Design Issues and QoS Handover Management for Broadband LEO Satellite Systems

S. Karapantazis* and F.-N. Pavlidou

Telecommunications Division, Department of Electrical and Computer Engineering,

Faculty of Engineering, Aristotle University of Thessaloniki,

54124 Thessaloniki, Greece

Abstract

Today, the wider spectrum of applications that wireless networks are called to support, presses the designers of Low Earth Orbit (LEO) satellite systems for a more efficient exploitation of the limited radio spectrum. The limited commercial success of the first LEO satellite networks, which were geared towards narrowband services, has been the main motive for the reconsideration of the set of services that these networks should provide. In this context, a broadband LEO satellite system is examined in this paper. In this kind of networks, the handing-over of a call between contiguous cells or satellites is one of the dominant factors that degrade the quality of the provided services. In this paper, we propose and evaluate a satellite handover technique for systems that present partial satellite diversity in order to provide an efficient handover strategy and QoS in multimedia applications, examining the impact of the footprint's overlapping area on the system performance as well.

KEY WORDS: LEO satellite systems, satellite handover management, multimedia services, QoS provisioning, partial satellite diversity, Doppler effect

1. Introduction

Satellite systems have attracted the interest of the scientific community for years, mainly due to their inherent broadcast and multicast capabilities. LEO satellite systems gained considerable interest towards the end of the previous century by virtue of their appealing characteristics, such as

*Correspondence to: skarap@auth.gr

low propagation delay, global coverage and the ability to communicate with handheld terminals. Currently, there are two LEO satellite networks in operation, namely Iridium and Globalstar. However, these networks have not flourished so much as their designers hoped. The limited commercial success of these stand-alone systems providing a similar set of services to terrestrial networks has been the main motive for the reconsideration of the role of LEO satellite systems in service provision. Satellite systems are now regarded more as complementary rather than competitive systems to terrestrial networks. Multimedia services enrich day by day every communication system satisfying the demand for Internet connectivity anywhere, anytime. Thus, 4G mobile systems will comprise inter-working terrestrial and satellite components, and LEO networks emerge as the most convenient solution for real-time and interactive services because of the low propagation delay that they provide.

LEO satellite networks can be a major asset to wireless infrastructure providers, and the experience gained by the two operating networks has offered a deep insight into the critical performance issues of these networks. One of the main characteristics of this kind of satellite systems is the relative movement of satellites with respect to the surface of the earth. Consequently, an efficient handover mechanism is of utmost importance on account of the significant probability of service interruption. That is, in LEO networks, in parallel with the blocking probability, the forced termination probability is a crucial parameter, as is the case with terrestrial wireless mobile systems. Owing to the advancement in antenna technology, the footprint of a satellite is divided into many cells in order to enhance frequency reuse policies. Therefore, two types of handover events can be distinguished: cell handover and satellite handover. The former refers to the transit of an ongoing call from one cell to the next one, while the latter describes the transfer of an ongoing call from one satellite to another. A footprint of a LEO satellite as well as the two types of handover events are illustrated in Figure 1.

Several studies have treated the issue of cell handover [1-10] for both narrowband and broadband LEO satellite networks. This type of handover is more frequent than the satellite handover. However, this fact does not lessen the importance that a satellite handover technique has on the overall system performance, especially in systems with partial satellite diversity. The term *"partial satellite diversity"* is used to describe the overlapping area between contiguous satellites as shown in Figure 2, while the term *"partial"* implies that there exists a portion of the footprint that is not covered by another satellite. Recently, some studies have been carried out on the topic of satellite handover [11-15], all of them focused on narrowband networks with the voice constituting the sole service provided. A recent paper examined the impact of partial satellite diversity on the performance of narrowband networks [11]. The positive results obtained from this study were the main motivation for its extension to a broadband network which supports more classes of services.

In this paper, we focus on the following approach. A broadband network with partial satellite diversity among its footprints is employed to provide multimedia services. In particular, we consider three service classes: voice, web browsing and live video. Each one of these classes is subject to different QoS limitations, and therefore, special treatment should be applied to calls of each service class. We propose a satellite handover algorithm that treats differently calls of different service classes. Delay during a handover is not acceptable for voice calls, so the forced termination probability should be fairly low. Regarding web browsing and video connections, a small delay during a handover is acceptable as far as the possibility of a delayed handover is rather low, and the mean delay is not large enough. Our algorithm aims at achieving a fair sharing of radio resources so that the QoS requirements of each service class are met.

We also capitalise upon the partial satellite diversity and propose three satellite selection criteria. Each one can be used to either new or handover calls, resulting in nine different service schemes. In order to evaluate the performance of each service scheme we propose a novel two-dimensional mobility model which takes the rotation of the earth into account. Our main contribution is to examine the impact of the common area that contiguous satellites share on the system performance, namely the schemes are evaluated in constellations with different percentage of partial satellite diversity.

The rest of the paper is structured as follows. In section 2 we present the mobility model that was used in our simulations and also propose three satellite selection criteria. Section 3 contains the description of the proposed handover technique. In section 4, we compare the performance of the proposed service schemes, while we assess our handover technique as well. Finally, section 5 concludes the paper.

2. Mobility Model and Satellite Selection Criteria

2.1. Mobility model

One of the main characteristics of non-Geostationary (non-GEO) satellite constellations is the limited visibility period of a satellite, which can be as short as 5 min. in the case of LEO satellite systems. As previously mentioned, this fact necessitates a handover mechanism in order to avoid service interruption. In most of the studies in the literature, handovers techniques have been examined only for the case of narrowband networks, that is, voice has been considered the sole service to be provided. On this occasion, a mobility model which takes only the movement of the satellites into account is valid since the duration of a voice call is usually fairly short. Nevertheless, valuable experience gained from Iridium and Globalstar has shown that these systems are unlikely to penetrate in the market. Multimedia services infuse day by day every wired or wireless network. Regarding a future LEO satellite network, it should provide a wide spectrum of services, such as voice, FTP, web browsing, video, etc. Even in studies that were focused on multimedia LEO satellite networks, a simple mobility model was employed where only the satellite movement was considered. Although the aforementioned model presents a simple model to work with, for services that their mean duration is more than a few minutes (that is the case of FTP, web browsing and video) it presents a drawback; in that model the rotation of the earth is not taken into consideration. Towards this end, we propose a novel two-dimensional mobility model which takes account of the earth's rotation and the overlapping coverage areas between contiguous satellites. The main points of this model, which is shown in Figure 3, can be summarized in the following:

- Every satellite has an orthogonal footprint area.
- Users are considered fixed on the surface of the earth since the velocity of a fast vehicle is much smaller than the velocity of a satellite.
- The rotation of the earth is taken into consideration since it may influence the performance of a system that provides services with long mean duration.
- The overlapping area between successive satellites in the same orbital plane is not considered, because a user should always select the following satellite in order to avoid an immediate handover. Therefore, only the overlapping area between contiguous satellites in different orbital planes is taken into account.
- The terminals are uniformly distributed on the surface of the earth and in every satellite's footprint.
- The constellation is polar and not inclined rosette (although this model can easily be modified in order to be valid for the case of inclined constellations).

According to this mobility model, the serving period of a satellite is not dependent only on the size of the footprint and the satellite's velocity. A user during a call may be handed-over to a satellite of the next orbital plane on account of the rotation of the earth and not due to the movement of satellites. This is the case of user A in Figure 3. Assuming that user A is served by satellite 4, then, owing to the rotation of the earth, he should be handed-over to satellite 6. Regarding user B, he is initially covered only by satellite 4. However, it is highly likely that within the duration of the call he may be covered by a satellite of the next orbital plane as well (for example satellite 7), and therefore, the next transit satellite can be of either the same or the next orbital plane.

In order to estimate if the next transit satellite will be the following one in the same orbital plane or the contiguous satellite in the next orbital plane, we consider that the user's mobility is the combination of the satellite's movement ($\overline{V}_{sat}$) and the earth's rotation ($\overline{V}_{rot}$). Let $\overline{V}_{user}$ be the velocity of a user. Therefore, $\overline{V}_{user}$ is:

$$\overline{V}_{user} = \overline{V}_{sat} + \overline{V}_{rot} = V_{sat}\hat{y} + V_{rot}\hat{x} \tag{1}$$

Let $(x_{0,} y_0)$ denote the coordinates of the user at the start of a call. The coordinates (x, y) of the user as a function of time t are given by the following expressions:

$$x - x_0 = V_{rot} t \tag{2}$$

$$y - y_0 = V_{sat} t \tag{3}$$

By dividing (2) with (3) we result in the expression that describes the movement of the user during the call:

$$y - y_0 = \lambda (x - x_0) \tag{4}$$

where λ denotes the slope of the direction of the user's movement. Clearly,

$$\lambda = \frac{V_{sat}}{V_{rot}} \tag{5}$$

In order to estimate the time instant of a handover occurrence let (x_s, y_s) be the centre of the orthogonal footprint, while x_{sat} and y_{sat} denote the dimensions of the footprint on the x and y axis respectively. The time interval till the next handover can be computed easily from (2) and (3) as:

$$t_{hand} = \min \left\{ \frac{x_s + \frac{x_{sat}}{2} - x_0}{V_{rot}}, \frac{y_s + \frac{y_{sat}}{2} - y_0}{V_{sat}} \right\} \tag{6}$$

Therefore, the coordinates $(x_{hand,} y_{hand})$ of the handover point are:

$$x_{hand} = x_0 + V_{rot} t_{hand} \tag{7}$$

$$y_{hand} = y_0 + V_{sat} t_{hand} \tag{8}$$

From (7) and (8) we can easily estimate the next satellite for relaying the call. Similarly, the time interval until the next handover and the coordinates of the next handover point can be derived in a straightforward manner.

2.2. Satellite selection criteria

The definition of satellite selection criteria is deemed necessary for users located within the coverage area that contiguous satellites share. In [11, 15] we have proposed three criteria which are the following:

- *Maximum available capacity (C criterion)*

  According to this criterion, the user will be served by the satellite with the maximum available capacity. 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 of their location, avoiding, therefore, overloaded satellites.

- *Maximum service time (T criterion)*

  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.

- *Minimum distance (D criterion)*

  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 failures occurrences, therefore, link failures were not taken into account in our simulations.

The above criteria can be applied to either new or handover calls, resulting in nine different service schemes which are presented in Table 1.

3. The Proposed Handover Technique

3.1. Prediction of the handover occurrence

The main issue of handover management is the trade-off between blocking (P_b) (i.e. the probability of not admitting a new call in the network) and forced termination probability (P_f) (i.e. the probability of dropping an ongoing call). The minimization of forced termination probability is more desirable from the user's point of view than the minimization of blocking probability. However, the former should not be attained at the expense of the latter since blocking probability is also an important parameter of the overall network performance. Future LEO satellite networks are foreseen to provide multimedia services, therefore, in addition to the two previous performance factors, the probability of a delayed handover and the mean delay per delayed handover are another two meaningful parameters. The major problem, that is to be overcome, is the early reservation of the limited radio resources, achieving at the same time an infallible handover.

Table 1. Service schemes

Service scheme	Criterion for New calls	Criterion for Handover calls
CC scheme	Max. available capacity	Max. available capacity
TT scheme	Max. service time	Max. service time
DD scheme	Min. distance	Min. distance
CT scheme	Max. available capacity	Max. service time
CD scheme	Max. available capacity	Min. distance
TC scheme	Max. service time	Max. available capacity
TD scheme	Max. service time	Min. distance
DC scheme	Min. distance	Max. available capacity
DT scheme	Min. distance	Max. service time

The proposed procedure relies on Doppler effect to estimate the handover requests and reserve capacity. The application of Doppler based techniques for users in a footprint has been well examined in the literature [2, 17, 18] and has been proved to be an efficient and low-complexity method for the prediction of the satellite's visibility. In [2] the Doppler effect was used in order to derive the location of a user terminal and the time instant of the handover occurrence. Describing briefly the framework of the Doppler-based prediction of the satellite's visibility, the serving satellite is able to derive the elevation angle of the communication at any instant based on the measured Doppler shift. This is equal to $(v/c)\cdot f$, where f is the central frequency of the outbound channel, v is the relative velocity of the satellite with respect to the user terminal and c is the speed of light. The measurement of the Doppler shift at two different instants makes possible the calculation of the azimuth angle between the direction of the satellite and the user. By calculating the azimuth angle, the satellite can derive the time instant at which a handover will take place. The above process necessitates satellites with on-board processing capabilities, a requirement that should be met by most of the future satellite networks. For the rest of the paper we assume that satellites are able to calculate the time instant of the handover occurrence and the location of the user terminal. By calculating the terminal's location, the serving satellite can derive the destination satellites.

3.2. The framework of the algorithm

Our algorithm is based on the estimation of the time instant of the handover occurrence. A capacity reservation request is sent to the candidate satellites for relaying the call at a specific instant before the handover occurrence. The system must complete the reservation in the residual time interval, named *handover threshold* (t_{TH}). It is obvious that different values of the parameter t_{TH} define different quality of service levels. Therefore, a different t_{TH} can be employed for each service class with the aim of satisfying the QoS limitations. Furthermore, we introduce the notion of the *Guard class capacity* which stands for the portion of the total capacity that is available only to calls of a specific service class. The rest of the capacity is available to calls of all service classes, and calls content in order to reserve the required by the service capacity.

The framework of the algorithm is independent of the service scheme that is used and we will spell it out for the case of a user covered by two satellites since this occasion is more complicated than the case of one satellite covering the user. This general framework is also the same for every service class. The difference among calls from different classes of service lies in the different values of t_{TH} and *Guard class capacity.* The new call admission procedure has as follows. The user first checks the satellite indicated by the criterion used for new calls. If the required capacity is available in that satellite, then the call is admitted in the network, otherwise the second satellite is checked. However, if the position of the user at call setup is such that the remaining time till the first handover is less than t_{TH}, then the required capacity should also be reserved in one of the two following satellites in order for the call to be admitted in the network. Again, the satellite indicated by the criterion for handover calls is checked, and so on.

Concerning the handover procedure, when a call is handed-over to a satellite, the serving satellite derives the next possible serving satellites. A capacity reservation request is scheduled to be sent to them at time t_H - t_{TH}, where t_H is the time instant of the next handover. At the handover instant, the user first checks if the required capacity is reserved in the satellite indicated by the criterion for handover calls. If the capacity is reserved, then the call is handed-over to this satellite. However, if the required capacity has also been reserved in the second satellite, then it is released, otherwise the request is deleted from its queue. If capacity has not been reserved in the first satellite, then the request is deleted from its queue and the second satellite is checked. For voice calls, a call will be forced into termination only if the call has not managed to reserve the required capacity in a satellite. As regards web browsing connections, if an unsuccessful handover occurs, then they wait until the required capacity is reserved in one of the visible satellites. Last but not least, video connections can wait for an extremely low time interval after an unsuccessful handover to reserve capacity in one of the candidate serving satellites; otherwise they are forced into termination. The delivery of capacity reservation requests is managed through inter-satellite links (ISLs). Each satellite maintains two different queues. In one queue the requests from video connections are placed, whereas the other queue contains the requests of all the other calls. Every time that capacity is released, the satellite tries to serve first the requests of video calls and then all the others. However, there is always the possibility of a user terminating a call in the t_{TH} interval. In this case, the handover request is removed from the queues of the next candidate serving satellites or, if capacity has been reserved, it is released. The general framework of our algorithm is described below.

if new call request

then

    if Required Capacity <= Available Capacity

    then

        "The Call is admitted in the network"

    else

        "The Call is blocked"

    end if

else *// namely a handover call request*

    if Required Capacity > Available Capacity *// in all visible satellites*

    then

        switch(Type of Call)

        {

        case Voice Call:

            "The Call is forced into Termination"

        case Video Call:

            "The Call waits a specific time interval to reserve the required capacity"

        case Web Browsing call:

            "The Call waits till the required capacity is reserved"

        }

    else

        “The Call is handed-over to the satellite at which capacity has been reserved”

    end if

end if

At this point, we should stress the importance of the *handover threshold* t_{TH} to the system performance. The selection of t_{TH} must be appropriate for each service class, so that there is enough time for reserving capacity. However, the *handover threshold* should not be extremely large in order to prevent the early reservation of the radio resources. A good technique is to select a large t_{TH} for broadband real-time services, while t_{TH} can be small enough for non-real-time services or narrowband real-time services. The larger the t_{TH}, the smaller the P_f, but P_b increases. Moreover, the selection of the *handover threshold* for one service class has an impact on the calls of other service classes.

4. Simulation Results and Discussion

In this section, we evaluate the performance of the proposed handover technique, as well as the performance of the proposed service schemes. For the needs of these experiments, the simulation runs were conducted using a custom simulation tool that was developed in C++ by the authors. For this set of comparisons, we employed a Teledesic-like system (the Boeing design with 288 satellites). The reasons for that selection can be ascribed to the fact that this network has been the only broadband LEO satellite system with quite well-defined specifications. The footprint area is 1790 km × 1790 km and it moves with a speed of 5.8928 km/sec. The capacity of a satellite is fixed and is 12800 kbps. The rest of the simulation parameters are presented in Table 2. Users are uniformly distributed in each footprint and generate calls according to a Poisson distribution with arrival rate λ_{user}, while the connection duration is exponentially distributed. The call arrival rates were selected in such a way that the traffic load was the 90% of the satellite's capacity, which indicates a heavy loaded network. This selection was made so that the differences among service schemes are more distinct.

Table 2. Simulation Parameters

	Voice Calls	Web Browsing Connections	Video Connections
Users per footprint	400	400	50
Mean Connection duration	180 sec	1800 sec	1800 sec
Bitrate	64 kbps	384 kbps	512 kbps
λ_{user} (arrival rate in 10^{-4} calls/sec)	4.166	0.2731	0.4444
Guard Class Capacity	0 kbps	0 kbps	1536 kbps
t_{TH}	6 sec	3 sec	24 sec

We tested the schemes for different values of the partial satellite diversity (*PSD*) (these values indicate the percentage of the footprint that is overlapped by the satellites of the contiguous orbital plane) , namely for 0%, 13%, 26%, 38% and 50%, which is the case of a system that presents full satellite diversity. In practice, an increase in the overlapping area can be attained by increasing the altitude of the satellites, decreasing the minimum acceptable elevation angle or adding one or more orbital planes to the already existing ones. We simulated four orbital planes with six satellites in each one, and therefore, we considered the velocity of the earth's rotation to be equal to the velocity at the equatorial level (approximately 0.46 km/sec). A wrap-around technique was employed in order to avoid the boundary effects. Three independent simulations runs were conducted and the results were averaged out. The simulated time in each run was 300,000 sec. The performance factors were blocking probability P_b for calls of all service classes, forced termination probability P_f for voice and video calls and the probability of a delayed handover (P_d) for web browsing and video connections. Concerning web browsing connections, the mean delay per delayed handover (D_m) was also evaluated. Moreover, for each service class we evaluated the performance of the proposed handover technique for every service scheme through a cost function which we call Grade of Service (GoS) and which is different for each service class.

The simulations results for voice calls are presented in Figures 4, 5 and 6. The following normalized cost function was used to evaluate the performance of the proposed handover technique for voice calls:

$$GoS_{voice} = 0.091 \cdot P_b + 0.909 \cdot P_f \quad (9)$$

The weighting factor that was given to P_f is tenfold greater than the one that was given to P_b since dropped calls are more annoying to users than blocked calls. In Figure 4 the blocking probability is presented and distinct differences are observed among the nine service schemes. In particular, the CC service scheme outperforms the rest schemes, while TC and DC schemes exhibit a good performance as well. The influence of the employed service scheme on system performance is obvious when the constellation presents full satellite diversity. For this case, P_b for the CC scheme is approximately three times smaller than the one for the DD scheme, which is actually the worst among the schemes. Regarding forced termination probability, which is shown in Figure 5, the same conclusions are drawn. Again the CC scheme presents the smallest values. Consequently, this scheme seems to be the best case for voice calls. Finally, concerning the percentage of partial satellite diversity, all schemes show a similar behaviour, that is, both P_b and P_f decrease as the percentage gets larger. Figure 6, which illustrates the Grade of Service, seems to reinforce all the aforementioned statements. For easy reference, the values of P_b and P_f can be found in Table 3.

Table 3. P_b and P_f for voice calls

PSD		CC	TT	DD	CT	CD	TC	TD	DC	DT
0%	P_b	0.03099	0.03099	0.03099	0.03099	0.03099	0.03099	0.03099	0.03099	0.03099
	P_f	0.00267	0.00267	0.00267	0.00267	0.00267	0.00267	0.00267	0.00267	0.00267
13%	P_b	0.02350	0.02701	0.02930	0.02611	0.02842	0.02352	0.02886	0.02445	0.02765
	P_f	0.00157	0.00206	0.00208	0.00203	0.00210	0.00158	0.00206	0.00152	0.00202
26%	P_b	0.01561	0.02370	0.02763	0.02120	0.02417	0.01713	0.02646	0.01714	0.02511
	P_f	6.24×10^{-4}	0.00150	0.00149	0.00140	0.00131	7.89×10^{-4}	0.00141	6.21×10^{-4}	0.00150
38%	P_b	0.00932	0.01806	0.02453	0.01519	0.02023	0.01216	0.02365	0.01137	0.01919
	P_f	1.48×10^{-4}	9.28×10^{-4}	8.03×10^{-4}	7.87×10^{-4}	7.24×10^{-4}	2.93×10^{-4}	9.59×10^{-4}	1.92×10^{-4}	8.50×10^{-4}
50%	P_b	0.00246	0.00586	0.00965	0.00449	0.00760	0.00320	0.00842	0.00346	0.00649
	P_f	6.68×10^{-6}	1.15×10^{-4}	1.07×10^{-4}	1.08×10^{-4}	1.18×10^{-4}	1.92×10^{-5}	1.22×10^{-4}	1.67×10^{-6}	6.37×10^{-5}

The next figure presents the performance metrics for web browsing connections. The results are also tabulated in Table 4. The normalized cost metric that was used for web browsing connections is given by

$$GoS_{web} = 0.67 \cdot P_b + 0.33 \cdot P_d \cdot \left(\frac{D_m}{D_{m_{\max}}} \right) \tag{10}$$

where $D_{m_{\max}}$ is the maximum of the nine values of D_m that correspond to the nine different service schemes. It should be noted that a greater weighting factor was given to P_b since it represents the most important performance metric for this non-real-time application. A significant improvement in the performance of each scheme is observed as the percentage of partial satellite diversity increases, as illustrated in Figure 7. A decrease by 47% is observed in P_b of the CC scheme, which is the best scheme in terms of P_b, when the partial satellite diversity percentage is increased from 0% to 50%. As can be seen from the figure that presents the probability of a delayed handover, for all the values of the partial satellite diversity percentage, the CC scheme exhibits again the best performance. Concerning D_m, the CD scheme seems to be the best case, though the CC scheme presents the minimum delay for full satellite diversity. Although it seems that for small values of the partial satellite diversity percentage D_m is fairly large, we should notice that P_d is rather small. Besides, this delay is acceptable since web browsing connections fall within non-real-time services. The last of the four graphs in Figure 7 illustrates the Grade of Service for each service scheme, as this was evaluated using equation (10). As expected, the best *GoS* is achieved by the CC service scheme.

Table 4. P_b, P_d and D_m (in sec) for web browsing connections

PSD		CC	TT	DD	CT	CD	TC	TD	DC	DT
0%	P_b	0.11805	0.11805	0.11805	0.11805	0.11805	0.11805	0.11805	0.11805	0.11805
	P_d	0.07844	0.07844	0.07844	0.07844	0.07844	0.07844	0.07844	0.07844	0.07844
	D_m	13.194	13.194	13.194	13.194	13.194	13.194	13.194	13.194	13.194
13%	P_b	0.10057	0.10733	0.11505	0.10496	0.11118	0.09997	0.11361	0.10087	0.10894
	P_d	0.06065	0.07025	0.06758	0.06704	0.06690	0.06016	0.06693	0.06188	0.07090
	D_m	11.737	12.178	11.464	12.150	11.491	11.943	11.442	11.586	12.299
26%	P_b	0.08297	0.10055	0.10970	0.09336	0.10389	0.08324	0.10965	0.08250	0.10376
	P_d	0.04062	0.06186	0.05445	0.05584	0.05010	0.04292	0.05429	0.04144	0.06224
	D_m	9.289	11.131	9.381	10.816	8.880	9.735	9.363	9.800	10.784
38%	P_b	0.06807	0.08827	0.10850	0.08263	0.10054	0.07376	0.10666	0.07093	0.08958
	P_d	0.02405	0.05045	0.04433	0.04391	0.04072	0.03034	0.04586	0.02776	0.05016
	D_m	6.923	9.706	7.054	8.688	6.844	7.857	7.349	7.392	9.410
50%	P_b	0.06228	0.07100	0.09420	0.06642	0.09394	0.05964	0.09208	0.06402	0.07110
	P_d	0.01110	0.02571	0.02515	0.02141	0.02332	0.01287	0.02520	0.01252	0.02451
	D_m	3.467	5.111	3.649	4.680	3.497	4.042	3.685	3.721	4.913

Figure 8 depicts the performance factors for video connections, that is P_b, P_f, P_d and *GoS*. The simulation results for video connections can also be found in Table 5. The cost metric that was employed for video connections is

$$GoS_{video} = 0.05 \cdot P_b + 0.475 \cdot P_f + 0.475 \cdot P_d \quad (11)$$

Greater weighting factors were given to P_f and P_d since these metrics are the most annoying from the user's point of view. Although the same weighting factor was given to P_d as to P_f, P_d does not impact so much on *GoS* since it is much smaller than P_f.

Generally, the conclusions that have been drawn above for voice calls and web browsing connections apply to video connections as well, namely the CC scheme outperforms all the other schemes. As regards P_b, we should mention that three schemes, DD, CD and TD, do not seem to be influenced by the increase in partial satellite diversity percentage. However, this applies only to P_b and not to P_f and P_d. In addition, P_d is extremely low even for 0% overlapping, while simulation runs showed that D_m was about 0.6 sec irrespective of the overlapping percentage and the service scheme employed, and that was the reason for not including this metric in the cost function. If we take into account that P_d is pretty small, this value of D_m is acceptable for live video. It is also worth pointing out that for lower traffic loads there is no delay in handovers of video connections. Concerning P_f, this can be further reduced if we increase the *Guard Class Capacity* of video connections, with a slight impact on voice calls and web browsing connections. An increase in t_{TH} can also improve the performance. This is one of the main features of the proposed technique, since each satellite can change the value of *Guard Class Capacity* and t_{TH} at any time instant in order to enhance network's operation. However, we preferred to use a rather small value for video *Guard Class Capacity* in our simulations since the influence of the partial satellite diversity percentage is more obvious in that case.

Table 5. P_b, P_f and P_d for video connections

PSD		CC	TT	DD	CT	CD	TC	TD	DC	DT
0%	P_b	0.12031	0.12031	0.12031	0.12031	0.12031	0.12031	0.12031	0.12031	0.12031
	P_f	0.07788	0.07788	0.07788	0.07788	0.07788	0.07788	0.07788	0.07788	0.07788
	P_d	0.00160	0.00160	0.00160	0.00160	0.00160	0.00160	0.00160	0.00160	0.00160
13%	P_b	0.11012	0.11559	0.12620	0.11488	0.12237	0.10886	0.11709	0.11040	0.11680
	P_f	0.04912	0.06597	0.05911	0.05555	0.05724	0.05687	0.06125	0.04916	0.06490
	P_d	0.00118	0.00137	0.00151	0.00133	0.00122	9.80×10^{-4}	0.00136	9.63×10^{-4}	0.00123
26%	P_b	0.09331	0.10946	0.12130	0.10346	0.11639	0.09687	0.11950	0.09558	0.11303
	P_f	0.02116	0.05288	0.04337	0.04526	0.03812	0.02702	0.04228	0.02426	0.05231
	P_d	6.44×10^{-4}	0.00113	9.04×10^{-4}	9.22×10^{-4}	8.70×10^{-4}	5.51×10^{-4}	8.62×10^{-4}	6.82×10^{-4}	0.00128
38%	P_b	0.08702	0.09969	0.12321	0.09751	0.11774	0.08851	0.12000	0.09361	0.10565
	P_f	0.01009	0.03439	0.02842	0.03011	0.02449	0.01366	0.03079	0.01215	0.03528
	P_d	1.68×10^{-4}	8.86×10^{-4}	5.37×10^{-4}	5.85×10^{-4}	5.16×10^{-4}	2.63×10^{-4}	6.13×10^{-4}	3.10×10^{-4}	0.00105
50%	P_b	0.09052	0.09141	0.11455	0.08139	0.11739	0.08626	0.11351	0.08745	0.08693
	P_f	2.01×10^{-4}	0.00501	0.00103	0.00233	5.53×10^{-4}	3.39×10^{-4}	7.01×10^{-4}	1.36×10^{-4}	0.00450
	P_d	0	2.34×10^{-4}	4.35×10^{-5}	1.19×10^{-4}	1.23×10^{-5}	0	7.81×10^{-5}	8.70×10^{-6}	1.87×10^{-4}

Finally, we evaluated the performance of the nine service schemes using a general cost function which is given by

$$GoS = 0.4 \cdot GoS_{voice} + 0.4 \cdot GoS_{web} + 0.2 \cdot GoS_{video} \quad (12)$$

and is made up from the cost functions that were used for voice, web browsing and video calls. A smaller weighting factor was given to video connections since they are less frequent than voice calls and web browsing connections. This general *GoS* is illustrated in Figure 9 for the nine service schemes. It should be stressed that the handover criterion dominates the criterion used for new calls. This was more obvious in web browsing and video connections which are subject to a large number of handover during their total duration. On the one hand, schemes that use the C criterion for handovers calls present always a good performance. On the other hand, when the D criterion is employed for handover calls, the scheme does not perform well. Regarding the best scheme, this is undoubtedly the CC service scheme. As for partial satellite diversity, it proved really beneficial to the network's performance. The obtained results were quite promising and illustrated that an effective design of a LEO constellation, in conjunction with a low complexity algorithm, results in a satisfactory QoS provision even for heavy traffic conditions.

5. Conclusions

In this paper a new satellite handover technique for multimedia LEO satellite systems has been proposed that avoids wasting the limited satellite bandwidth, along with a novel mobility model that takes into account the rotation of the earth and the overlapping area between contiguous satellites. Three satellite selection criteria have also been proposed that led to nine different service schemes. The new technique was assessed for the nine service schemes and for different percentages of the overlapping area. It proved to provide really beneficial conclusions for the performance of each service scheme and the design of a LEO satellite constellation. The best service scheme was derived and it has been shown that an increase in the percentage of the partial satellite diversity results in an enhanced network performance. Furthermore, the proposed technique aims to satisfy the QoS constraints even for the case of a heavy loaded network when its parameters are selected according to the constellation's configuration and traffic conditions. Finally, it can be considered adaptive and fully distributed in the sense that each satellite is able to change the value of the *handover threshold* parameter according to the prospective telecommunication load.

References

1. 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, pp. 1200-1214, November 1998.
2. E. Papapetrou and F.-N. Pavlidou, "QoS Handover Management in LEO/MEO Satellite Systems", *Kluwer Academic Publishers, Wireless Personal Communications*, vol. 24, no. 2, pp. 189-204, 2003.
3. 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, pp. 448-458, March 1999.
4. Sungrae Cho, Ian F. Akyildiz, Michael D. Bender, Huseyin Uzunalioglu, "A New Connection Admission Control for Spotbeam Handover in LEO Satellite Networks", *Kluwer Academic Publishers, Wireless Networks,* vol. 8, no. 4, pp. 403-415, July 2002.
5. S. Olariu, S. Rashid, A. Rizvi, R. Shirhatti, P. Todorova, “Q-Win - A New Admission and Handoff Management Scheme for Multimedia LEO Satellite Networks", *Kluwer Academic Publishers, Telecommunication systems*, vol. 22, no. 1-4, pp. 151-168, January-April 2003.
6. 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, no. 1, pp. 75-85, January 2001.
7. Enrico Del Re, Romano Fantacci, Giovanni Giambene, "Characterization of user mobility in low earth orbit mobile satellite systems", *Kluwer Academic Publishers, Wireless Networks,* vol. 6, no. 3, pp. 165-179, July 2000.
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. P. Todorova, S. Olariu, H. Nam Nguyen, "A Two-Cell-Lookahead Call Admission and Handoff Management Scheme for Multimedia LEO Satellite Networks", *The Thirty-Sixth Annual Hawaii International Conference on System Sciences (HICSS-36),* January 6-9, 2003, Big Island od Hawaii, USA.

10. 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.

11. E. Papapetrou, S. Karapantazis, G. Dimitriadis, F.-N. Pavlidou, "Satellite Handover Techniques for LEO Networks", *International Journal of Satellite Communications and Networking*, vol. 22, no. 2, pp. 231-245, March/April 2004.

12. 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'Ol),* Toulouse, France, April 2001.

13. Maria Gkizeli, Rahim Tafazolli, Barry G. Evans, "Hybrid Channel Adaptive Handover Scheme for Non-GEO Satellite Diversity Based Systems", *IEEE Commun. Letters,* vol. 5, no. 7, pp. 284-286, July 2001.

14. Maria Gkizeli, Rahim Tafazolli, Barry G. Evans, "Performance Analysis of Handover Mechanisms for Non-Geo Satellite Diversity Systems", *Proc. IEEE GLOBECOM 2001,* vol. 4, pp. 2744-2748, 25-29 November 2001, San Antonio, Texas, USA.

15. E. Papapetrou, S. Karapantazis, F.-N. Pavlidou, "Handover Policies in LEO Systems with Satellite Diversity" *First International Conference on Advanced Satellite Mobile Systems - ASMS 2003,* 10-11 July, Frascati - Italy.

16. A. Jamalipour, *"Low Earth Orbital Satellites for Personal Communication Networks",* Artech House, Boston-London, 1998.

17. 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, pp. 1183-1190, October 1999.

18. Irfan Ali, Naofal Al-Dhahir, John E. Hershey, "Doppler Characterization for LEO Satellites", *IEEE Transactions on Communications,* vol. 46, no. 3, pp. 309-313, March 1998.

List of figure captions:

Figure 1. Handovers in LEO networks

Figure 2. Partial Satellite Diversity

Figure 3. Mobility Model

Figure 4. P_b of Voice Calls for different service schemes and different percentages of Partial Satellite Diversity

Figure 5. P_f of Voice Calls for different service schemes and different percentages of Partial Satellite Diversity

Figure 6. *GoS* of Voice Calls for different service schemes and different percentages of Partial Satellite Diversity

Figure 7. Performance metrics of Web Browsing Connections for different service schemes and different percentages of Partial Satellite Diversity

Figure 8. Performance metrics of Video Connections for different service schemes and different percentages of Partial Satellite Diversity

Figure 9. General *GoS* for different service schemes and different percentages of Partial Satellite Diversity

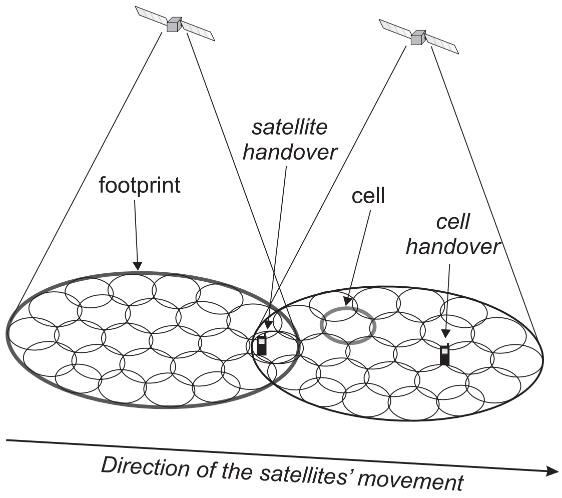

Figure 1. Handovers in LEO networks

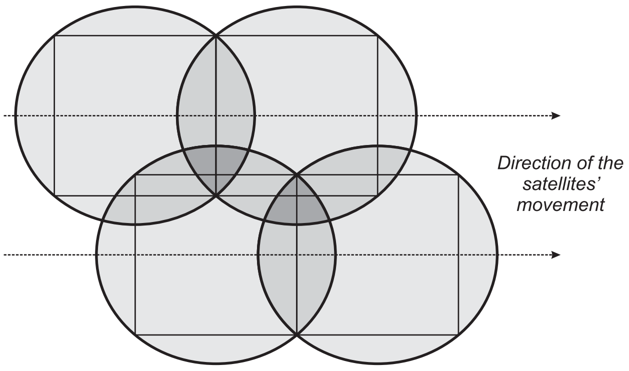

Figure 2. Partial Satellite Diversity

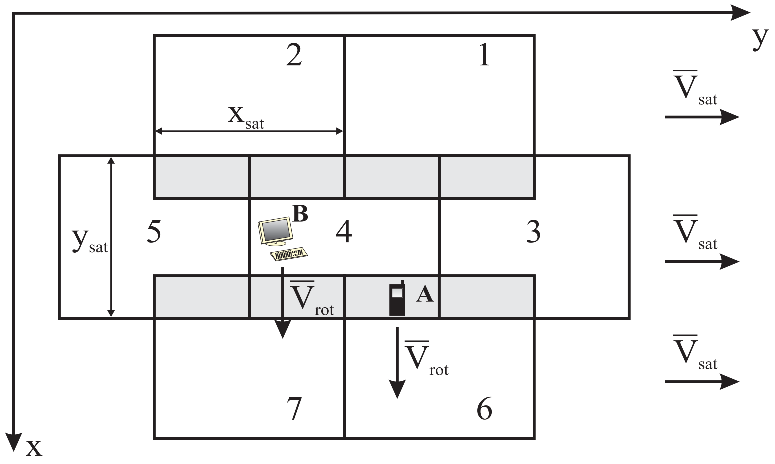

Figure 3. Mobility Model

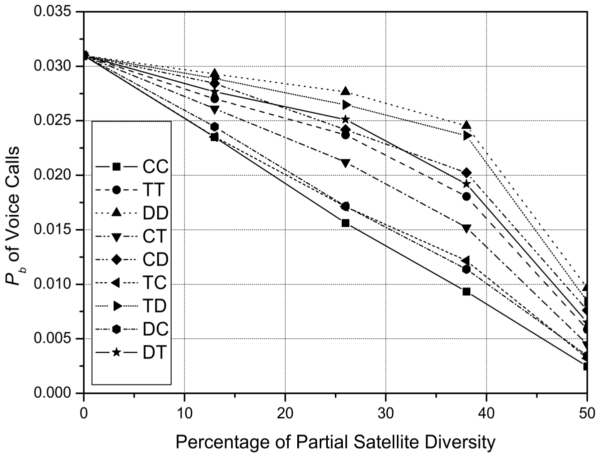

Figure 4. P_b of Voice Calls for different service schemes and different percentages of Partial Satellite Diversity

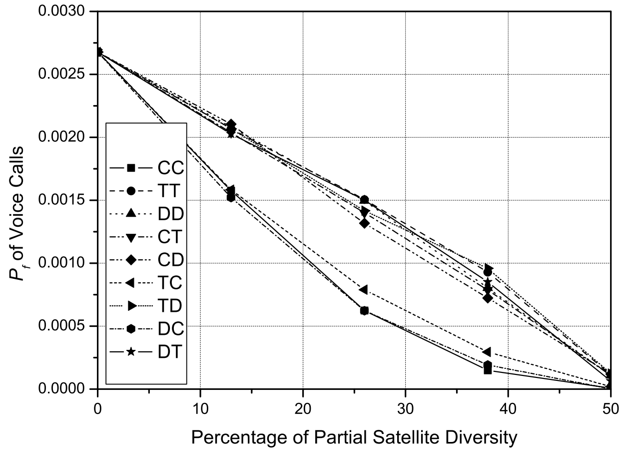

Figure 5. P_f of Voice Calls for different service schemes and different percentages of Partial Satellite Diversity

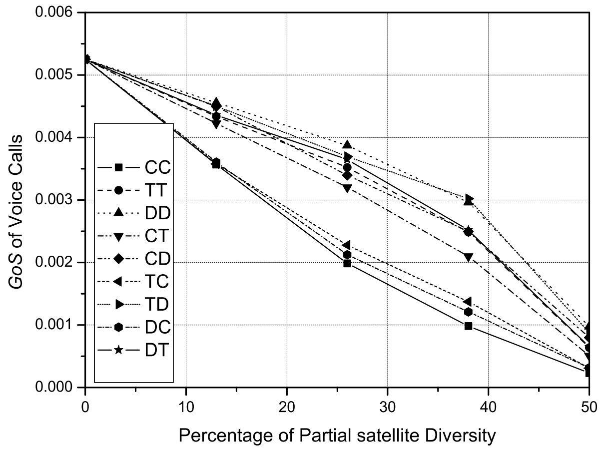

Figure 6. *GoS* of Voice Calls for different service schemes and different percentages of Partial Satellite Diversity

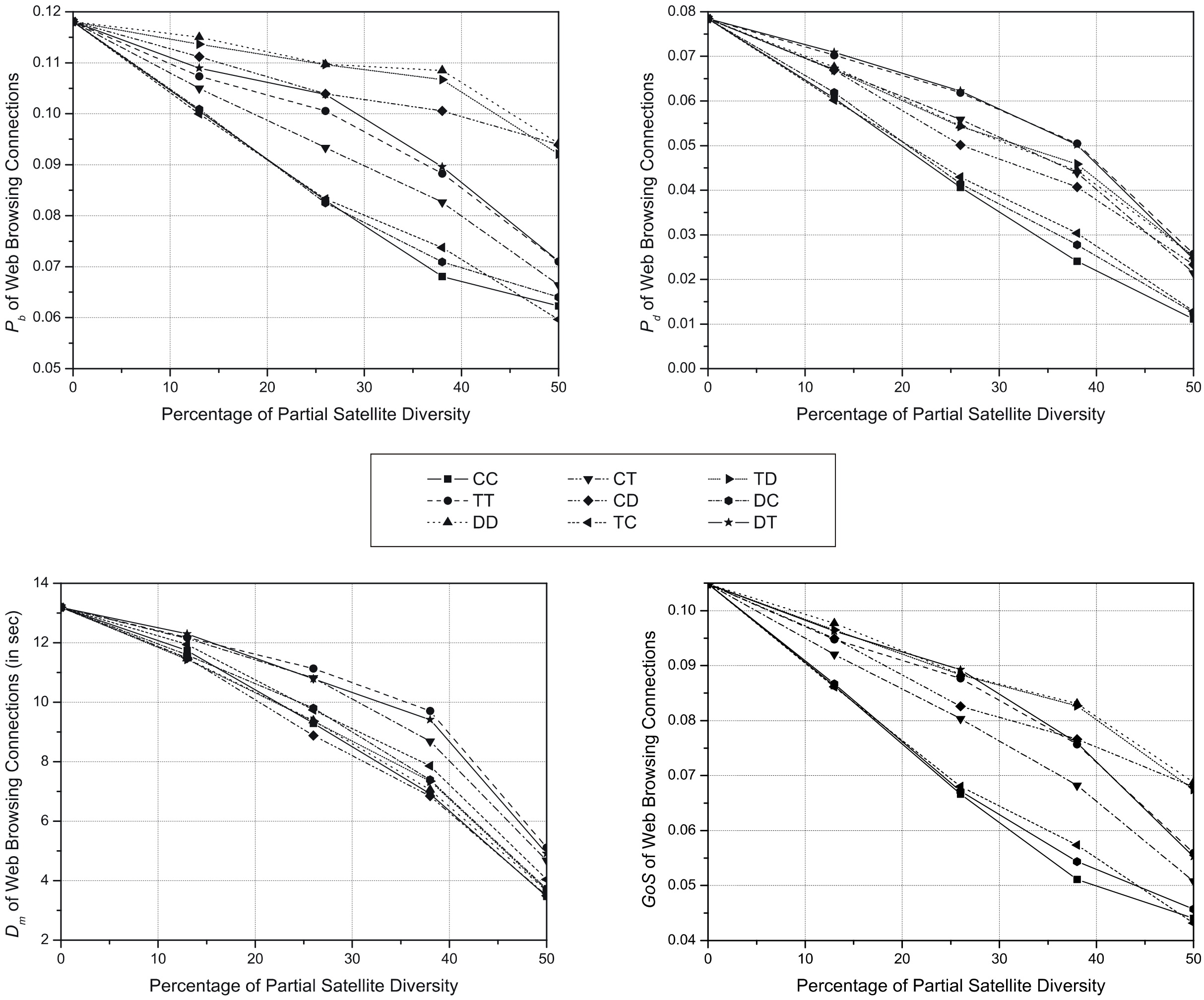

Figure 7. Performance metrics of Web Browsing Connections for different service schemes and different percentages of Partial Satellite Diversity

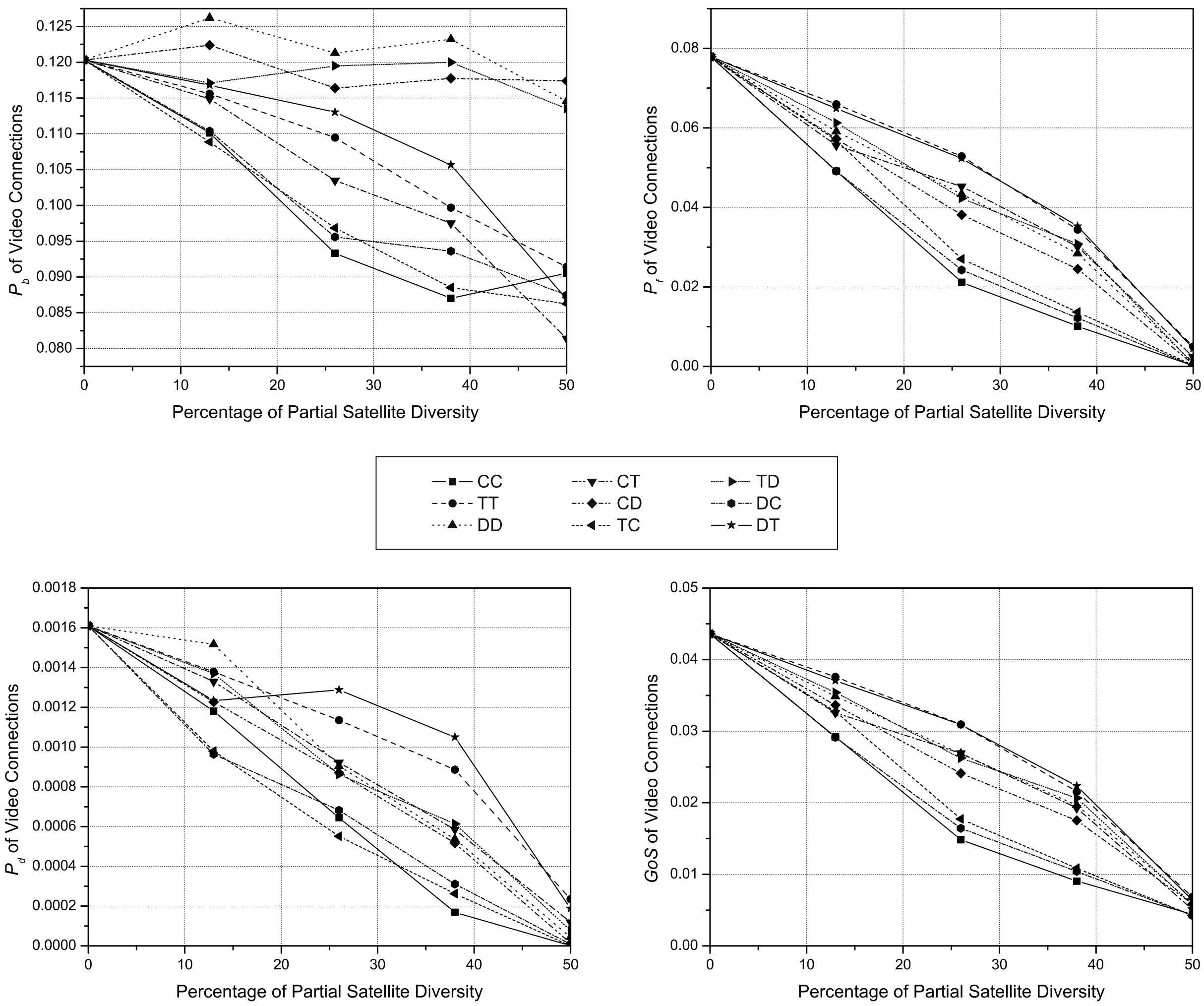

Figure 8. Performance metrics of Video Connections for different service schemes and different percentages of Partial Satellite Diversity

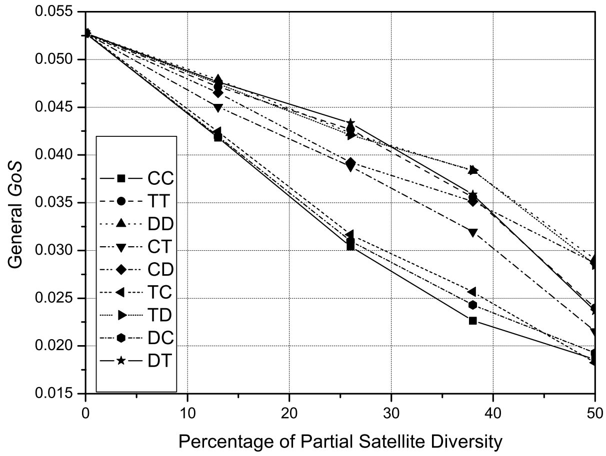

Figure 9. General *GoS* for different service schemes and different percentages of Partial Satellite Diversity