ATCR : An Adaptive Time-based Channel Reservation Mechanism for LEO Satellite Fixed Cell Systems

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Abstract— **In this paper, we propose an Adaptive Time-based Channel Reservation mechanism (ATCR) suitable for handover and call admission procedure control in future multi-services mobile satellite systems. These systems are characterized by a high rate of handover. While guaranteeing a null handover failure probability, by using a channel reservation strategy in the cells to be crossed by the user, ATCR optimizes the utilization of resources. The performance of our mechanism has been compared to other schemes. ATCR method has the advantage of a better channel utilization by sharing channels between users. An approximate analytical model has been developed, and its results have been validated through simulations.**

I. INTRODUCTION

Launching of satellites constellations, at low and medium earth orbits (LEO and MEO for short), constitutes one of the major strategic events. The satellites offer a total coverage, endowed of network flexibility, diffusion and multipoint services capabilities, as well as of rapid configuration and deployment.

The areas covered by satellites are such that it is possible for a mobile user not connected to a fixed network, to be connected by satellite links to benefit from services offered by the various terrestrial networks. Because of the non-geostationnarity of satellites, the mobility of satellites (and sometimes even that of users) must be taken into account in order to consider the exit of some users from the coverage areas. Thus, those users have to be dealt with by other satellites. This handover procedure must be carried out in a transparent way to the user and to the quality of service negotiated. This property is particularly valuable to ensure the connections in urban zones with strong demographic density. In general, data flow interruption, in course of transfer, is much more undesirable than new access refusal.

As in terrestrial cellular networks, a satellite spot is divided into cells to increase the total capacity of the satellites by a frequency re-use improvement. Thus, each cell corresponds to a frequency of satellite antenna.

In this paper, we are interested in systems with Satellite Fixed Cell (SFC) coverage where cells are constantly associated to a given beam. These are fixed antenna systems. Each cell scrolls on the surface of the ground at the satellite speed (5 to 8 Km/s). Handover occurs each time a terrestrial terminal changes from cell. Transfer is a continuous function of time, determined by the terrestrial terminals geographical distribution and the traffic generated by the terminal.

Various strategies were already proposed to manage handover in LEO SFC systems. The first one, *Guaranteed Handover* [1] (GH), ensures a null handover blocking probability. Then, *Time-Based Channel Reservation Algorithm* [2] (TCRA) has been proposed. It better manages channels reservation, while utilizing an allocation time concept. A new method, *TCRA with Overbooking* [3] (TCRA-O) improves the preceding method by proposing resources over-allocation, to make possible the acceptance of an additional number of new calls, beyond real resources, by hoping that an equivalent number of calls will leave the system and will thus release their resources. Both mechanisms were evaluated for inter-personal communication systems. In this paper, a new mechanism is presented: ATCR. It adapts the throughput allocated to the user according to its class and to the available bandwidth. The aim of ATCR is to take into account two points of view: the operator wants to use the resources and the user wants not to be interrupted.

II. TIME-BASED CHANNEL RESERVATION ALGORITHM

TCRA is based on the reservation principle introduced by GH algorithm. However, it has the advantage of better using the system resources, by exploiting more efficiently the satellite movement.

The TCRA algorithm can be described as follows:

At the call initialization time, T_{setup}, a channel reservation request is sent to the first two cells to be crossed by the user, source cell C_0, where the call is initiated, and the first transit cell C_1. These reservations are done only for the time period during which the user is in the corresponding cells. Exact localization of user in source cell can be given and be calculated by the system with a sufficient precision. The availability of an integrated *Global Positioning System* (GPS) within the network is assumed.

If the two requests are satisfied, the call is then accepted. At this level, if no blocking occurs with call initialization then no future handover failure will be regretted.

At every handover time: When a user carries out his handover from cell C_i to cell C_{i+1} at time T_{HOi}, TCRA can anticipate its next handover by holding a channel in the next cell C_{i+2}.

At the termination of a call: When a user finishes his communication in a given cell C_i , it releases current channel and sends a reservation cancellation request to cell C_{i+1} .

Both algorithms, GH and TCRA, have obvious common weakness: In a multi-service system, to which several types of traffics are offered, a fixed allocation strategy introduces a bandwidth loss. One may allow the same quality suggested by these algorithms while allowing a dynamic channel allocation, according to their availability. On another hand, allocation strategies performances strongly depend on each type of traffic intrinsic nature. In this paper, we propose an adaptive channel mechanism based on TCRA.

III. ADAPTIVE TIME-BASED CHANNEL RESERVATION MECHANISM

In handover studies several authors [1, 2, ...] propose to consider two types of traffics (associating them to users): Users with guaranteed handover (GH) and those with non-guaranteed services (non-GH). We can imagine that, this classification is possible, within personal communication networks framework. Merely, within multi-service network framework, operators would be attached to guarantee their network effectiveness to satisfy users requests. This need is much more important for satellite constellation networks, undergoing dynamicity risks, covering broad extended zones with variable users density.

At a zone of coverage level, federating a great number of mutually independent sessions, the traffic can be modeled by a locally stationary Poisson process. This assumption is used for descriptive models whose objective is to understand the impact of control mechanisms on flow performance, in opposition to predictive models whose objective is to obtain precise quantitative results (for dimensioning goals, for example).

Adaptive mechanisms [4-7] suppose that network terminals have a rather precise knowledge of the network state. However, this precision is not always guaranteed. It depends much on network topology. The advantage of topologies, for access constellations, is precisely to facilitate control and to yield account quickly and efficiently to terminals, directly joined with minimal jump.

Packet level does not allow a rather precise description of flows aggregate state for each class of traffic which will be considered. In this paper, we consider multi-service network architecture based on flows recognition, which means that control decisions such as routing and admission control, are made at flow level. The handover decision is also made at flow level (based on several local or global criteria, on terminal or network initiative).

We consider, here, two kinds of flows: *stream* and *elastic*. The *first* class corresponds to continuous flows with regular rate (voice, video…), whose temporal integrity is preserved. The *second* class corresponds to an elastic rate flow with a minimal threshold (file transfer…). Each customer class has particular flow characteristics, associated to a communication management strategy.

In multi-service networks integrating stream and elastic traffic, the network performance depends on the bandwidth sharing strategy, both between these two traffic classes and between flows of the same class.

A. Flow acceptance conditions

Each new customer must satisfy acceptance criteria to obtain one of the satellite's *C* channels. If this first condition is fulfilled, the second depends then on the selected strategy. For a connection working up TCRA, one will ensure that one can lock channel in source cell and in the following cell. Without a specific strategy, one lets the customer start his connection if a channel is temporarily free, with the risk that in the following cell, no channel is free for him, which would put an end to his connection.

The associated acceptance criteria make it possible to know instantaneously, according to the number and the nature of the customers in source cell, if connection is possible or not, before even using reservation methods (such as TCRA) which would give eventually a call blocking. Lastly, these criteria guarantee especially minimal balance between the two classes. Indeed, for stream flows, the rate is regular. Therefore, same bandwidth percentage ensured to each one of these customers is assumed. For elastic flows, the rate is variable, but must not go down below a threshold, assumed to be fixed at the same percentage delivered to the stream flows.

The rates may have continuous or discrete values varying from *one* to the number of available channels. The minimal percentage is taken as a rate equal to *one,* for discrete rates, because any communication will require at least one channel. Thereafter, for the customers with elastic flow, this number of channels can increase or decrease without going down below this threshold, but have to be the same number for all these customers. A customer having an elastic flow can thus potentially be allotted the entirety of the satellite channels if he is alone in the cell. In the same way, since it is at least necessary to allot a channel to each user, all class confused, it is sufficient to make sure that at least a channel can be released, so for any acceptance of a new customer, reception cell must check: $C - N_{stream} - N_{elastic} \geq 1$ where, C is the number of available channels per satellite, N_{stream} is the number of customers benefiting from a stream flow in the cell, $N_{elastic}$ is the number of customers benefiting from an elastic flow in the cell.

IV. THE SIMULATION MODEL

Let us first describe the simulation model of ATCR. It will explain how the reservation works and let us explore its use. Results of the two types of classes will be presented: one has a fixed rate and a TCRA reservation method, and the other has a variable rate, with or without reservation strategy: the first class rate will be always equal to the fixed rate, while for the other, this rate will be equal to or higher than this fixed rate, according to the channels availability. A first study [2] had compared simulations relating to these two types of classes, but without proposing adaptive mechanisms, such as what is proposed here. The idea is thus to increase the available satellite bandwidth by allocating non-common channels to the elastic flow customers (file transfers). Basically, TCRA allocates to the customers a fixed rate even if there remains available channels. With ATCR, transfer durations may decrease. Therefore, the users suffer less handover failures. This method optimizes at the same time customer and resource management, because whatever the number of customers is and insofar as the customer can require it, the maximum of channels are allocated, and the flow of the elastic customers can be brought back to the minimal flow to release sufficient channels and thus to accept a maximum of users within the cell.

A satellite constellation band of coverage, may be modeled by a queuing network (cf. **Fig. 1**). Each satellite and its terrestrial coverage are represented by a queue with a null waiting time and having an infinity of servers managing C resources: thus each customer knows immediately if he will be served or not. The users are supposed to have an uniform displacement and a speed of V_{sps} (opposite to the displacement of the satellites).

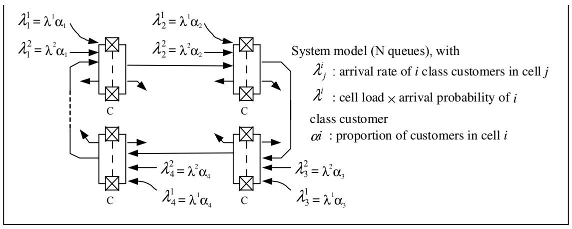

Fig. 1. Modeling of a queuing network with N queues

Let us mention, thereafter, the following assumptions and parameters: Each cell has C channels (in our model C=10). The rates are discretized (from *0* to C). The minimal rate to ensure is 1 (in general *1%* to *10%* of the total capacity is a viable assumption for cells of a capacity of *100* megs). The *C1* class follows a stream flow and benefits from the TCRA reservation algorithm. The *C2* class corresponds to elastic flows and may or may not benefit from a reservation. The duration of the communications follows an exponential distribution. The average duration is 180 seconds for the users of class *C1*, and 300 seconds of file transfer for the users of class *C2* class with a minimal rate. Satellite speed relatively to earth (V_{sps}) and cells size (R) are worth respectively 25000 km/h and *250* km. There are N satellites (N = 31). The proportion of the *C1* users will be *40%* and thus the *C2* users will be *60%*.

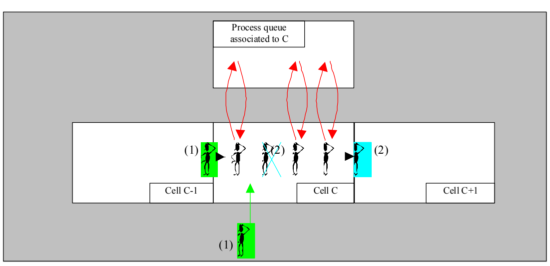

Fig. 2. Rates update events

Fig. 2 describes the simulation model such as implemented. Note here, the two types of events: Initially, events (1) correspond to a customer entry in the cell (new calls and handover from cell C_{-1}). Then, events (2) correspond to a customer exit of the cell (either handover failure or end of communication). When an event occurs, the elastic flows rate and the associated communication duration are modified (cf. Table 1).

There are four types of rates updates, according to the event and to the flow type. Indeed customer is included in the calculations before his effective entry, and not included once his exit is carried out. In the case of a stream flow customer entry, the number of locked channels is decreased accordingly, while in the case of an elastic flow customer entry, the new rate is equitably distributed by taking this new user into account.

TABLE 1. RATES GENERAL EXPRESSION

	Stream flow	Elastic flow
Entry	$\frac{C-NbStream-1}{NbElastic}$	$\frac{C-NbStream}{NbElastic+1}$
Exit	$\frac{C-NbStream}{NbElastic}$	$\frac{C-NbStream}{NbElastic}$

V. THE APPROXIMATE ANALYTICAL MODEL

In order to dimension the mechanism, we propose to study an approximate analytical model for ATCR. A TCRA model was designed [2]. It adopts usual traffic assumptions: we assume uniform traffic (all the cells are assumed to receive the same intensity of traffic). New calls are assumed to arrive according to a Poisson process with parameter λ_{nc}.

The state of the system is characterized by the quadruplet (i,j,k,l), representing the numbers of new calls and calls of handover, for the first, and respectively second, class of customers.

The sojourn time T_n, of a user in his source cell, is assumed to be uniformly distributed between *0* and D. In the following cells (of transit), this time T_h is equal to D (where $D = R/V_{sps}$).

The duration of stream flows is independent of the state of the system. For this class, the duration of the calls, is assumed to follow an exponential distribution of parameter $\mu_c'^{(1)}(i,j,k,l)$ (with $\mu_c'^{(1)}(i,j,k,l) = \mu_c^{(1)} = 1/180$). On the contrary, elastic flow duration depends on the state of the system. The duration of calls is assumed to follow an exponential law of parameter $\mu'^{(2)}_c(i,j,k,l)$.

$$\mu'^{(2)}_c(i,j,k,l) = \frac{C-(i+j)}{k+l}\mu_c^{(2)}\text{, with } \mu_c^{(2)} = 1/300 \quad (1)$$

Consequently, a new call will be taken in charge, in its source cell, during a time $T_{nc}^{(1)}$ (resp. $T_{nc}^{(2)}$), that takes the minimal value between $T_c^{(1)}$ (resp. $T_c^{(2)}$) and T_n. In the following cells, this sojourn time, noted $T_{ho}^{(1)}$ (resp $T_{ho}^{(2)}$), is the minimum between $T_c^{(1)}$ (resp. $T_c^{(2)}$) and T_h. All variables related to class 2 depend on the system state (i,j,k,l). To make reading easier, we omit the parameters (i,j,k,l). $1 \le m \le 2$

$$T_{nc}^{(m)} = \inf\left(T_c^{(m)}, T_n\right),\ T_{ho}^{(m)} = \inf\left(T_c^{(m)}, T_h\right) \quad (2)$$

Their expected values are $1 \le m \le 2$:

$$\begin{cases} E\left[T_{nc}^{(m)}\right] = \dfrac{1}{\mu_c'^{(m)}} - \dfrac{1-e^{-\mu_c'^{(m)}D}}{(\mu_c'^{(m)})^2 D} = \dfrac{1}{\mu_{nc}^{(m)}} \\ E\left[T_{ho}^{(m)}\right] = \dfrac{1-e^{-\mu_c'^{(m)}D}}{\mu_c'^{(m)}} = \dfrac{1}{\mu_{ho}^{(m)}} \end{cases} \quad (3)$$

Let $\tau_{nc}^{(m)}$ be the probability that a new call undergoes a handover and $\tau_{ho}^{(m)}$ the probability that a call of handover undergoes a new handover $(1 \le m \le 2)$. It follows

$$\tau_{nc}^{(m)} = \frac{1-e^{\mu_c'^{(m)}D}}{\mu_c'^{(m)}D} \text{ and } \tau_{ho}^{(m)} = e^{\mu_c'^{(m)}D} \quad (4)$$

The ATCR model is based on TCRA model [2]. It can be expressed as follows. Let $N_t(y)$ be the number of users at time t having a x-coordinate ranging between y and $(y+R)$. $N_t(y)$ extends on an area which covers part of two consecutive cells (see **Fig. 3**). If a user arrives, at a given time t, with a x-coordinate x, $0 \le x \le R$, its call will be accepted if and only if: $\forall y,\quad x-R \le y \le x,\quad N_t(y) < C$. (5)

These formula relate to cells C_0, C_{-1} and C_1.

An exact resolution of the model describing the entire system is very complicated to realize, because it is necessary to know the number of calls in progress, in each cell, as well as their relative positions. Consequently, we describe here an approximate model.

As usual, the handover traffic is assumed to follow a Poisson process of parameter $\lambda_{ho}^{(1)}$ (resp. $\lambda_{ho}^{(2)}$), parameters which will have to be calculated.

Let us remind that, in the model, the users are assumed to be uniformly distributed on all cells. In other words, we assume that at the times of arrival of calls, the users are uniformly distributed in cells. An isolation method is then proposed; it consists in considering independence between the various cells [1]. Under all these approximations, a cell is modeled by a multi-classes $M/G/C/C$ queue with reservation [8].

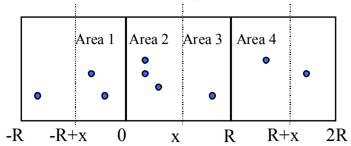

Fig. 3. Determination of the probability of blocking

Let P_K be the new calls blocking probability when K users are occupying resources (new calls or handover calls). The arrival rate of new accepted calls is consequently equal to $\lambda_{nc}(1-P_K)$. Since the blocking probability depends on the total number of occupied resources, the steady states probabilities are not of product form; they depend on the service time distribution. However, we use the steady state distribution of $M/M/C/C$ queue with reservation [8], with the respective service rates: $\mu_{nc}^{(1)}, \mu_{ho}^{(1)}, \mu_{nc}^{(2)}, \mu_{ho}^{(2)}$.

Let $\pi_{(i,j,k,l)}$ be the steady state probability of (i,j,k,l) and Π_K be the marginal probability to have K users occupying resources. Being given the uniform users distribution and the uniform users arrival in a cell, P_K can be derived as follows (one considers only the values of the steady states). Let Y be the initial shift of a new call, and ν current configuration at the time of its arrival:

$$P_k = \frac{1}{R}\int_{x=0}^{R}\sum_{l,m=0}^{C}\Pr[\mathit{New\ call\ blocked}\ /\ \nu]\,\Pi_l\Pi_m\,dx \qquad (6)$$

with, $\nu = \{Y = x,\ N_t(-R) = l,\ N_t(+R) = m,\ N_t(0) = k\}$

(In configuration ν, there are k users in cell C_0, l in cell C_{-1} and m in cell C_1). This blocking probability depends on the number of users located in area $[x-R, x+R]$ (see **Fig. 3**). When a user arrives, he will be accepted if he finds a configuration which satisfies condition (5). Let $\phi(C-k,i,j)$ be the number of configurations with i users in area 1, j in area 3 and k-1 in the area 2 (see **Fig. 3**) for which (7) holds:

$$\forall y,\quad x-R \le y \le 0,\quad N_t(y) < C \qquad (7)$$

Let us note that this number does not depend on the value of x, this formula can also be applied to areas 2, 3 and 4. So:

$$1-P_k = \sum_{l=0}^{C}\sum_{m=0}^{C}\sum_{l'=0}^{C}\Pi_l\Pi_m\sum_{m'=0}^{m}\sum_{k'=0}^{k}\Phi\int_{x=0}^{R}\frac{G}{R}dx \qquad (8)$$

where $\Phi = \dfrac{\phi(C-k+k',l',k')}{\phi(C-k+k'+1,l',k')}\,\dfrac{\phi(C-k',k-k',m')}{\phi(C-k'+1,k-k',m')}$

and $G = \binom{k}{k'}\binom{l}{l'}\binom{m}{m'}\left(1-\dfrac{x}{R}\right)^{I}\left(\dfrac{x}{R}\right)^{J}$

with $I = (l'+m-m'+k-k')$ and $J = (l-l'+m'+k')$

since, $\dfrac{1}{R}\int_{x=0}^{R}\left(1-\dfrac{x}{R}\right)^{n}\left(\dfrac{x}{R}\right)^{p}dx = \dfrac{n!\,p!}{(n+p+1)!}$

The equation (8) can be simplified as follows:

$$\int_{x=0}^{R}\frac{G}{R}dx = \binom{k}{k'}\binom{l}{l'}\binom{m}{m'}\frac{I!\,J!}{(I+J+1)!} \qquad (9)$$

$\phi(K,i,j)$ can be calculated in a recursive way:

$\phi(K,i,j) = i\phi(K+1,i-1,j) + j\phi(K-1,i,j-1)$

with, $0 < K < (i+j); i > 0; j > 0$

The limits are obtained as follows:

$\phi(0,i,j)=0, \phi(K,i,j)=i!, K>0, \phi(K,i,j)=j!, K>0, j<K$.

Since PASTA stands, the blocking probability of the new calls are:

$$P_{b,nc} = \sum_{k=0}^{C}\Pi_k p_k \qquad (10)$$

They depend on the steady state probabilities $\pi_{(i,j,k,l)}$ which are the numerical solutions of the Markov chain for which the transition rates are handover rates $\lambda_{ho}^{(m)}$ $(1 \le m \le 2)$.

$$\lambda_{ho}^{(1)} = \lambda_{nc}^{(1)}(1-P_{b,nc})\,\tau_{nc}^{(1)} + \lambda_{ho}^{(1)}\tau_{ho}^{(1)}$$

It leads to: $\lambda_{ho}^{(1)} = \dfrac{\lambda_{nc}^{(1)}(1-P_{b,nc})\,\tau_{nc}^{(1)}}{1-\tau_{ho}^{(1)}}$

resp. $\lambda_{ho}^{(2)} = \sum_{i,j,k,l}\left(k\mu_{nc}^{(2)}\tau_{nc}^{(2)} + l\mu_{ho}^{(2)}\tau_{ho}^{(2)}\right)\pi_{(i,j,k,l)}$ (11)

So it appears that steady state probabilities depend on the handover rates and handover rates depend on steady state probabilities. A recursive approach is then necessary to obtain the blocking probabilities and the handover rates. At the first iteration, the new calls blocking probability is neglected.

$$\lambda^{0}{}_{ho}^{(1)} = \frac{\lambda_{nc}^{(1)}\tau_{nc}^{(1)}}{1-\tau_{ho}^{(1)}} \qquad (12)$$

The iterative method is stopped when the difference between the values of calculated blocking probabilities at two successive stages falls below a fixed threshold ξ.

VI. RESULTS AND DISCUSSIONS

The simulated model makes it possible to generate new calls blocking probabilities, according to the system total load (**Fig. 4**). The new calls and handovers failure probability is zero for the two traffic classes. In the fixed mechanism, the channels are not entirely used. They are better used when the adaptive mechanism lets elastic flows release the system more quickly and then lets the system accept more flows. The new calls blocking probability is definitely better when resource allocation is adaptive and continuous (CAA).

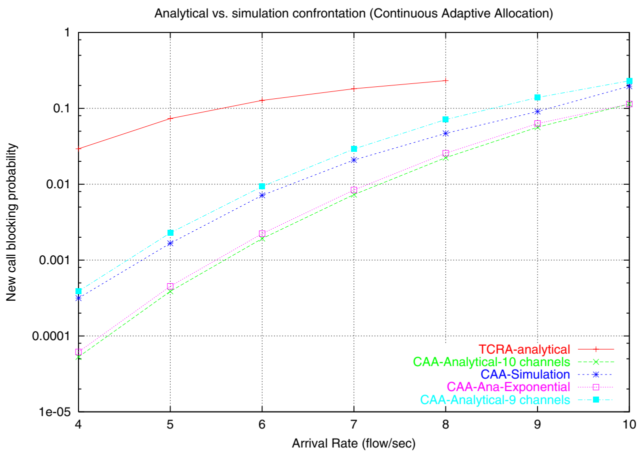

Fig. 4. New calls blocking probability for fixed and adaptive allocation

Blocking probability trends are verified by the analytical model. Increasing the intensity of the traffic (varying the value of λ_{nc}), the new calls blocking probability increase consequently for the two allocation mechanisms. For high values of load, the simulation and analytical results are closer. For lower values of the input load, the analytical model overestimates the blocking probabilities but leads to a right order of magnitude. Nevertheless, as well simulations as the analytical model show that this reduction is much more important for low load values. The ratio between new calls blocking probabilities for the fixed and the adaptive versions may reach about 100, for the considered values of load (the analytical model does not converge for blocking probabilities higher than 30%).

VII. CONCLUSION

This paper proposes a new adaptive time-based channel reservation scheme called ATCR for channel allocation in LEO satellite systems with SFC coverage. We studied interactions which exist between various handover mechanisms, one for each type of traffic. We examined in particular the advisability of using only ATCR for each traffic flow. The approximate analytical model is validated by simulation[1]. Simulation results as analytical model highlight the quality of service improvement, when using ATCR mechanism.

It would be interesting to extend those models taking into account routing and end-to-end QoS.

Those results could be generalized to other traffic models.

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