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Adaptive Channel Reservation Schemes in multitraffic LEO Satellite Systems

Andr-Luc Beylot¹ and Selma Boumerdassi²

¹ENSEEIH, Laboratoire IRIT/TSA, 2, rue C. Camichel, BP7122
F-31071 Toulouse Cedex 7 – France

²CNAM, Laboratoire CEDRIC, 292, rue St-Martin
F-75141 Paris Cedex 3 – France

Abstract— The satellite component of the future Universal Mobile Telecommunications System (UMTS) is anticipated to be partly composed of non-geostationary satellites such as Low-Earth Orbit (LEO) satellites. Those networks are designed to support multimedia traffics with different Quality of Service (QoS) requirements. This paper deals with the performance evaluation of a new channel resource management technique in Low-Earth Orbit (LEO) satellite systems based on a satellite-fixed cell concept. In cellular and satellite networks the resource capacity is shared among handovers and new calls. Forced termination has a significant impact on the quality of service perceived by the users. This is especially the case for those which have delay constraints (such as video or voice traffic). The guard channel scheme is an access priority that has been proposed in order to reduce the handover failure probability. Its effectiveness has been emphasized in terrestrial cellular networks. In this paper, we propose a dynamic reservation scheme for satellite networks which adapts the number of reserved channels, according to the current number of ongoing calls (voice or video traffic) and on the localization of users. A performance evaluation of the proposed mechanism has been carried out by simulations as regards with the blocking probabilities of each type of users.

Keywords — LEO, satellite-fixed cells, handover, resource allocation.

I. INTRODUCTION

Many Low-earth orbit (LEO) satellites systems have been designed to provide a global, seamless personal communication service. The most important advantages of LEOs are their global coverage and their presence all over the world. They also offer a better end to end delay and increase the potential frequency reuse by dividing the satellite footprint into cells, each one corresponding to a specific beam of the satellite antenna radiation pattern [1].

With *satellite-fixed cells (SFC)* systems, beams maintain a constant geometry with respect to the spacecraft, and the cells on the ground move along with the satellite. With *earth-fixed cells (EFC)*, the antenna beams are steered so as to point toward a given cell on the earth during some time interval [2]. In this paper we focus on the handover aspect of the *satellite-fixed cells (SFC)*. In such a configuration, due to the short visible period of the satellites, an active user, wherever mobile or fixed, may change beam and eventually satellite. Those transfers are respectively named *beam handover* and *satellite handover*. The handover mechanism is an important aspect of SFC systems, because a terminal would be served by the same cell only a few seconds before a channel reassignment would be necessary. Without signal consideration, the handover may fail as a result of the incoming cell having not enough idle resources. As in all cellular networks, forced call termination due to handover call blocking are more objectionable than new call blocking. Consequently, in order to offer a given Quality of Service (QoS) to the user, it is necessary to propose mechanisms which protect handover calls.

Deterministic solutions were proposed in order to guaranty han-

dover services during a given period of time [2]. This solution may lead to a bad resource utilization because channels are blocked even if the considered call is finished. Other solutions, such as guard channels or handover queueing may be implemented. Fixed guard channel mechanisms consist in giving a prioritized access scheme which allows new calls and handovers to share the capacity and give a larger resource capacity to handover calls [3] [4] [5]. The guard bandwidth is defined as the difference between the two capacity limits. Fixed guard channel schemes are usually considered.

In this paper, we propose a new dynamic channel reservation mechanism called multitraffic Channel Reservation (CR) which consists in reserving channels according to the current number of occupied channels in neighboring cells and on the user's position. In the following, we consider a classical regular honeycomb cellular network. Discrete event simulations were run to validate our proposition.

The paper is organized as follows: Section II presents the proposed mechanism. Section III deals with some preliminary assumptions. Section IV presents and discusses simulation results obtained. Finally, Section V concludes the paper.

II. CR SCHEME

CR scheme consists in having a variable number of guard channels in each cell in order to keep the handover call blocking probabilities close to the target objective without deteriorating significantly new call blocking probabilities. The reserved channel number in a cell depends upon two parameters: the current number of ongoing calls in the neighboring cells and the position of the users in these cells. The second parameter allows the Network Manager System (NMS) to perform the next cell to be visited (see Fig. 1) by a user (if its call goes on) and the time when the next handover will occur. Therefore, as the user speed may be neglected with respect to the satellite speed, the user can be considered as fixed. Thus, the mobile motion could be approximated by the satellite ground-track speed, and the destination cell for any user will be the neighboring cell in the opposite direction of the satellite motion.

A. Description

Let $N_{i,j}(t)$ be the number of customers of traffic class j in area i who could have a handover in less than t seconds. Traffic class j is assumed to require b_j channels.

When $N_i(t) = \sum_j N_{i,j}(t)b_j$ reaches a threshold T (or a multiple of T) the cell reserves a resource in neighbor i (see Fig. 2). If this neighbor has a free channel, the reservation takes place im-

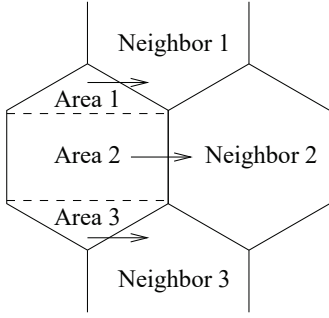


Fig. 1. Handover generation process

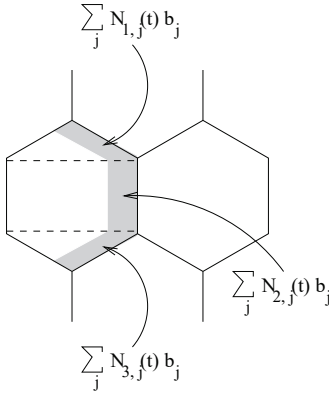


Fig. 2. Reservation for different areas

mediately, otherwise it waits for a channel to become free. Only ongoing calls with delay constraints (voice or video traffic) can use the reserved channels. Thus, in case of overload (or a state close to overload), the system does not accept incoming calls but only calls in progress with high priority. Parameter t allows the reservation of channels for customers who have a high handover probability. Thus, parameters t and T have to be carefully chosen to offer a good QoS to handover calls without deteriorating the QoS of new calls. The maximum value for t is the time spent by the user to cross the cell from border to border.

In the fixed reservation scheme, channels are reserved whatever the traffic conditions are. This leads to a bad use of the bandwidth, especially when the number of handovers is low. In our proposition, reservations are done for a short period of time for customers which have a high probability to go from one cell to another one. Thus, CR leads to a better utilization of the bandwidth.

III. THE MOBILITY MODEL

In the present paper, a regular honeycomb cellular network is considered. Let R denote the cell side. Consequently, the centers of adjacent cells are separated by $R\sqrt{3}$. Classical assumptions are made. New calls of class j are assumed to arrive according to a Poisson process with parameter $\lambda_{i,j,nc}$ where index i refers to cell number i . The call duration is assumed to be exponentially distributed with parameter μ_j .

The QoS parameters studied are:

- the blocking probabilities of class j new call attempts, $P_{j,nc}$
- the handover failure probability, $P_{j,ho}$

Let $\lambda_{i,j,ho}$ be the class j handover rate in cell i . The performance criteria can be derived as follows:

$$P_{j,nc} = \frac{\sum_i \lambda_{i,j,nc} P_{i,j,nc}}{\sum_i \lambda_{i,j,nc}}$$

$$P_{j,ho} = \frac{\sum_i \lambda_{i,j,ho} P_{i,j,ho}}{\sum_i \lambda_{i,j,ho}}$$

where index i and j refer to the performance criteria of traffic class j in cell i . In order to show the influence of the CR scheme on the performance criteria, it is also convenient to define a global metric for each traffic class. The Grade of Service can be defined as:

$$GoS_j = P_{j,nc} + \alpha P_{j,ho}$$

In such networks, forced call termination due to handover call blocking are more objectionable than new call blocking. In order to comply with QoS constraints, α is usually set to 10. The input load expressed in Erlangs may be defined as follows:

$$\rho = \frac{1}{M} \sum_{i,j} \frac{\lambda_{i,j,nc}}{\mu_j} b_j$$

where M is the number of cells.

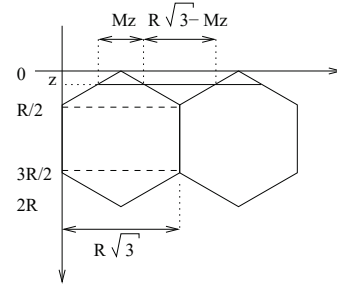


Fig. 3. New Call and Handover Motions

In the present paper, the cell radius considered is quite large. Nevertheless, non-uniform traffic conditions are considered (i.e. the actual arrival rates depend on the the cell). Let us now focus on a given cell. In order to simplify the notations, index i will be omitted in the following. Users are supposed to be uniformly generated within a cell. The relative satellite motion is approximated by a ground-track speed V which is assumed to be horizontal with respect with the hexagonal topology [6] [7], (see Fig. 3). A given call will consequently be characterized by a given offset z . The time spent by a user in its first cell is uniformly distributed between 0 and M_z multiplied by V (the relative velocity of the satellite). In order to simplify the notations, let $T_z = M_z V$ and $\theta = \frac{R\sqrt{3}}{V}$. Let τ be the threshold of the reservation zone,

$$\tau = \frac{t}{\theta}$$

The proposed mechanism is based on the actual number of calls in the different areas. For symmetry reasons, index 1 will refer

to traffic characteristics in area 1 and 3, index 2 to area 2 (see Fig. 1). It can be easily shown that the probability density function of random variables T_z^1 (area 1 or 3) and T_z^2 (area 2) are respectively:

$$f_{T_z^1}(x) = \frac{2x}{\theta^2}, 0 \leq x \leq \theta$$

$$f_{T_z^2}(x) = \delta(x - \theta)$$

where $\delta(x)$ denotes the Delta Dirac function. The arrival rate in the different areas are:

$$\lambda_{j,nc}^1 = \frac{\lambda_{j,nc}}{3}, \lambda_{j,nc}^2 = \frac{2\lambda_{j,nc}}{3}$$

It is consequently convenient to derive time $T_{j,nc}$, during which a given traffic class j new call will be taken into account in its original cell. $T_{j,nc}$ is the minimum between the call duration and the previous coverage time.

It can be shown that the conditional complementary distribution of $T_{j,nc}$, given $T_z = x$, is equal to:

$$Pr[T_{j,nc} > y | T_z = x] = (1 - \frac{y}{x})e^{-\mu_j y} 1_{\{0 \leq y \leq x\}}$$

The expectation of $T_{j,nc}$, with the same assumption, can be derived. In area 1 or 3,

$$E[T_{j,nc}^1 | T_z = x] = \frac{1}{\mu_j} - \frac{1 - e^{-\mu_j x}}{x\mu_j^2}$$

Since,

$$E[T_{j,nc}^1] = \int_{x=0}^{\theta} E[T_{j,nc}^1 | T_z = x] f_{T_z^1}(x) dx$$

It leads to,

$$E[T_{j,nc}^1] = \frac{1}{\mu_j} + \frac{2(1 - 2\mu_j\theta)}{\mu_j^3\theta^2} - e^{-\mu_j\theta} \frac{2(1 - \mu_j\theta)}{\mu_j^3\theta^2}$$

In area 2, we obtain:

$$E[T_{j,nc}^2] = \frac{1}{\mu_j} - \frac{1 - e^{-\mu_j\theta}}{\theta\mu_j^2}$$

The time spent by a user to cross a cell from border to border T_c depends on its initial offset z . If $\frac{R}{2} \leq z \leq \frac{3R}{2}$, time T_c is θ ; in the other case, it is alternately equal to $\theta - T_z$ and to T_z . Finally, due to the memoryless property of the exponential distribution, the time $T_{j,ho}$ a handover call spends in a given cell, given $T_c = y$, can be described as follows:

$$Pr[T_{j,ho} > x | T_c = y] = e^{-\mu_j x} 1_{\{0 \leq x < y\}}$$

and

$$E[T_{j,ho} | T_c = y] = \frac{1 - e^{-\mu_j y}}{\mu_j}$$

In area 2, it leads to:

$$E[T_{j,ho}^2] = \frac{1 - e^{-\mu_j\theta}}{\mu_j}$$

Those parameter values will be used in the following simulations.

IV. SIMULATION MODEL AND PERFORMANCE CRITERIA

A. Description of the simulation model

During the simulation process following assumptions related to the traffic model have been made :

- a cell cluster with $M = 30$ hexagonal has been considered. Edge effects on handovers at the cluster boundary are handled by wrapping them around thereby assuming that arrival rates and handover departure rates from cluster to cluster are equivalent;
- Fixed Channel Allocation (FCA) is used, this means that each cell has a fixed number of channels C equal to 24 in this case;
- the average call duration are: 180 s (voice), 300 s (video) and 360 s (web);
- the number of channels required by the different traffic classes are respectively: $b_v = 1$ (voice), $b_{vi} = 2$ (video) and $b_w = 1$ (web);
- the cell radius R is 500 km and the satellite velocity ground-track V is set to 5,9 km/s.

B. Dimensioning CR parameters

In order to find the best values for T^* and τ^* , we run simulation with only voice traffic Fig. 4 represents the GoS as a function of τ for different values of the input load (expressed in Erlangs). The results obtained with the best value of reservation threshold T^* (the one that leads to the best GoS) have only been depicted in the curves. It is shown that the performance of our mechanism are obtained with a given threshold τ^* (in the considered examples $\tau^* = \frac{1}{16}$). In the simulated system, the best configuration is obtained when one channel is reserved for each customer who is situated near the border of the cell and when this reservation is not done too late (τ^* too low). Table I shows the best reservation threshold T^* as a function of τ .

TABLE I
BEST RESERVATION THRESHOLD AS A FUNCTION OF τ

τ	1	1/2	1/4	1/8	1/16	1/32	1/64
T	6	4	2	1	1	1	1

For high values of τ , the best results are obtained for large values of T . In this case, CR can be viewed as a statistical mechanism, reservations are done for a group of users, some of the corresponding calls may be finished before the handover procedure occurs. For lower values of τ , most of the considered users will experience a handover and consequently a reservation should be processed for each of them.

For high values of threshold τ , reservations are useless because resources are reserved too early. For lower values of τ , reservations occur too late and in case of congestion, they cannot be processed.

In Fig. 5, the GoS obtained using CR is compared to the results obtained with classical FCA and FCA with a fixed number of reservations (1 or 2 channels). The curves are represented as a function of the input load. It is shown that CR leads to better results because reservations are taken into account only according to the actual position of users.

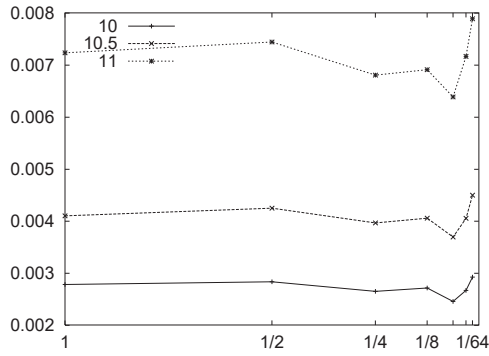


Fig. 4. Gos as a function of τ

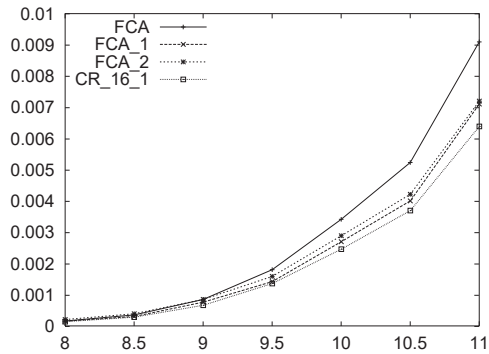


Fig. 5. Gos as a function of the input load - $CR_{\frac{1}{\tau}T}$, FCA, FCA1, FCA2 policies

C. CR Performance

Let γ_v (respectively γ_{vi} and γ_w) be the proportion of voice traffic (respectively video and web traffics). Fig 6 and Fig 7 show the comparison of simulation results for both CR and classical FCA (having voice, video and web traffics) with two different traffic distributions:

- $(\gamma_v = \frac{1}{3}, \gamma_{vi} = \frac{1}{3}, \gamma_w = \frac{1}{3})$ for the first one.
- $(\gamma_v = \frac{1}{2}, \gamma_{vi} = \frac{1}{4}, \gamma_w = \frac{1}{4})$ for the second one.

It is shown that the GoS increases with the input load ρ for each traffic type. Both distributions lead to very good performance for voice and video traffics whatever the part of the voice traffic. The improvement is about 20% for voice traffic and about 40% for video traffic.

V. CONCLUSION

In this paper the effect of guard bandwidth mechanisms on the performance of LEO systems has been investigated. A dynamic reservation scheme (CR) has been proposed to improve the performance of the system. It has been shown that the choice of both the number of reserved channels and the ratio of the reservation zone have a noticeable influence on the QoS offered to the users. Thus, CR enables significant improvement of the GoS, because the number of guard channels are adapted according to the fluctuations of the traffic. It is shown in this paper, that CR mechanism leads to better performance than a fixed reservation

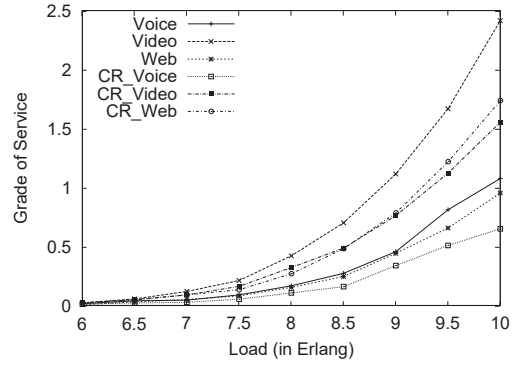


Fig. 6. Gos with a traffic $(\gamma_v = \frac{1}{3}, \gamma_{vi} = \frac{1}{3}, \gamma_w = \frac{1}{3})$

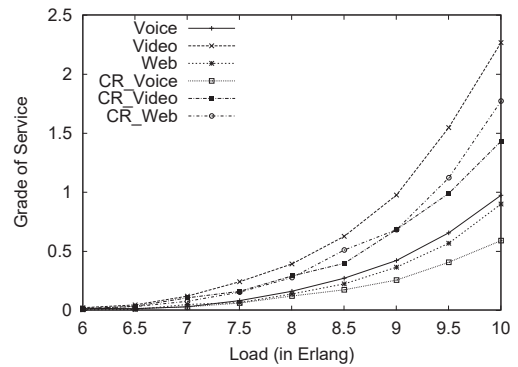


Fig. 7. Gos with a traffic $(\gamma_v = \frac{1}{2}, \gamma_{vi} = \frac{1}{4}, \gamma_w = \frac{1}{4})$

mechanism.

CR scheme appears to be very useful for satellite and cellular networks, especially if these systems allow different kind of traffic with different level of QoS.

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