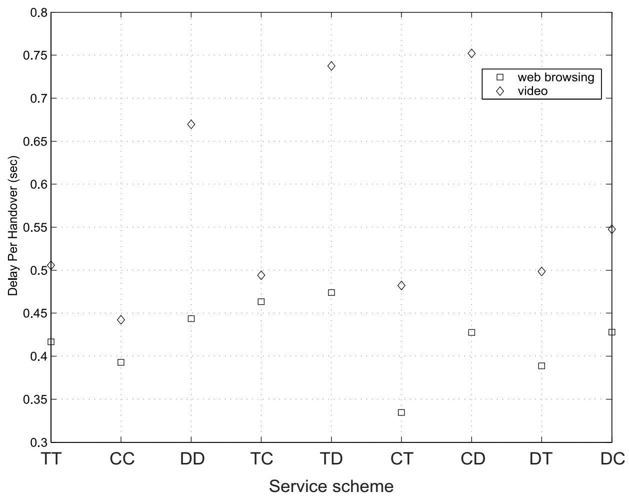

Fig. 24. Mean delay time per handover for different service schemes and for $G.C._{voice}=640Kbps$, $G.C._{w.b.}=0Kbps$, $G.C._{video}=4608Kbps$, $(t_{TH}/t_F)_{voice}=2\%$, $(t_{TH}/t_F)_{w.b.}=0.5\%$, $(t_{TH}/t_F)_{video}=12\%$

This time four service schemes comply with the QoS constraints, the CC, the TC, the CT and the DT scheme. As for the schemes with the best performance, these seem to be the CT and CC scheme. Also, the performances of the TT and DT schemes are very good. Therefore, the conclusion made in the case of the narrowband network is in agreement with the conclusion made for the case of the wideband network, that is to say that the CC and CT schemes perform better than the other service schemes.

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

In this paper a prioritization technique that is based upon the *DDBHP* technique for handling the satellite handover issue has been proposed. 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 and we tested these schemes using a two-dimensional mobility model in two different narrowband networks and in a wideband network that supports multimedia services in order to derive the scheme with the best performance. We also tested that schemes in a narrowband network using a three-dimensional mobility model. Obviously, different criteria and different values of the time threshold can be used either by users in different areas or by users of different service classes and either for the access or the handover procedure, always according to the prospective telecommunication load.

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