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► **To cite this version:**

André-Luc Beylot, Selma Boumerdassi. An efficient reservation strategy for LEO satellite systems. 54th IEEE Vehicular Technology Conference (VTC Fall 2001), IEEE, Jan 2001, Atlantic City, NJ, United States. pp.310-314, 10.1109/VTC.2001.956609 . hal-01124648

HAL Id: hal-01124648

<https://hal.science/hal-01124648>

Submitted on 9 Dec 2022

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An efficient reservation strategy for LEO satellite systems

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Abstract—Satellite systems will be employed to extend the terrestrial cellular networks and to provide a global coverage, for both mobile and fixed users. In these networks, the resource capacity is shared among handoffs and new calls. Forced termination has a significant impact on the user's quality of service. Several mechanisms such as guard channels or handoff queuing have been proposed in order to reduce handoff failure probability. The guard channel scheme consists in giving a prioritized access to the handoff calls. The penalty is the reduction of the total carried traffic. This paper proposes a dynamic reservation scheme for LEO satellite system, which adapts the number of reserved channel according to the current number of ongoing calls and on the localisation of users in the considered area.

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

I. INTRODUCTION

Existing terrestrial radio networks provide mobile communications services within limited regions. In order to extend the availability of these services and finally provide global coverage several satellite systems including GEO stationary (GEO), Medium-Earth Orbit (MEO) and Low Earth Orbit (LEO) have been proposed as an supplement to these networks [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 handoff aspect of the *satellite-fixed cells* (SFC). In such a configuration, the cell layout is fixed with respect to the satellite. Thus, the cell pattern moves over the Earth surface as the satellite orbits. Due to the velocity of the satellite, the handoff mechanism is an important aspect of SFC systems, because a terminal is served by the same cell only a few seconds before a channel reassignment would be necessary. Without signal consideration, the handoff may fail as a result of the incoming cell having not enough free resources. As in all cellular networks, forced call terminations due to handoff call blocking are less acceptable than new call blockings. In order to offer a given Quality of Service (QoS) to the user, it is important to propose mechanisms which protect

handoff calls.

Several scenarios for efficient handoff and resource allocation have been proposed in literature. In general, well-established techniques for terrestrial cellular networks can be expanded to satellite cellular systems. One of these well-known schemes is the guard channel concept, which allows to reduce the handoff failure probability by reserving a fixed number of channels exclusively for handoffs. The remaining number of channels is used for handoffs as well as for originating calls. The penalty is the reduction of the total carried traffic due to the fact that fewer channels are granted to new calls. This disadvantage can be bypassed by dynamically adjusting the number of reserved channel and/or by allowing the queuing of new calls.

In this paper, we propose a new dynamic channel reservation mechanism called **Satellite Variable Reservation (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. The efficiency of the proposed mechanism has been investigated by an analytical model.

II. SVR SCHEME

The SVR scheme consists in having a variable number of guard channels in each cell in order to keep the handoff 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 calculate the next cell to be visited (see Fig 1) by a user (if its call goes on) and the time when the next handoff will occur. Thus, when a handoff occurs, the destination cell is the adjacent one in the direction of the satellite sub-satellite point motion. Users cross cell boundaries at a constant velocity aligned and opposite to the satellite ground-track speed. This is true as far as the rotation of the earth (maximum speed at equator 0.463 km/s) and the user speed (considered to be less than a few hundred m/s) are negligible with respect to the speed of the sub-satellite point on the earth, comprised between

7.1-5.3 km/s for satellite altitude from 500 to 2000 km, respectively. These altitudes are the practical limits for LEO satellite systems [3].

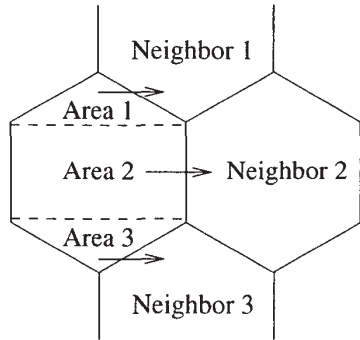


Fig. 1. Handoff generation process

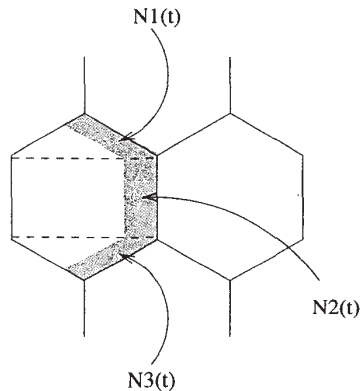


Fig. 2. Reservation for different areas

Let us now describe the proposed mechanism. Let $N_i(t)$ be the number of customers in area i who could experience a handoff in less than t seconds (see Fig 2). 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 processes calls in progress. Parameter t allows the reservation of channels for customers who have a high handoff probability. Thus, parameters t and T have to be carefully chosen to offer a good QoS to handoff 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 an inefficient use of the bandwidth, especially when the number of handoffs is low. In our proposition, reservations are made for a

short period of time for customers who have a high probability to go from one cell to another one. Thus, SRV 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 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 .

Two QoS indicators are studied:

- $P_{b,nc}$, the blocking probabilities of new call attempts
 - $P_{b,ho}$, the handoff failure probability
- Let $\lambda_{i,ho}$ be the handoff rate in cell i . The performance criteria can be derived as follows (Poisson approximations will also be considered for handoff traffic):

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

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

where index i refers to 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 termination due to a handoff call blocking is less acceptable than new call blocking. In order to comply with QoS constraints, α is usually set to 10.

In the present paper, the cell radius considered is quite large; consequently, uniform traffic conditions are used. Thus, in the following, index i will be omitted.

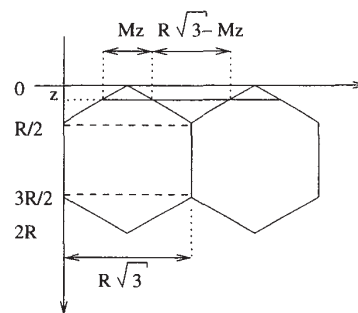


Fig. 3. New Call and Handoff Motions

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 $M_z \times V$ (where V is the relative velocity of the satellite). In order to simplify the notations, let $T_z = M_z \times V$ and $\theta = \frac{R\sqrt{3}}{V}$. 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).

Under these traffic assumptions, the study of one cell is done iteratively. In each step:

- the steady state probabilities are derived through a M/G/C/C multiclass analysis with Trunk Reservation [9]. There are actually four classes of traffic, new calls in area 1 (or 3) and in area 2, handoff in area 1 (or 3) and in area 2. They are characterized by an arrival rate (a Poisson approximation is used for handoff traffic) and a mean sojourn time which have to be computed.

- the steady state probabilities of the number of reservations are performed through a convolution method derived from the proportion of calls in the reservation area.

The new call arrival rates in the different areas are:

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

It is necessary to determine the mean sojourn time of new calls and of handoff calls. It can be shown (details are presented in [10]) that:

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

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

For handoff traffic, it is necessary to determine, in area 1 or 3, the handoff arrival rate $q(x)$ with an initial offset $x < T_z \leq x + dx$. By neglecting the handoff blocking probability, it can be shown that:

$$q(x) \approx \frac{2\lambda_{nc}}{3\theta^2}$$

Finally,

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

In area 2, one can easily find that:

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

The handoff rates can also be determined:

$$\lambda_{ho}^1 = \frac{2\lambda_{nc}^1}{\mu\theta}, \quad \lambda_{ho}^2 \approx \frac{\lambda_{nc}^2}{\mu\theta}$$

In order to determine the proportion of call in the reservation area, let Q_{nc}^i (resp. Q_{ho}^i) be the time spent by a new call (resp. a handoff) in the reservation area of area i . Let $\tau_2 = \frac{t}{\theta}$ be the ratio of the reservation zone in area 2. It can be shown that it corresponds to a ratio $\tau_1 = 1 - (1 - \tau_2)^2$

in area 1 and 3. The expectation of Q_{ho}^1 and of Q_{ho}^2 can then be derived:

$$E[Q_{ho}^1] = \frac{\tau_2}{\mu} - \frac{e^{-\mu\theta(1-\tau_2)} - e^{-\mu\theta}}{\mu^2\theta}$$

$$E[Q_{ho}^2] = \frac{e^{-\mu\theta(1-\tau_2)} - e^{-\mu\theta}}{\mu}$$

The proportion of handoff in area i (p_{ho}^i) is consequently equal to:

$$p_{ho}^i = \frac{E[Q_{ho}^i]}{E[T_{ho}^i]}$$

The proportion of new call in area i (p_{nc}^i) can then be derived:

$$p_{nc}^1 = \frac{\tau_1(2+\mu\theta) - 2p_{ho}^1}{2+\mu\theta}, \quad p_{nc}^2 = \frac{\tau_2(1+\mu\theta) - p_{ho}^2}{1+\mu\theta}$$

IV. SIMULATION MODEL AND PERFORMANCE CRITERIA

A. 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 handoffs at the cluster boundary are handled by wrapping them around thereby assuming that arrival rates and handoff 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 ground-track V is set to 5,9 km/s.

B. 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 handoff 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 I shows the best reservation threshold T^* 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 ,

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

TABLE I
Best reservation threshold as a function 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.

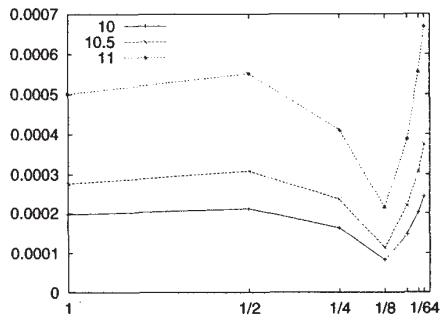


Fig. 4. Handoff Blocking Probability as a function of τ for different values of the input load

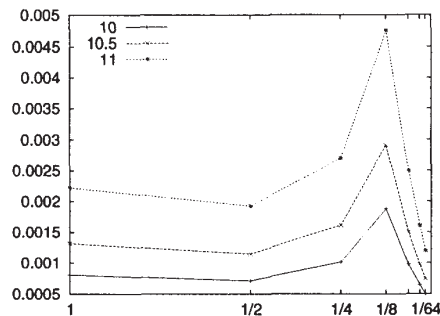


Fig. 5. New Call Blocking Probability as a function of τ for different values of the input load

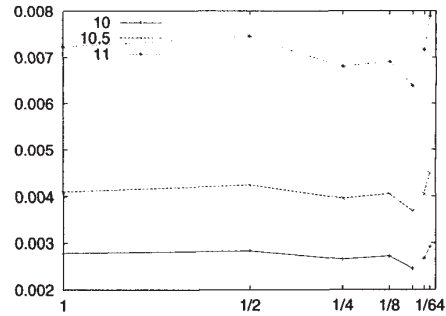


Fig. 6. Gos as a function of τ

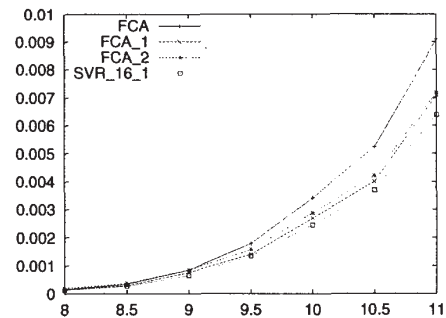


Fig. 7. Gos as a function of the input load - $SVR_{\frac{1}{\tau}-T}$, FCA, FCA1, FCA2 policies

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

SVR scheme can be very useful 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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