Adaptive Channel Assignment in LEO Satellite Systems based on "Satellite-Fixed Cell" Coverage

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Abstract. 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. The guard channel scheme is an access priority that has been proposed in order to reduce the handover failure probability. The effectiveness of this mechanism 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 and on the localization of users. The effeciency of the proposed mechanism has been investigated for Low-Earth Orbit (LEO) satellite systems based on an satellite-fixed cell concept.

Keywords: Satellite Constellation Systems, LEO, Satellite-fixed cells, Handover.

1 Introduction

IMT 2000 and UMTS will constitute the third generation of mobile systems which aim is to provide new services to the users. The satellite component part of UMTS (i.e Mobile Satellite Systems) will extend the terrestrial cellular networks and provide global mobile telephony and data transfer for both mobile or fixed users. Those systems may include GEOstationary (GEO), Medium-Earth Orbit (MEO) and Low-Earth Orbit (LEO) satellites [1]. LEO systems offer 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.

The success or failure of a given LEO communication system depends on how well the chosen technology performs with respect to system capacity, quality of service and cost [2]. In this paper we focus on the handover aspect of the *satellite-fixed cells(SFC)*. In such a configuration, beams maintain a given geometry and

cells on the ground move along with the satellite. Consequently, due to the velocity of the satellite, 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 handover services during a given period of time [3]. 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 [4] [5] [6]. 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 **S**atellite **V**ariable **R**eservation (SVR) which consists in reserving channels according to the number of ongoing calls on neighboring cells. Consequently, it depends upon the actual geometry of cells. In the following, we consider a classical regular honeycomb cellular network. Discrete event simulations were run to validate our proposition.

2 SVR scheme

SVR 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.

2.1 Description

Let $N_i(t)$ be the number of customers in area i who could have a handover in less than t seconds (see Fig 2).

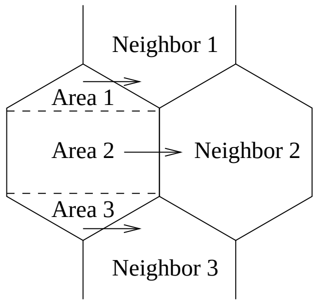

Fig. 1. *Handover generation process*

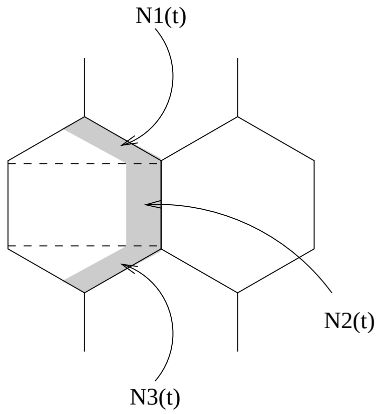

Fig. 2. *Reservation for different areas*

When $N_i(t)$ reaches a threshold T (or a multiple of T) the cell reserves a resource in neighbor i (see Fig 1). If this neighbor has a free channel, the reservation takes place immediately, otherwise it waits for a channel to become free. Only ingoing calls 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. 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 the 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, SRV leads to a better utilization of the bandwidth.

3 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 are assumed to arrive according to a Poisson process with parameter $\lambda_{i,nc}$ where index i refers to cell number i. The call duration is assumed to be exponentially distributed with parameter μ. The QoS parameters studied are:

- the blocking probabilities of new call attemps, $P_{b,nc}$
- the handover failure probability, $P_{b,ho}$

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

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

where index i refers to the performance criteria in cell i. In order to show the influence of the SVR scheme on the performance criteria, it is also convenient to define a global metric. The Grade of Service can be defined as:

$$GoS = P_{b,nc} + \alpha \; P_{b,ho}$$

In such networks, forced call terminations 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.

In the present paper, non-uniform traffic conditions may be taken into account, the input rate may depend on the cell.

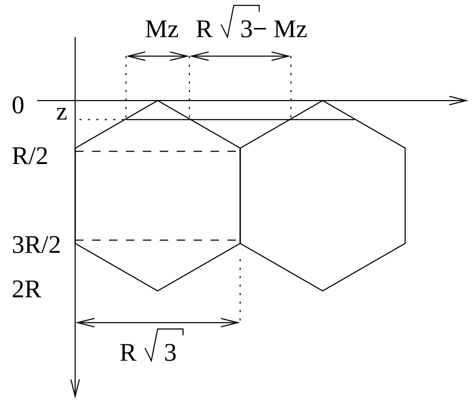

Fig. 3. New Call and Handover Motions

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 [7] [8], (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 divided by V (the relative velocity of the satellite). It can be easily shown that the probability density function of r.v. M_z is:

$$f_{M_z}(x) = \begin{cases} \dfrac{2x}{9R^2} & 0 \leq x < R\sqrt{3} \\ \dfrac{2}{3}\delta(x - R\sqrt{3}) & x = \sqrt{3} \end{cases}$$

where $\delta(x)$ denotes the Delta Dirac function. Time T_{nc}, during which a given new call will be taken into account in its original cell, is the minimum between the call duration and the previous coverage time.
It can be shown that the conditional complementary distribution of T_{nc}, with $M_z = x$, is equal to:

$$Pr[T_{nc} > y | M_z = x] = (1 - \frac{yV}{x}) e^{-\mu y} 1_{\{0 \leq y \leq \frac{x}{V}\}}$$

The expectation of T_{nc}, with the same assumption, can be derived:

$$E[T_{nc} | M_z = x] = \frac{1}{\mu} - \frac{V(1 - e^{-\frac{\mu x}{V}})}{x\mu^2}$$

which finally leads to :

$$E[T_{nc}] = \int_{x=0}^{R\sqrt{3}} E[T_{nc} | M_z = x] f_{M_z}(x) dx = \frac{1}{\mu} + \frac{2(1 - 2\mu\theta)}{3\mu^3\theta^2} - e^{-\mu\theta} \frac{2(1 - \mu\theta)}{3\mu^3\theta^2}$$

where $\theta = \frac{R\sqrt{3}}{V}$

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 $\theta - \frac{M_z}{V}$ and to $\frac{M_z}{V}$. Finally, due to the memoryless property of the exponential distribution, the time T_{ho} a handover call spends in a given cell, given $T_c = y$, can be described as follows:

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

and

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

4 Simulation Model and Performance Criteria

4.1 Description of the simulation model

In order to estimate the performance of SVR, discrete event simulations were run, using the following parameters :

- a cell cluster with 30 hexagonal has been considered. Edge effects on handovers at the cluster boundary are handed 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;
- non-uniform traffic is considered which means that for each period of time each cell has its own arrival rate;
- the average call duration is 180 seconds;
- the cell radius R is 500 km and the satellite velocity V is set to 5900 m/s.

4.2 Simulation results

Let $\tau = \frac{t}{\theta}$ be the ratio of the reservation zone. The results are presented as a function of this ratio.
Figures 4, 5 and 6 represent handover blocking, new call blocking and 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 1 shows the best reservation thresold T^* 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

Table 1. *Best reservation thresold as a function of* τ

For high values of τ, the best results are obtained for large values of T. In this case, SVR 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 handoff procedure occurs. For lower values of τ, most of the considered users will experience a handoff 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 figure 7, the GoS obtained using SVR 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 SVR leads to better results because reservations are taken into account only according to the actual position of users.

5 Conclusion

In this paper the effect of guard bandwidth mechanisms on the performance of LEO systems has been investigated. A dynamic reservation scheme (SVR) 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, SVR enables significant improvement of the GoS, because the number of guard channels are adapted according to the fluctuations of the traffic. It is

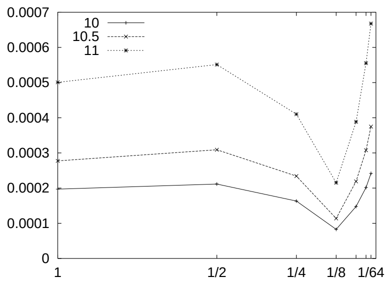

Fig. 4. *Handoff Blocking Probability as a function of* τ for different values of the input load

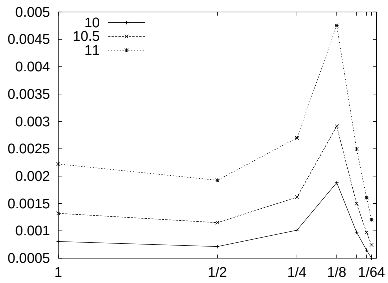

Fig. 5. *New Call Blocking Probability as a function of* τ for different values of the input load

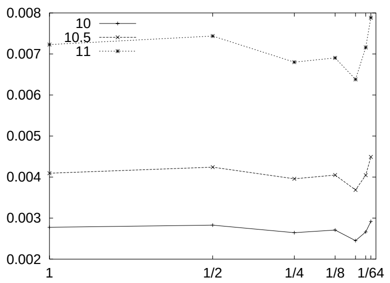

Fig. 6. *Gos as a function of* τ

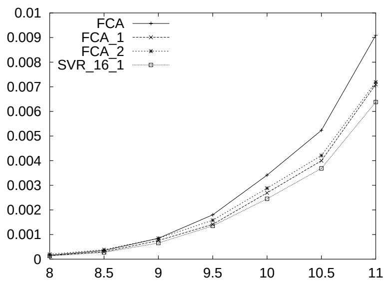

Fig. 7. *Gos as a function of the input load -* $SVR\_\frac{1}{\tau}\_T$*, FCA, FCA1, FCA2 policies*

shown in this paper, that SVR mechanism leads to better performance than a fixed reservation mechanism.

SVR scheme can be very usefull for satellite and cellular networks, especially if these systems allow different kind of traffic with different level of QoS. In this case, each traffic will have its own values for parameters T and τ. Thus, the choice for these two parameters depends on the level of the QoS.

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