Channel Allocation with and without Handover Queuing in LEO Satellite Systems based on an “Earth-Fixed Cell” Coverage

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Abstract— This paper deals with the performance evaluation of different channel resource management techniques in LEO satellite systems based on an earth-fixed cell concept. Furthermore, in order to reduce the handover failure probability, we assumed that handover attempts can be queued. Both fixed and mobile users have been considered resulting in several classes of users. Each class requires a given Quality of Service (QoS) and thus a fixed part of the shared resource. Two channel allocation techniques are investigated: fixed channel allocation (FCA) and dynamic channel allocation (DCA). An analytical model is derived to analyze the performance of the FCA scheme supporting different kinds of users. A second analytical approch is proposed, in the FCA case, where a handover queuing strategy is taken into account. Implementation aspects for FCA and DCA strategies are discussed and compared in terms of blocking probabilities relative to each type of users.

Keywords — **LEO, earth-fixed cells, handover, FCA, DCA.**

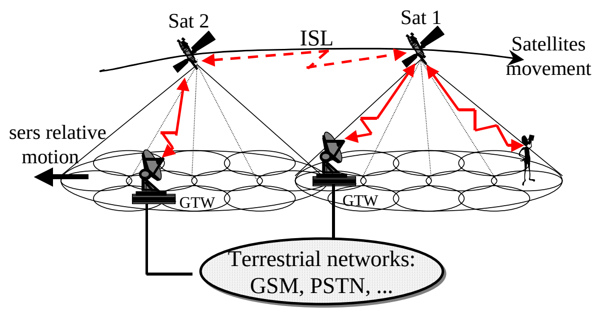

Fig. 1. Satellite network architecture

I. Introduction

The increasing demand for mobile personal communications has involved many research and development efforts towards a new generation of mobile systems. The future third generation of mobile systems is referred to as IMT 2000 (International Mobile Telecommunications for the year 2000). A member of this familly is provided by the Universal Mobile Telecommunication System (UMTS). The aim of this new mobile communication technology is to offer new worldwide personalized services. Mobile Satellite Systems (MSSs) constitute an important component of UMTS [1]. They will extend and complement the existing terrestrial cellular networks and provide global mobile telephony and data transmissions for both mobile and fixed users especially those located in rural, sparsely populated and remote areas.

Several satellite constellation systems have been proposed, including Geostationary (GEO), low-earth orbit (LEO) and medium-earth orbit (MEO) satellite systems. The term LEO is used to identify satellites with orbiting altitudes between 500 and 2000 km above the earth's surface. LEO systems offer small end-to-end delays which constitute an essential feature needed to support time-sensitive applications [2]. They also have the ability to provide large coverage areas and constitute an ideal solution for the support of multicast applications [2], [3]. Another important advantage of LEO systems is their frequency reusability. Due to its closeness from the earth's surface, a LEO satellite involves additional areas in which the same frequency can be used by another satellite. This allows a high degree of channel reusability and increases the overall system capacity [3]-[6].

A general network architecture is illustrated in figure 1. The satellite system is interconnected to the terrestrial networks via gateway stations (GTW). The space segment of the system is composed of a given number of satellites which can be connected between each other through inter-satellite links (ISL).

The footprint of each satellite can be divided into several cells, each one corresponding to a “spot-beam” of the satellite antenna. Depending on a coverage concept, two kinds of LEO systems are defined: *satellite-fixed cell* (SFC) and *earth-fixed cell* (EFC) systems.

In SFC systems, beams remain constant relative to the spacecraft, the corresponding cells on the ground move along with the satellite. Hence, it is the satellite motion which introduces the handover process and not the mobile users motion. Therefore, users will experience two kinds of handover: *beam handover* (from beam to beam) and *satellite handover* (from satellite to satellite). It is important to point out that, unlike terrestrial systems, all users either fixed or mobile experience the handover procedure in the LEO SFC satellite context.

In a system that employs earth-fixed cells, the earth surface is divided into predetermined cells that have fixed boundaries, just like in terrestrial cellular networks. Most of the under-developing non-GEO projects providing multimedia services have adopted the EFC concept. This paper mainly focuses on earth-fixed cell systems.

EFC systems are intended to provide several services for both fixed and mobile users. Our objectives in this paper is to study the performance of a LEO system which supports several classes of users, in terms of channel allocation. Moreover, we aim to study the joined effect of different channel allocation strategies and a queuing policy of handover attempts. We have considered fixed channel allocation (FCA) and dynamic channel allocation (DCA) strategies, and we have derived by simulation the performance of each technique. A mathematical model is proposed in the case of the FCA scheme. We have divided it into two parts. In the first part, the model considers various classes of users and derives the corresponding blocking probabilities. In the second part, the mathematical approach has been extended to support the handover queuing strategy. The proposed mathematical models constitute the main originality of the work since the major difficulty was to chose and combine the suited resolution techniques and to adapt them to our special context. Finally, a performance comparison of both FCA and DCA schemes, with and without handover queuing, has been investigated by simulations under non-uniform traffic conditions and considering different classes of users.

The paper is organized as follows: Section II presents the concept of the EFC coverage and introduces the handover procedure in such systems. Section III deals with some preliminary assumptions. A mathematical description of the model for the FCA technique with and without considering handover queuing is presented in Sections IV. Fixed and dynamic channel allocation schemes are described in Section V. Finally, section VI presents and discusses simulation results obtained for both schemes.

II. EFC Systems

Implementing the EFC coverage means that the satellite is able to perform two main functions: beam steering and cell switching.

A. Beam steering

As satellite beams are assigned to the earth-fixed cells during a given time period and since the satellite is moving relative to these cells, each beam antenna has to adapt its direction to maintain the illumination of the corresponding cell. Thus, during the considered time interval, the beam steering is achieved and the beam-to-cell allocation remains fixed (see figure 2(a)).

Due to physical limitations, the steering angle of the antenna is bounded. This limitation fixes the time interval during which the beam steering is achieved. When this interval duration has elapsed, a new beam-to-cell allocation is performed.

Two steering techniques can be carried out: mechanical and electronic steering [7]-[9]. When the satellite motion relative to the earth surface is quite slow, such as in MEO satellite systems, the mechanical steering is more suitable. The electronic technique is chosen when the satellite velocity with respect to earth cells is high, as in LEO systems.

B. Cell switching

When the beam steering time interval expires, the maximum steering angle is reached. This introduces the "cell switching" phase, which corresponds to a modification of the beam-to-cell allocation. The switching procedure is illustrated in figure 2(b). When the beam *Sat1-b1* covering cell $c1$ reaches its maximum steering angle, it frees cell $c1$ and takes over the entering cell $c2$. The other beams also move forward a row to take over the adjacent cell.

C. Handover in EFC systems

The great advantage of using earth-fixed cells is achieved when a mobile user experiments a beam or a satellite handover. With satellite-fixed cells, this handover means that a new channel has to be allocated to the mobile user within the new beam. The call can be interrupted and dropped if no channel is available in the next serving beam. Moreover, the allocation process involves time and processing requirements at both terminal and satellite sides. Many solutions have been proposed to handle the handover issue in SFC systems [10]-[15].

In EFC systems, the relatively small fixed cells provide a means to contour service areas to country boundaries. A database onboard each satellite defines the type of services allowed within each cell, and also ensures that interference to or from specific areas is avoided [16]. Communication channels (frequencies and time slots) are associated with each fixed cell, and are managed by the current serving satellite. As long as the user terminal remains within the cell, it keeps the same channel during the call duration, whatever is the serving beam or satellite. Channel reassignments will thus become the exception rather than the rule. Therefore, the EFC coverage offers significant advantages in terms of no handover failure probability for fixed users, and a low probability for mobile ones.

Consequently, the handover failure probability, in EFC systems, depends on the number of mobile users which leave their cell during their communication's lifetime. Thus, this probability is a function of both users mobility and earth-fixed cell size. In under-developing EFC systems, cells sizes are quite small (53.3 km for Teledesic system for example [8]). Furthermore, systems designers are studying, for the future generation of LEO satellite systems, a new generation of efficient satellites which use extremely narrow beam antennas able to cover very small areas on the earth's surface. With such small earth-fixed cells, the frequency reuse factor is maximized, leading to an extremely efficient use of the spectrum and thus a large number of simultaneously active users. In such a context, the handover probability increases since the considered cell size is reduced. For our investigations, we consider small size cells systems.

III. Initial considerations

In this paper, the system is assumed to be composed of a set of adjacent square cells supporting a non-uniform traffic. Moreover, we consider that the model supports different kinds of users. Fixed and mobile users are considered, and both of them can also be divided into different kinds according to a given criterion (here, the required bandwidth). The available bandwidth is divided into equal parts called sub-channels, and each user terminal, depending on its class, asks for a given number of sub-channel units.

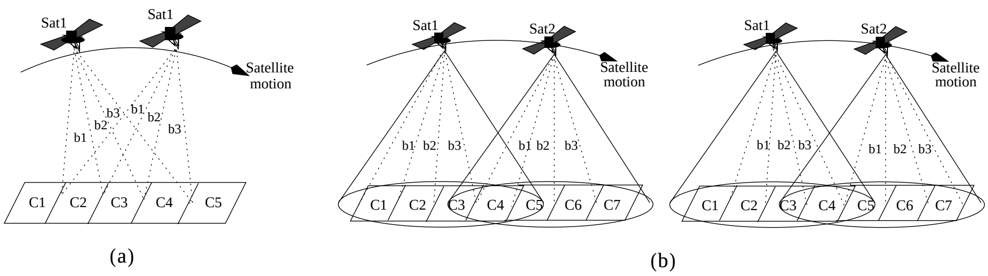

Fig. 2. Beam steering (a) and cell switching (b).

In this study, we are interested in two different QoS parameters: new call blocking and handover call dropping probabilities. Since the blocking of a call in progress is less tolerable than blocking of a new call request, it is important to reduce the handover call dropping even if it is at the expense of an increased new call blocking.

IV. Mathematical models

A. Basic assumptions

In this section, we propose two analytical approaches to assess the blocking probability for each class of users. The first one considers that the handover and new call traffics are treated in the same way, while the second model takes into account the handover queuing strategy. We assume that the system supports k customer types and contains M cells, each one has a finite capacity of C sub-channels.

The models require the following assumptions:

- New call arrivals for a type i user in cell j are assumed to be Poisson processes with a parameter $\lambda_{i,j,nc}$.

- A user with type i requires b_i units of sub-channel resources; the user is blocked and cleared if fewer that b_i units of the total sub-channel resource is available (Complete Sharing policy).

- The sub-channel holding time in a cell by a type i user is exponentially distributed with a parameter $\mu_{i,h}$.

- The communication's lifetime of a type i user is exponentially distributed with a parameter $\mu_{i,c}$.

- $T_{ijj'}$ denotes the probability **for a given mobile user with type** i to go from cell j to cell j', and $N(j)$ is the set of neighbor cells of cell j.

Let us denote by $P_{i,j,nc}$ the blocking probability of new call attempts of type i users in cell j, and $P_{i,j,ho}$ the handover failure probability.

The following mathematical models can be applied only for EFC systems. In SFC systems, the users mobility model is different since all users can be considered as moving in the same direction and with the same velocity (when considering a plan where satellites are fixed). This introduces a kind of prediction in their movement. Some works have addressed this kind of handover. For more details, the reader can refer to [10], [11].

B. Mathematical model without handover queuing

B.1 Traffic contributions in a given cell

Figure 3 shows the various traffic components that ask for a sub-channel in a given cell j. We can remark that the cell receives new call attempts of different type i users and also the handover traffic coming from the adjacent cells. Let $\lambda_{i,j,ho}$ denotes the handover arrival rate in cell j for users with type i.

The mean output rate can be expressed as follows:

$$\Lambda_{i,j} = \Lambda_{i,j,out} + \Lambda_{i,j,ho} \quad (1)$$

$$\Lambda_{i,j} = \lambda_{i,j,nc}(1 - P_{i,j,nc}) + \lambda_{i,j,ho}(1 - P_{i,j,ho}). \quad (2)$$

The output handover traffic rate of cell j is given by:

$$\Lambda_{i,j,ho} = \frac{\mu_{i,h}}{\mu_{i,h} + \mu_{i,c}}(\lambda_{i,j,nc}(1 - P_{i,j,nc}) + \lambda_{i,j,ho}(1 - P_{i,j,ho})). \quad (3)$$

However, approximating the handover call arrival process by a Poisson process and seeing that handover and new call traffics are treated within the server (cell) in the same manner (no priority of one traffic over the other), we can group together, in this paragraph, the two probabilities $P_{i,j,nc}$ and $P_{i,j,ho}$ into a global blocking probability $P_{i,j}$.

Then the equation (3) becomes:

$$\Lambda_{i,j,ho} = \frac{\mu_{i,h}}{\mu_{i,h} + \mu_{i,c}}(\lambda_{i,j,nc} + \lambda_{i,j,ho})(1 - P_{i,j}). \quad (4)$$

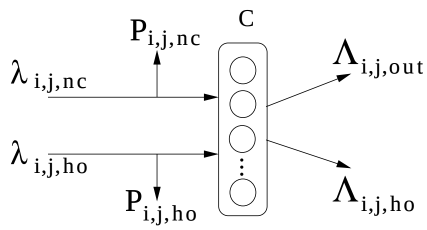

Fig. 3. Cell model without handover queuing.

We face here a fixed-point problem since the input handover traffic depends on the output one:

$$\lambda_{i,j,ho} = \sum_{j' \in N(j)} T_{ij'j}\Lambda_{i,j',ho}. \quad (5)$$

The problem can be solved using an iterative method through the following linear system [17]:

$$\left\{ \begin{array}{l} \lambda^0_{i,j,ho} = \sum_{j' \in N(j)} \Lambda^0_{i,j',ho} T_{ij'j} \\ \Lambda^0_{i,j,ho} = \frac{\mu_{i,h}}{\mu_{i,h}+\mu_{i,c}} (\lambda_{i,j,nc} + \lambda^0_{i,j,ho}) \end{array} \right. \tag{6}$$

In each step n of the iterative method, the value of $\lambda^n_{i,j,ho}$ is computed and compared to the one found in the previous step. The procedure is repeated until a convergence criterion ϵ is reached:

$$\parallel \lambda^{n+1}_{i,j,ho} - \lambda^n_{i,j,ho} \parallel < \epsilon.$$

The first value $\lambda^0_{i,j,ho}$ is computed disregarding the blocking probabilities as shown in the system (6).

Once the handover arrival rate $\lambda^0_{i,j,ho}$ is derived, the blocking probability of each user class can be determined.

All C sub-channels of a given cell j are shared by new calls and handover traffics. Therefore, the analytical structure of this problem is essentially the same as in a system where several types of customers share a finite group of servers. The sharing policy considered in this paper is known as the Complete Sharing (CS) [18].

Let us consider the state description n:

$$n = (n_1, n_2, ..., n_k)$$

where n_i = number of type i customers using the cell sub-channels. The remaining notations needed are as follows:

$$n_i^+ = (n_1, ..., n_{i-1}, n_i + 1, n_{i+1}, ..., n_k)$$
$$n_i^- = (n_1, ..., n_{i-1}, n_i - 1, n_{i+1}, ..., n_k).$$

The set of allowable states is referred to as Ω (determined by the CS policy). It has been shown that the state probabilities can be expressed in a product form [18]:

$$P_j(n) = \prod_{i=1}^{k} \frac{\rho_{i,j}^{n_i}}{n_i!} . G^{-1}(\Omega) \qquad \forall n \in \Omega \tag{7}$$

where the normalization constant $G(\Omega)$ is defined by the formula:

$$G(\Omega) = G(C, k) = \sum_{n \in \Omega} \left(\prod_{i=1}^{k} \frac{\rho_{i,j}^{n_i}}{n_i!} \right) \tag{8}$$

and $\rho_{i,j} = \lambda_{i,j}/\mu_{i,c}$ given that $\lambda_{i,j} = \lambda_{i,j,nc} + \lambda_{i,j,ho}$.

The probability $P_{i,j}$ that a type i arrival is blocked in cell j is given by:

$$P_{i,j} = \sum_{n \in B_i^+} P_j(n) \tag{9}$$

where $B_i^+ = \{ n \in \Omega : n_i^+ \notin \Omega \}$. B_i^+ denotes the set of blocking states for type i users.

The probability $P_{i,j}$ can be written as:

$$P_{i,j} = \sum_{n \in B_i^+} P_j(n) = 1 - \sum_{n \in \Omega - B_i^+} P_j(n) \tag{10}$$

$$P_{i,j} = 1 - G^{-1}(\Omega) \sum_{n \in \Omega - B_i^+} \prod_{i=1}^{k} \frac{\rho_{i,j}^{n_i}}{n_i!} = 1 - \frac{G(\Omega - B_i^+)}{G(\Omega)} \tag{11}$$

thus,

$$P_{i,j} = 1 - \frac{G(C - b_i, k)}{G(C, k)}. \tag{12}$$

Computing the normalization constant $G(\Omega)$ involves significant computation problems especially for large size systems. Therefore, to bypass this problem, a Buzen-type recursion expression was found by Kaufman [18], considering the distribution of the number of allocated resource units. Let $q(m)$ be this quantity:

$$q(m) = \sum_{\{n : n \bullet b = m\}} \prod_{i=1}^{k} \frac{\rho_{i,j}^{n_i}}{n_i!} \cdot G^{-1}(C, k) \tag{13}$$

where $m = n \bullet b$ = total number of occupied resource units. The recursion expression is as follows:

$$q(m) = \left\{ \begin{array}{ll} \frac{1}{m} \sum_{i=1}^{k} \rho_{i,j} b_i q(m - b_i) & m > 0 \\ 0 & m < 0 \\ G^{-1}(C, k) & m = 0 \end{array} \right. \tag{14}$$

At this step, the probability $P_{i,j}$ is determined using $\lambda^0_{i,j,ho}$. With these two values, $\Lambda^1_{i,j,ho}$ can be computed using system (6). The iterative procedure is repeated until the convergence criterion ϵ is reached.

C. Mathematical model with handover queuing

C.1 Queuing handover attempts

From a user point of view, the most important performance criterion is the probability of forced call terminations. Therefore, to reduce this probability, a queuing procedure has been carried out. Queuing of handover requests requires a given degree of overlap between the footprints of adjacent beams. The time spent by a mobile user to cross the overlap area defines the maximum waiting time for handover demands. This time depends on several parameters such as the user mobility and the overlap area extension crossed by the mobile user. Let us assume that the entire bandwidth resource is divided into a fixed number of sub-channels (units), and each user with type i requires b_i units. We denote by $A(x)$ the number of available sub-channels for cell x at the call arrival instant in x. $A(x)$ is defined by the chosen channel allocation strategy (here FCA and DCA). In this study, the handover waiting time is limited and assumed to be exponentially distributed with a parameter $\mu_{i,w}$.

The queuing policy can be resumed as follows:

- Let us assume that a handover request of a mobile user with type i arrives in cell x, and requires b_i units of the shared bandwidth. If it results that $A(x) \geq b_i$, the user is accepted in cell x and the requested sub-channel(s) is(are) allocated to him. Otherwise, the handover attempt is queued in the handover queue (using a FIFO policy) waiting for an available sub-channel in cell x. If a sub-channel is released before the handover waiting time has expired, the call is served. Otherwise, the call is lost.

• Let us assume that a call termination of a user with type i occurs in cell x. This termination is due either to a handover or to the end of the call. In both cases, b_i units of the sub-channel resource are released and can thus be allocated to a queued request.

C.2 Traffic contributions in a given cell

Figure 4 shows the different traffic components that require a sub-channel in a given cell j. Here again, we note that a given cell receives sub-channel requests due to new call attempts of different type i users and also the handover traffic coming from the adjacent cells. This traffic can be queued if no resources are available. Let $\lambda_{i,j,ho}$ denotes the handover arrival rate in cell j for type i users. Here, $P_{i,j,h}$ the handover failure probability corresponds to the fact that resources cannot be allocated to the user during his handover waiting period.

When the queuing strategy is considered, the above analytical model is still valid except for the blocking probabilities computation. The same iterative method is applied using the linear system (6), and at each step n, the value of $\lambda^n_{i,j,ho}$ is derived. However, it is worth stressing that the blocking probabilities $P_{i,j,nc}$ and $P_{i,j,ho}$ can not be grouped into a global one, as in the above model, since the handover traffic is prioritized over the new call traffic (handover attempts are queued).

At this point, we have to compute the blocking probabilities of each user class. The analytical structure of this problem is essentially the same as in a system where several types of customers share a finite group of servers, some of the customers may be queued but have a limited waiting time. In order to determine those parameters, we use a classical approximation, handover traffics are approximated by Poisson processes.

In this study, two types of users are considered: M denotes mobile users and F corresponds to fixed users with higher rates supporting a wide range of fixed broadband services.

The analytical model is derived in the proposed study case but may be extended in a more general traffic case. Let $N_{j,f}(t)$ and $N_{j,m}(t)$ denote respectively the number of fixed and mobile users in cell j at time t. Mobile users may either occupy sub-channels or wait for resources. Under the considered traffic conditions and the proposed approximations, the stochastic process $\{N_j(t) = (N_{j,f}(t), N_{j,m}(t)), t \in I\!R\}$ is a Markov process.

The set of allowable states, referred to as Δ, can be described as follows. Let $K_f = \lfloor \frac{C}{b_f} \rfloor$ denote the maximum number of fixed users that can be accepted. Thus,

$$\Delta = \{n = (n_f, n_m)/0 \le n_f \le K_f, n_m \in I\!N\}.$$

An approximate aggregation method based on Courtois decomposition method [19] is used to solve this Markov chain and derive the performance criteria.

In order to simplify the notations, the dependence on the cell j has been omitted. Index f and m refer respectively to fixed and mobile users. The structure of the graph corresponding to the Markov process $N(t)$ is too complex to derive an exact solution. Consequently, we propose an approximate solution based on the following remarks.

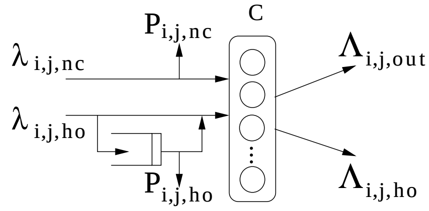

Fig. 4. Cell model considering the handover queuing.

• In the case when, $1 \le n_f \le K_f$ and $n_m > 0$, state $n = (n_f, n_m)$ is connected to states (n_f+1, n_m), (n_f-1, n_m) (n_f, n_m+1), (n_f, n_m-1).

• In the case when at least one handover is waiting, only the last three ones are reachable.

• $\mu_m = \mu_{m,c} + \mu_{m,h} \ll \mu_{m,w}$ and $\mu_{f,c} \ll \mu_{m,w}$.

We consequently suggest the following decomposition. Let Γ denote the set of states for which the handover queue is empty:

$$\Gamma = \{n = (n_f, n_m)/n_f b_f + n_m b_m \le C\}. \qquad (15)$$

Let Ω_k denote the set of states for which there are k fixed users in the considered cell and for which the handover queue is not empty.

$$\Delta = \Gamma \cup \Omega_1 \cup \ldots \cup \Omega_{K_f}.$$

The method consists on decomposing the original infinitesimal generator Q into blocks. Each block corresponds to one of the previous set of states. The aggregation technique is detailed in Annex A. It leads to an approximate determination of the steady state probabilities π_n of the system.

Performance criteria determination

We are supposed to compute the new call blocking and the handover failure probabilities. The probability for a new call to be accepted is the probability that, when a new call arrives, the available bandwidth is greater than the required bandwidth. Since, new call arrivals are assumed to be Poisson, PASTA property leads to:

$$\begin{cases} P_{f,nc} = 1 - \displaystyle\sum_{k=0}^{K_f} \sum_{j=0}^{M_k-1} \pi_{k,j} \\ P_{m,nc} = 1 - \displaystyle\sum_{j=0}^{K_m} \sum_{k=0}^{F_j-1} \pi_{k,j} \end{cases} \qquad (16)$$

where F_j and K_m are defined in the same way as M_k and K_f,

$$K_m = \lfloor \frac{C}{b_m} \rfloor, \qquad F_j = \lfloor \frac{C - j.b_f}{b_m} \rfloor.$$

The handover failure probability depends on the handover

flow accepted in the different states: when handover calls are accepted, the accepted flow is $\lambda_{m,ho}$. When handover traffic is queued, this rate will depend on the departure rates of calls. When a mobile user will leave a cell or finish his call, the sub-channels will be allocated to the first handover which is queued. When a fixed user will finish his call, several handover calls may be dequeued.
We obtain the accepted handover rate $\lambda_{m,a}$:

$$\begin{aligned}\lambda_{m,a} = \quad & \lambda_{m,ho} \sum_{k=0}^{K_f} \sum_{j=0}^{M_k-1} \pi_{k,j} \\ & + \sum_{k=0}^{K_f} \sum_{j=M_k}^{+\infty} \pi_{k,j} (M_k \mu_m + k \mu_f a_{k,j})\end{aligned}$$

where

$$a_{k,j} = Min\{j - M_k, \lfloor \frac{b_f + (C - b_f k - b_m M_k)}{b_m} \rfloor\}.$$

We finally obtain the handover failure probability:

$$P_{m,ho} = 1 - \frac{\lambda_{m,a}}{\lambda_{m,ho}}. \tag{17}$$

At this step, the $P_{i,j,nc}$ and $P_{i,j,ho}$ values are determined using $\lambda^0_{i,j,ho}$. With these two values, $\Lambda^1_{i,j,ho}$ can be computed using system (6). Once again, the iterative procedure is repeated until the convergence criterion ϵ is reached.

V. Channel allocation techniques

In the earth-fixed cell coverage, the earth surface is mapped into a fixed grid of "super-cells" (or clusters, as known in terrestrial cellular systems), each one is again divided into a given number of cells. Bandwidth resources (sub-channels) are associated to each cell or super-cell, and managed by the serving satellite. Different manners to allocate the system sub-channels to the cells exist. In the following, we present the two channel allocation schemes we used for our investigations.

Two different cells may reuse the same sub-channel resource only if they are at a suitable distance, called reuse distance D, which allows tolerable levels for co-channel interference. We will describe below two channel allocation techniques we used for our simulations: FCA and DCA schemes [20].

A. Fixed channel allocation (FCA)

With fixed channel allocation, the full set of A available sub-channels of the system is divided into S equal groups each composed of A/S sub-channels. Regular groups of S cells (clusters) are formed such that the frequency reuse distance is maximized. Decreasing S (the cluster size) increases the frequency reuse. However, S must be large enough to provide sufficient frequency reuse distance and guarantee the required carrier to interference ratio (CIR).

A set of A/S sub-channels is permanently assigned to each cell. A new call can be served only if a free sub-channel is available in the set of the cell. If all sub-channels are used, the new call will be blocked and lost even if other sub-channels are available within the frequency reuse area (cluster).

For high network loads, fixed channel allocation is efficient if the traffic is equally distributed among the cells. For a non-uniform traffic, a complex planning is required to allocate more sub-channels in the cells where a higher traffic is expected. Therefore, for varying traffic loads and non-uniform traffic, more flexible allocation strategies are necessary [21], [22].

B. Dynamic channel allocation (DCA)

With dynamic channel allocation, all sub-channels are kept in a common pool. Any sub-channel can be temporarily allocated to any cell, provided that the constraint on the reuse distance is fulfilled (a given signal quality can be maintained). All DCA schemes evaluate the cost of using each available sub-channel and choose the one which introduces the minimum cost.

In satellite systems, a dynamic channel allocation means that all sub-channels of the satellite are variably shared by all beams. The satellite can be a centralized controller which holds the pool and assigns the minimum cost sub-channel to an initiated call.

Several DCA schemes were proposed. For our implementation we have chosen the algorithm described in [23].

VI. Simulation results

In this section, the performance of channel allocation techniques FCA and DCA have been derived by simulations. As achieved for the mathematical model, the obtained simulation results are divided in two parts. The handover queuing approach is considered in the second part.

We have considered that the simulated cellular network is a grid of 36 square shaped cells folded onto itself with six cells per side. Each cell corresponds to a beam of the satellite. In fact, in the analytical models, handoff traffics are approximated by Poisson processes and their parameter is derived from the study of the cell itself. This allows to study only one cell at a time. Consequently, in the simulation model, a larger number of cells has to be considered in order to validate these approximations. In a general way, the used parameter values are:

- two tiers of interfering cells (for FCA);
- the average call duration is 3 minutes for mobile users and 4 minutes for fixed ones;
- the system has 180 sub-channels, thus 20 sub-channels/cell are available with FCA;

A. No handover queuing

In this scenario, three kinds of users are considered: M denotes mobile users and F_1 corresponds to fixed users with a relatively low channel rate. The third type F_2 corresponds to higher channel rates supporting a wide range of fixed broadband services. The proportions of user groups are assumed to be 20% for users with a type M (requiring one sub-channel), 50% for type F_1 (requiring one sub-channel) and 30% for type F_2 (requiring two sub-channels).

As uniform traffic conditions are considered , in the following, index j corresponding to cell number j is omitted.

In all this section, index nc relative to new calls and ho for handover traffic is added. In fact, in the analytical model, the blocking probabilities are equal for a given traffic class (Poisson approximations). This assumption has to be validated by simulations.

Figure 5 plots the handover blocking probability P_{ho} for the FCA scheme. The figure indicates that the analytical analysis is consistent with the simulation study.

Figure 6 shows different blocking probabilities as a function of the traffic load for the FCA scheme. A global call blocking probability P_{nc} and a class call blocking probability ($P_{nc,M}$, P_{nc,F_1}, and P_{nc,F_2}) relative to each type of users are represented. Moreover, the handover dropping probability P_{ho} resulting from the mobile traffic has also been derived.

As stated in the analytical model (section IV-B), we can note that the behavior of P_{ho} is basically the same as $P_{nc,M}$ since handovers are not queued and have the same service priority as new call arrivals. Furthermore, as users of type F_1 require the same number of sub-channels as type M users, blocking probabilities P_{nc,F_1} and M are quite equal (from a theoretical point of view, they are equal). However, P_{nc,F_2} shows a higher blocking probability since the users of this class require more sub-channels than the other kinds of users. As P_{nc} is the mean blocking probability of new calls (including traffic $F2$ which require more resources), P_{nc} is greater than P_{ho} which only corresponds to the blocking probability of mobile handovers which need less bandwidth.

Performance of FCA and DCA schemes are shown in figure 7 and figure 8 in terms of P_{nc}, P_{ho} and all call blocking probabilities of different classes. We can see, in both figures, that the DCA scheme outperforms FCA for medium and low traffic loads, but in the presence of congestion there is a trend inversion. We expect that the performance of DCA can be enhanced by implementing a rearrangement technique at call termination times.

B. Handover queuing

In order to validate the proposed mathematical model supporting the handover queuing approach, a second scenario is investigated. To be consistent with the this model, two kinds of users are considered, mobile and fixed users noted respectively M and F. The proportions of users are fixed to: 40% of type M (requiring 1 sub-channel) and 60% of type F (requiring 2 sub-channels). Moreover, we assumed an infinite queue capacity for handover requests.

Figure 9 compares analytical and simulation results in terms of new call blocking probability of fixed and mobile users (respectively $P_{nc,F}$ and $P_{nc,M}$) and handover blocking probability $P_{ho,M}$. We can note that there is a good agreement between analytical predictions and simulation results. However, concerning $P_{ho,M}$, there is a slight difference which is exclusively due to the pessimist approximation of handover arrivals to a Poisson traffic.

Figure 10 shows the different blocking probabilities as a function of the traffic load for FCA scheme. It plots the obtained results considering both cases with and without queuing (we used the suffix Q for the probabilities obtained with the queuing strategy). The average queuing time has been fixed to 2 seconds. One can easily note that the queuing strategy allows a significant reduction of $P_{ho,M}$ without really affecting the values of $P_{nc,F}$ and $P_{nc,M}$. Furthermore, we can see that the behavior of $P_{nc,F}$ and $P_{nc,M}$ are different; $P_{nc,F}$ shows a higher blocking probability since fixed users require more sub-channel units than mobile users.

A performance comparison between FCA and DCA sup-

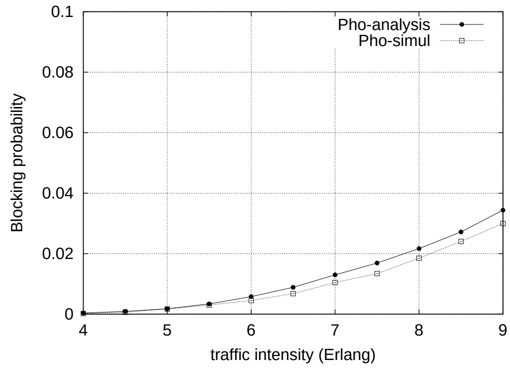

Fig. 5. No handover queuing: Performance of FCA - simulation and analytical results

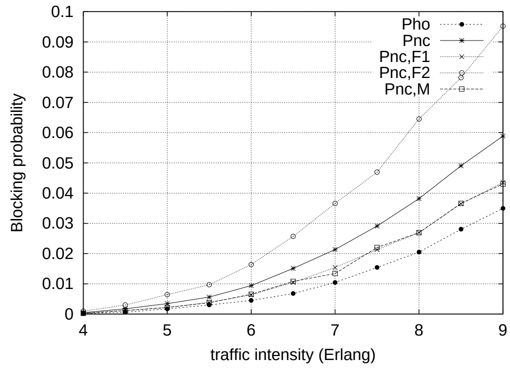

Fig. 6. No handover queuing: Blocking probabilities of each type of users for FCA

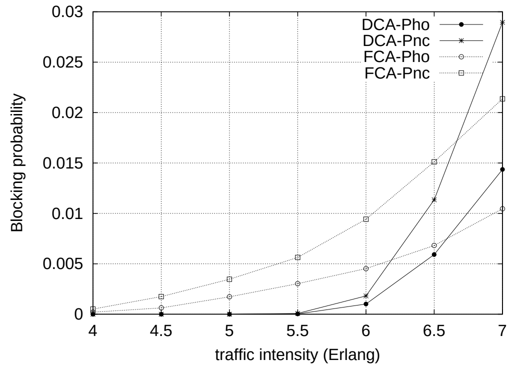

Fig. 7. No handover queuing: FCA versus DCA, P_{nc} and P_{ho} performance

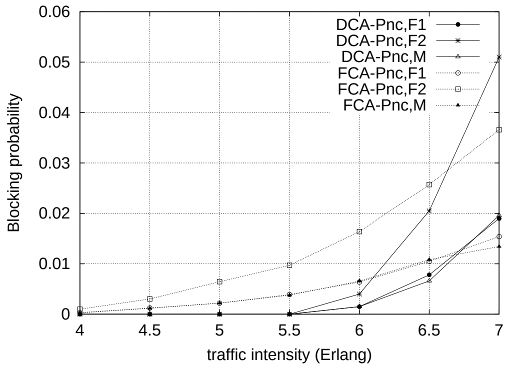

Fig. 8. No handover queuing: FCA versus DCA, call blocking probabilities of each type of users

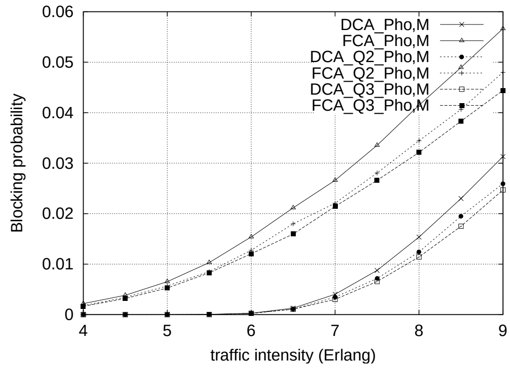

Fig. 11. FCA versus DCA: with and without handover queuing

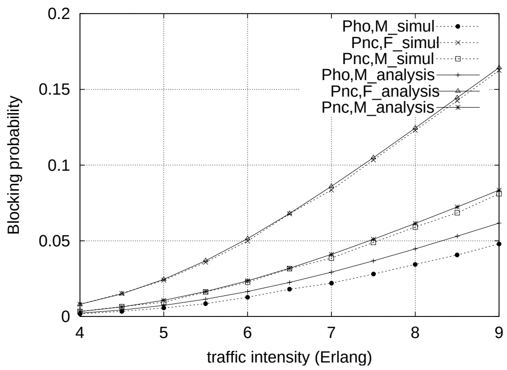

Fig. 9. Handover queuing: Simulation and analytical results (FCA)

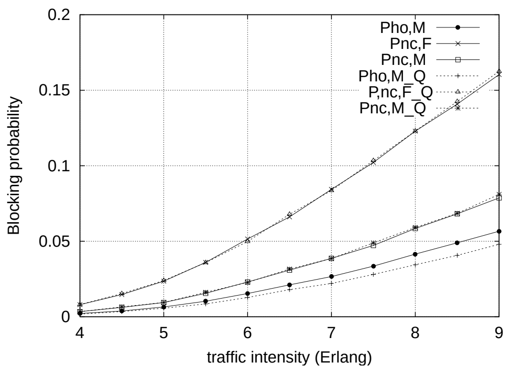

Fig. 10. FCA, with and without queuing

porting the handover queuing is presented in Figure 11. The average waiting time parameter has been fixed to 2 and 3 seconds (we used the notations $Q2$ and $Q3$ respectively). The results show that DCA outperforms FCA in the traffic range under examination.

VII. Conclusion

In this paper, a performance evaluation of two channel assignment techniques with and without handover queuing has been addressed. The context of the study was a LEO satellite constellation system based on an earth-fixed cell concept. Fixed and dynamic channel allocation schemes have been evaluated considering the case where handover requests are queued using a FIFO strategy. Furthermore, it has been assumed that the system supports different categories of fixed and mobile users. We proposed two mathematical models for the FCA strategy. In both models users diversity has been taken into account. Furthermore, the second model considers in addition a handover queuing strategy. Performance evaluations and comparisons have been carried out in terms of blocking probabilities of the different classes of users. In particular, we have proved by simulations that the DCA technique outperforms the FCA scheme under non uniform traffic conditions. Finally, we have shown that the queuing strategy enhances the performance of both the classical FCA and DCA schemes.

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Annex A - Aggregation Method

The aggregation technique leads to the following two steps.

Decomposition Phase

In this first step, we solve the unnormalized systems:

$$\pi_\delta Q^*_\delta = 0,$$

where π_δ denotes the vector of steady state probabilities of the different states of aggregate δ and Q^*_δ is the approximate infinitesimal generator of aggregate δ defined as follows:

$$\begin{cases} q^*_{ij} = q_{ij}, (i,j) \in \delta^2, i \neq j \\ q^*_{ii} = -\sum_{j\in\delta, i\neq j} q_{ij} \end{cases} \tag{18}$$

The solution of those systems leads to the determination of the steady state probabilities of the different states as a function of a constant which may be the steady state probability of being in aggregate δ. It can easily be shown that aggregates Ω_k subchains are of birth-death process type. The solution of the previous systems leads to:

$$\pi_{k,M_k+j} = \prod_{r=2}^{j} \frac{\lambda_{m,ho}}{M_k\mu_m + r\mu_{m,w}} \pi_{k,M_k+1},$$

where $\pi_{k,l}$ is the steady state probability of state (k,l) $M_k = \lfloor \frac{C-k.b_f}{b_m} \rfloor$.
Let $\Pi(\Omega_k)$ denote the steady state probability of being in one of the states of aggregates Ω_k, it can be shown that:

$$\begin{aligned} \Pi(\Omega_k) &= \sum_{j=1}^{+\infty} \pi_{k,M_k+j} \\ &= \pi_{k,M_k+1}\{1 + \sum_{j=2}^{+\infty}\prod_{r=2}^{j} \frac{\lambda_{m,ho}}{M_k\mu_m + r\mu_{m,w}}\} \end{aligned}$$

which may be approximated if $M_k\mu_m \ll \mu_{m,w}$ by:

$$\Pi(\Omega_k) \simeq \frac{\pi_{k,M_k+1}}{\rho_{m,h}}(e^{\rho_{m,h}} - 1), \quad \text{with } \rho_{m,h} = \frac{\lambda_{m,ho}}{\mu_{m,w}}.$$

For the subchain corresponding to aggregate Γ, one can easily find that:

$$\pi_{k,j} = \pi_{0,0}\frac{\rho_f^k}{k!}\frac{\rho_m^j}{j!},$$

where $\rho_m = \frac{\lambda_{m,nc}+\lambda_{m,ho}}{\mu_m}$ and $\rho_f = \frac{\lambda_{f,nc}}{\mu_f}$.
Consequently, the steady state probability of being in aggregate Γ is:

$$\Pi(\Gamma) = \pi_{0,0}\sum_{k=0}^{K_f}\sum_{j=0}^{M_k}\frac{\rho_f^k}{k!}\frac{\rho_m^j}{j!}. \tag{19}$$

Aggregation Phase

In the second step, we shall find relations between the different aggregates.
Let us note:

$$\Theta_\Gamma = \frac{\Pi(\Gamma)}{\pi_{0,0}} \quad \text{and} \quad \Theta_{\Omega_k} = \frac{\Pi(\Omega_k)}{\pi_{k,M_k+1}}.$$

Using the Chapmann Kolmogorov equations, we can derive:

$$\begin{aligned} \lambda_{m,ho}\pi_{K_f,M_{K_f}} &= (M_{K_f}\mu_m + \mu_{m,h})\pi_{K_f,M_{K_f}+1} \\ &+ K_f\mu_f \sum_{j=M_{K_f}+1}^{+\infty} \pi_{K_f,M_{K_f}+j} \end{aligned}$$

which allows to express $\Pi(\Omega_{K_f})$ as a function of $\Pi(\Gamma)$:

$$\frac{\lambda_{m,ho}}{\Theta_\Gamma}\frac{\rho_f^{K_f}}{K_f!}\frac{\rho_m^{M_{K_f}}}{M_{K_f}!}\Pi(\Gamma) = \{\frac{M_{K_f}\mu_m}{\Theta_{\Omega_{K_f}}} + K_f\mu_f\}\Pi(\Omega_{K_f}).$$

Using an iterative method, we can find:

$$\begin{aligned} &\lambda_{m,ho}\pi_{(k,M_k)} + (k+1)\mu_f \sum_{j=M_k+1}^{+\infty} \pi_{k+1,j} \\ &= (M_k\mu_m + \mu_{m,h})\pi_{k,M_k+1} + k\mu_f \sum_{j=M_k+1}^{+\infty} \pi_{k,j} \end{aligned}$$

which leads to an expression of $\Pi(\Omega_k)$ as a function of $\Pi(\Gamma)$. Using the equation of normalization:

$$\Pi(\Gamma) + \sum_{k=0}^{K_f} \Pi(\Omega_k) = 1,$$

the steady state probabilities and the performance criteria can consequently be derived.