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Performance Analysis of a Dynamic Channel Reservation-Like Technique for Low Earth Orbit Mobile Satellite Systems

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***Abstract*—**In order to derive important parameters concerning mobile subscriber MS with ongoing calls in Low Earth Orbit Mobile Satellite Systems LEO MSSs, a positioning system had to be integrated into MSS in order to localize mobile subscribers MSs and track them during the connection. Such integration is regarded as a complex implementation. We propose in this paper a novel method based on advantages of mobility model of Low Earth Orbit Mobile Satellite System LEO MSS which allows the evaluation of instant of subsequent handover of a MS even if its location is unknown. This method is utilized to propose a Dynamic Channel Reservation DCR-*like* scheme based on the DCR scheme previously proposed in literature. Results presented show that DCR-*like* technique gives different QoS performance than DCR. Indeed, an improve in handover blocking probability and an increase in new call blocking probability are observed for the DCR-like technique.

***Keywords*—**cellular layout, DCR, LEO mobile satellite system, mobility model, positioning system

I. INTRODUCTION

LEO satellite systems present different advantages for universal mobile telecommunication systems such as relatively low transmit power and short transmission delay [1],[2].Because of the high speed movement of LEO satellites and their relatively small size spot-beams, inter beam handover requests occur rather frequently during a call s life time in the LEO MSSs. A call dropping due to an unsuccessful handover is less desirable, from the MS point of view, than the blocking of a new call attempt, this justifies quite many handover policies management techniques privileging handover service at the expense of new arrival [3]-[7].In [8],[9] a DCR technique was proposed; in this technique the channel reservations are based on the expected number of handover requests. For that the system must know the initial position of MSs with call in progress in order to evaluate the instants of subsequent handovers. So a positioning system had to be integrated to the LEO MSS. However, the integration of a positioning system to the LEO MSS seams to be a complex implementation.In [7] E Del Re *et al.* consider that the position can be estimated using a suitable positioning system, by measuring the propagation delay and Doppler frequency shift for the MS transmissions.The intersection on the Earth between the constant propagation delay circle and the cone identifies two points. A possible solution to solve this spatial ambiguity is to take another Doppler frequency shift measurement from a second satellite in visibility; this adds some constraints on the satellite constellation.In this paper we use the DCR scheme in different conditions; the system is unable to localize MSs with ongoing calls, no positioning system is integrated to the LEO MSS. In this case, instants of subsequent handover requests are derived, even if their exact locations are unknown, by taking benefit of both the deterministic behavior of the MS-satellite relative motion and the regular cellular layout of the network [10] [11].Indeed, a significant advantage of LEO MSSs systems is the deterministic behavior of relative motion MS-Satellite. Indeed, the ground track speed of satellites V_{trk} is much greater than the MS speed and the earth rotation, so that the relative motion MS-Satellite can be approximated only by the satellite motion. Thus the handover destination cell will always be the neighboring cell in the direction of the relative motion MS-Satellite, so that, it is possible in those systems to predict the movement of satellites, and thus to obtain at any instant, an actual scenario of the satellite constellation [3].Some of important parameters of a MS with a call in progress have specific values according to the location of the MS in the cell. One of those parameters is the maximum sojourn time, which can be estimated for each call in progress initializing its second handover request even if its location is unknown. Indeed, this period equal to the period separating two successive handover initializations. We demonstrate in this paper that it is possible to use the DCR scheme in such case. But since in this case the instant of subsequent handover is not available at the initialization of the call, some of changes are made, for this the method used here is called DCR- *like*.This paper is organized as follow: in the second section the system model considered in the study is presented, the DCR scheme is presented in section 3. In section 4, the DCR-like technique is introduced, and an analytic approach for Fixed Channel Reservation FCR-*like* is developed.

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Simulations and results for Fixed Channel Allocation with DCR and DCR-*like* strategies are presented and discussed in section 5.

II. System model

A. Review Stage

The mobility model considered in this paper is the iridium one which consists of 66 satellites equally distributed in six near polar circular orbits at about 780 km of altitude with ground-track speed V_{sat} =26 600 km/h. The coverage area has been assumed divided into cells and each cell is illuminated by an antenna spot-beam from a satellite. Cells are disposed according to a hexagonal regular layout and have a circular shape obtained by means of beam forming in order to compensate the footprint distortion due to the spherical nature of the Earth surface. Due to the high value of the satellite ground-track speed, the Earth rotation and the user speed are neglected [7]. This means that the relative motion has a fixed orientation with respect to the cellular layout irradiated on the Earth by satellites. Propagation conditions are neglected and only user mobility and network topology are considered.

The Fixed Channel Allocation FCA technique is considered; if a call does not find any free channel in the cell the call will be blocked immediately. We make the usual assumptions that the new call arrival process is independent Poisson process, and the call duration is exponentially distributed with an average value T_m. moreover, a uniform traffic condition is assumed; a new call can arrive at any point of the satellite cellular network with equal probability.

In the considered model, user orientation is as in Fig.1. The direction of the MS is assumed to be the inverse of the satellite direction and orthogonal to the side of cells R_h is the cell side and d(z) the maximum distance a call may cross in a cell.

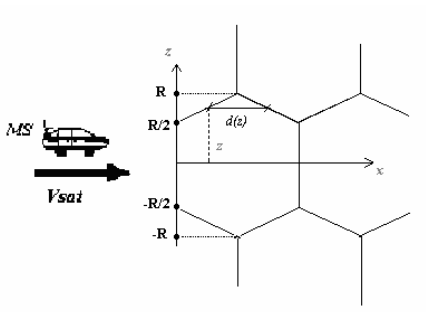

Fig. 1 Mobility model assumption

III. Dynamic Channel Reservation DCR technique [8] [9]

In the DCR scheme the system records the origin time of each ongoing call in its coverage area and track how long it has been going on. The longer the call has lasted, the less likely it will require a handover to the next cell. The system parameter Channel Reservation Number *CRN* is updated every time an event happens, i.e. a call arrivals, handovers or call terminations. *CRN* is given according to P_{hi} and w_i:

$$CNR = \sum_{i=1}^{C} w_i P_{hi} \tag{1}$$

C: the total number of channel in each cell.

P_{hi} is the handover probability for each call *i* in progress. It is equal to

$$P_{hi} = \exp\left(-\frac{t_{Msj}}{T_m} \right) \tag{2}$$

With t_{Msj} the sojourn time of the call in the current cell.

This probability needs to be recalculated when the call performs a handover.Each probability is weighted by the position factor w_i which is the MT s position x_i divided by the cell size *R*, i.e. $w_i = x_i / R$. This factor is used to determine the urgency of making such a corresponding channel reservation. The reservation of channels in a cell is done according to the *CRN* system parameter in the subsequent cell. *CRN* is rounded to the closest integer to be the number for channel reservation in the next cell.This process is graphically illustrated in figure 2. With the arrival of a new call, the traffic conditions in cell 1 have been changed so that the *CRN* of that cell will be recalculated and cell 2 will try its best to reserve the number of channels according to the *CRN* value. When a handover is performed from cell *B* to cell *C*, the traffic conditions of cell *B* and cell *C* has been changed so that we recalculate the *CRNs* of cell *B* and cell *C*. in the mean time, because there is a channel released in cell *B*, there is a possibility that it can be reserved for the possible handovers from cell *A* if the cell *A* has not got enough reserved channels. Therefore, cell *B*, *C* and *D* will adjust their reserved channels according to the *CRNs*. when a call terminates in cell *a*, the *CRN* of cell *a* will then be calculated and cell *a* and *b* will adjust their reserved channels.

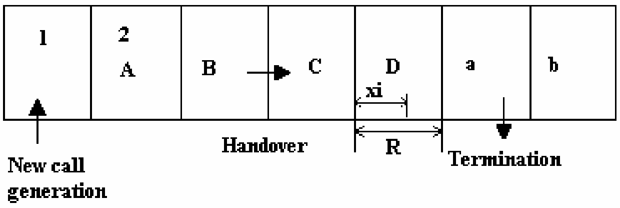

Fig. 2 Dynamic channel reservation

IV. Dynamic Channel Reservation DCR-*like* technique

In [8], the assumption that the user position at the beginning of the call was made, and that by considering that a positioning system is integrated to the LEO MSS. It is important for the DCR scheme since the system parameter *CRN* is calculated in function of positions of calls in cell. However, such integration is regarded as complex.

An other approach to evaluate the MS position in a cell is presented in [10] [11]. Indeed, considering the hexagonal cellular layout presented in fig.1 and based on both the deterministic behavior of satellite –MS motion and the regular cellular layout, some of important parameters such us the instant of next handover request can be derived as explained bellow.

The necessary period for a MS to cross the maximum distance in a cell before giving rise to a handover request (i. e. the maximum sojourn time t_{Msj}) is equal to the period separating two successive handover initializations an MS performs. t_{Msj} is equal to

$$t_{Msj} = d(z) / V_{sat}. \tag{3}$$

With d(z) equal to:

$$d(z) = \begin{cases} \sqrt{3}R_h, & \text{if } |z| \le R_h/2 \\ 2\sqrt{3}(R_h - |z|), & \text{if } R_h \ge |z| \rangle R_h/2 \end{cases} \tag{4}$$

This period, t_{Msj}, can be estimated for each MS with a call in progress from the second handover request initialization.

Fig.3 represents the variation of t_{Msj} according to z for the considered mobility model. We remark that for the center area of cell, t_{Msj} has constant values equal to $T_{sM} \approx 50sec$. While for the seam area t_{Msj} values are less than T_{sM} and vary according to absolute values of z (z and $-z$ give equal values of t_{Msj}).

According to the cellular layout and mobility assumptions, a call belonging to the center (seam) area of a cell is handed over toward the center (seam) area of the transit cell.

So for a call belonging to center area of a cell t_{Msj} value remains the same in any subsequent cell the call will reach since in this area t_{Msj} values are constant.

For calls belonging to the seam area, this period change from cell to cell. However, it is easy to derive next value of t_{Msj} using the previous one in the previous cell:

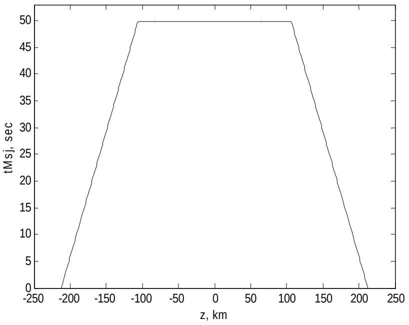

Fig. 3 Maximum sojourn time according to z

Suppose that a MS with ongoing call at offset z in the seam area of a cell and with maximum sojourn time t_{Msja} is handed over toward an other cell. The new offset z_n (see Fig.1) related to this call in the coordinate system of the transit cell is equal to:

$$|z_n| = \frac{3}{2}R_h - |z| \tag{5}$$

And then the value of the maximum sojourn time in this cell t_{Msjb} is given by:

$$t_{Msjb} = d(z_n) / V_{sat}. \tag{6}$$

Let us represent the variation of t_{Msja}, t_{Msjb} and $t_{Msja} + t_{Msjb}$ according to $|z|$, in the seam area of a cell. The result is given in Fig.4. We notice that the sum of t_{Msja} and t_{Msjb} is constant and equal to T_{sM}. And then for a call in the seam area initializing its second handover request the maximum sojourn time in the next cell is given by:

$$t_{Msjb} = T_{sM} - t_{Msja}. \tag{7}$$

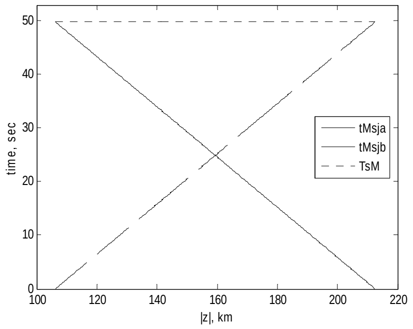

Fig. 4 Maximum sojourn time in source and transit cell according to |z|

This period t_{Msj} allow the system to exactly estimate the remaining time before a call initialize a new handover request: a timer is turned on when a call performs a handover request. The time elapsed from this moment, let denote it by t_{hr}, is then used to evaluate the remaining time before the call performs the forthcoming handover: $T_{nxt} = t_{Msj} - t_{hr}$.

A. DCR-like Scheme

We use in this section the DCR scheme but in different condition: MS position is unknown and instant of subsequent handovers are derived using the method explained in the preceding section.

At the instant of the first handover there is no method to discern if the call is in the seam or center area. In this case, we must wait for the second handover request initialization to be able to determine the value of the maximum sojourn time. So for less complexity, we'll consider here only the center area of cells; this is such as having rectangular cellular layout. In this area the t_{Msj} has a constant value; consequently the system determines the x position of a call at the first handover initialization $x=0$ and then the period t_{hr} is used to evaluate x position at any instant: $x=V_{sat}\, t_{hr}$.

For new initialized calls, since the system is unable to determine the MS position the channel locking mechanism is used: for each new call arrival a channel is allocated for in the source cell and a second channel is locked in the subsequent transit cell for its first handover. So the DCR scheme is applied only for handed over calls. New calls have a guaranteed handover:

When a new call arrives in cell 1 the system tries to allocate a channel in cell 1 and to lock another channel in cell 2. A new call is accepted only if two channels are available in both the two cells.

If the termination of a new call occurs in cell 1 the channel is released, and the channel locked for its first handover in cell 2 too. The *CRNs* of cells are recalculated as explained in the DCR technique.

B. Analytic approach for FCR-like

Due to mathematical difficulty in analyzing DCR-*like* we present in this section a theoretical analysis for FCR-*like* technique. The number of fixed channels for handover requests is taken equal to $C_h=2$, and the channel locking mechanism is adopted for new call arrivals.

We develop in this section an analytical model to study each cell; that is the Marcov chain model M/M/C (M: Poisson arrival process, M: service time exponentially distributed, C: number of channels assigned per cell). So we consider that new call arrivals and handover arrivals are independent Poisson processes, channel holding time is exponentially distributed, a uniform traffic and an infinite user population.

Traffic components in a given cell are: λ_{Gn}: new call arrival rate, λ_h: handover arrival rate, $\lambda_h = \lambda_{Fh} + \lambda_{Sh}$. with λ_{Fh} first handover arrival rate and λ_{Sh}: successive handover arrival rate.

Remark that a given cell will receive channel requests due to new call attempts generated by both users residing in the cell itself and in the preceding one.

Handover probabilities (P_{fh} for the first handover and P_{oh} subsequent ones) depend on parameter α that is a dimensionless parameter characterizing the user mobility: $\alpha = \frac{T_m V_{sat}}{R}$.

$$P_{h1} = \frac{1-e^{-\alpha}}{\alpha}, \qquad P_{h2} = e^{-\alpha} \tag{8}$$

In order to derive the expression of the handover request arrival rate, as a function of both the new call arrival rate and the blocking probability P_b (i.e., the probability that a channel request finds all channels busy in a cell), the handover requests are assumed to arrive in a cell according to a Poisson process, independent of the new call arrival process and subjected to the condition of flux equilibrium in a cell between incoming and outgoing handovers [12]. This equilibrium condition will be separately applied for new calls and handed over calls taking into consideration that:

- A new call attempt is accepted only if a channel is idle both in its source cell and in the first transit one. As all cells are identical and have the same traffic parameters, the probability of finding simultaneously an idle channel in each one of the two different cells is expressed by the factor which represents the connection probability for new call attempts, with the consequence that the blocking probability for new call attempts is equal to: $P_{b1} = 1-(1-P_b)^2$.
- First's Handed-over calls never are blocked; then the probability of success for each first handover is equal to one; so the connection probability related to first hand-over for each call is equal to one.
- New calls initialized generate only first handover attempts, and those lasts with subsequent handovers generate subsequent handovers, so we have:

$$\lambda_{Gn}(1-P_b)^2 P_{h1} = \lambda_{Fh} \tag{9}$$

$$\lambda_{Sh}(1-P_{b2})P_{h2} + \lambda_{Fh}P_{h2} = \lambda_{Sh} \tag{10}$$

Then we obtain:

$$\lambda_{Sh} = \frac{P_{h2}}{1-(1-P_{b2})P_{h2}}\lambda_{Fh} \tag{11}$$

$$\Rightarrow \lambda_{Sh} = \frac{P_{h1}P_{h2}(1-P_b)^2}{1-(1-P_{b2})P_{h2}}\lambda_{Gn} \tag{12}$$

From the above relationships, the handover call arrival rate $\lambda_h = \lambda_{Fh} + \lambda_{Sh}$ is given by:

$$\lambda_h = \frac{P_{h1}(1-P_b)^2(1+P_{h2}P_{b2})}{1-(1-P_{b2})P_{h2}}\lambda_{Gn} \tag{13}$$

The derivation of the channel holding time in a cell by an exponential distribution, with rate μ follows that of [6], [13] and [14]. One considers the mean channel holding time in a cell for different types of calls; subsequently, each average value is weighted with its occurrence probability; then, these contributions are summed so as to obtain the average channel holding time. The following definitions are relevant:

P_1: probability that a channel is occupied/locked by a new call in considered /preceding cell.

P_2: probability that a channel is occupied by a handed over call(a call that is not in his 1st handover).

$E[T_{H1}]$: average value of the channel holding time in the source cell .

$E[T_{H2}]$: average value of the channel holding time in transit cell.

$E[T_{H3}]$: average value of the channel locking time in the first transit cell. Note that it incorporates both standby and active periods.

So mean channel holding time in a cell is given by:

$$\frac{1}{\mu} = P_1 E[T_{H1}] + P_2 E[T_{H2}] + P_1 E[T_{H3}] \tag{14}.$$

With P_1 and P_2 equal to:

$$P_1 = \frac{\lambda_{Gn}(1-P_b)^2}{\Lambda} \tag{15}$$

$$P_2 = \frac{\lambda_{Sh}(1-P_b)}{\Lambda} \tag{16}$$

Λ is the mean generation rate of carried traffic.

$$\Lambda = 2\lambda_{Gn}(1-P_b)^2 + \lambda_{Sh}(1-P_b) + \lambda_{Fh} \tag{17}$$

Mean holding times are equal to:

$$E[T_{H1}] = T_{call}[1 - P_{h1}] \tag{18}$$

$$E[T_{H2}] = T_{call}[1 - P_{h2}] \tag{19}$$

$$E[T_{H3}] = T_{call}[1 - P_{h1}P_{h2}] \tag{20}$$

$$\frac{1}{\mu} = \frac{\lambda_{Gn}(1-P_b)^2}{\Lambda}\left(T_m[1-P_{h1}] + T_m[1-P_{h1}P_{h2}]\right) + \frac{\lambda_{SH}(1-P_{b2})}{\Lambda}T_m[1-P_{h2}]$$

The total mean call arrival rate in a cell is the sum of different types of average arrival rates. It is equal to:

$$\lambda_t = 2\lambda_{Gn}(1-P_b) + \lambda_h \tag{21}$$

This expression take into account the two contributions related to new calls: that originated in the given cell, and the other originated in the preceding one, each one is conditioned by having an idle channel in the preceding or following cell.

Finally, the total traffic intensity per cell is:

$\rho_t = \dfrac{\lambda_t}{\mu}$ (erlang).

and the total traffic intensity per cell new arrivals. $\rho_{tn} = \lambda_{Gn} T_{call}$.

C. Markov Chain Approach

From the above section, we have that each cell can be modeled as an M/M/C queuing system with arrival rates λ_{Gn} *and* λ_h [6]. Number of calls in service represents the state of this queuing system. The probability of state j, P_j is given by:

$$P_j = \begin{cases} \dfrac{\lambda_t^{\,j}}{j!\,\mu^j} P_0 & 1 \le j \le C - C_h \\[2ex] \dfrac{\lambda_t^{(C-C_h)} \lambda_h^{\,j-(C-C_h)}}{j!\,\mu^j} & C - C_h + 1 \le j \le C \end{cases} \tag{22}$$

Where the idle system probability P_0 is:

$$P_0 = \left[\sum_{k=0}^{C-C_h} \frac{\lambda_t^{\,k}}{k!\,\mu^k} + \sum_{k=C-C_h+1} \frac{\lambda_t^{\,C-C_h} \lambda_h^{\,k-(C-C_h)}}{k!\,\mu^k} \right]^{-1} \tag{23}$$

The probability of finding all channels busy in a cell P_b is:

$$P_b = \sum_{j=C-C_h}^{C} P_j$$

A new call is accepted only if a channel is idle both in the source cell and the first transit one. Therefore, the blocking probability of a new call is given by:

$$P_{b1} = 1 - (1-P_b)^2 = 2P_b - P_b^{\,2} \tag{24}$$

The probability of handover failure is:

$$P_{b2} = P_C = \frac{\lambda_t^{(C-C_h)} \lambda_h^{\,C_h}}{C!\,\mu^C} \tag{25}$$

The call dropping probability P_{drp} and The unsuccessful probability P_{ns} are:

$$P_{drp} = \frac{P_{h1}(1 + P_{h2}P_{b2})P_{b2}}{1 - (1-P_{b2})P_{h2}} \qquad P_{ns} = P_{b1} + (1-P_{b1})P_{drp} \tag{26}$$

Fig.5 presents variation of P_{b1}, P_{b2} *and* P_{drp} according to traffic intensity per cell of new arrivals.

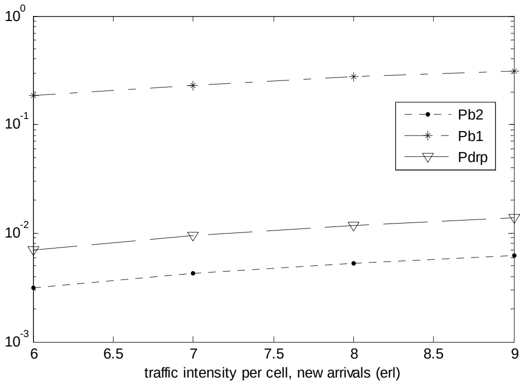

Fig. 5 Performance analysis of DCR-like

V. SIMULATION AND RESULTS

The above-described system in the second section is simulated using the following system parameters:

- The iridium mobility model is used
- The new call arrival rate of each cell is λ.
- The average call duration is 180 sec.
- The channel allocation scheme is FCA and each cell has 10 channels.
- A uniform traffic model is assumed.
- The simulated network consists of rectangular shaped cells, which form a street of coverage on the earth.
- A 7- cell model is used, a call goes out of the 7th cell will request a handover from the first cell.

Performance evaluation results for new call blocking probability, handover failure probability, and unsuccessful call probability are given in figure 6. for DCR and DCR-like techniques.

We can see from these figures that the DCR-like scheme provides better handover failure probability comparing with the DCR scheme; this is due to the channel locking mechanism adopted for new calls which guarantees success to the first handover. But such reservation causes an increase in the new call blocking probability since a new call originating in a cell is accepted only if there is a free channel in both source and transit cell.

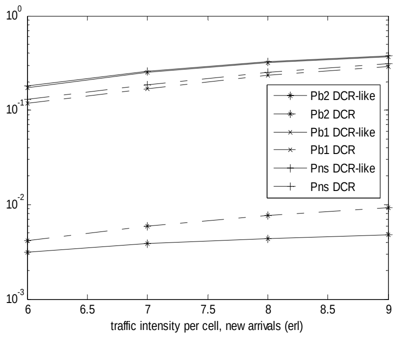

Fig. 6 Performance evaluation of DCR and DCR-like techniques

VI. CONCLUSION

A new method for evaluating next handover request instant for LEO MSS without positioning system is presented. The method is used to propose a DCR-*like* technique.

Results show that performance of the DCR and the DCR-*like* techniques are not the same. Indeed The channel locking mechanism adopted for new calls in the DCR-like technique causes a decrease on the handover failure probability and an increase in the new call blocking probability which is not considerable. So the DCR-*like* technique seams to be a good approach of the DCR technique for LEO MSSs without a positioning system, since it achieves acceptable performance..

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