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Pseudo Last Useful Instant Queuing Strategy for Handovers in Low Earth Orbit Mobile Satellite Networks

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***Abstract*—**This paper presents an alternative strategy of queuing handover called Pseudo Last Useful Instant PLUI scheme for Low Earth Orbit Mobile Satellite Systems LEO MSSs. The PLUI scheme uses the same approach as the Last Useful Instant LUI scheme previously proposed in literature, with less complex implementation. Simulation tests were carried out using Dynamic Channel Allocation DCA in order to evaluate the performance of this scheme and also an analytical approach has been presented to allow the performance evaluation of Fixed Channel Allocation FCA, with different handover queuing disciplines. The results show that performances achieved by the proposed strategy are close to those achieved using the LUI scheme.

***Keywords*—**LEO mobile satellite networks, LUI and FIFO schemes, queuing handover.

I. Introduction

IN recent years, extensive researches are investigated in order to provide users with advanced telecommunication service any time and any where. LEO satellite constellation systems seam to be a promising choice for universal mobile telecommunication systems for advantages they presents such as relatively low transmit power and short transmission delay [1], [2].

A significant problem faced in low earth orbit mobile satellite systems LEO-MSSs is handover; when an active mobile subscriber MS goes out from a cell and enters an adjacent one, a new channel must be automatically assigned to the call in order to avoid forced termination. If there is no free channel in the destination cell 'transit cell', the call is lost.

In such MSSs, interbeam handover requests occur rather frequently during a call life time; one could expect that a call experiences a handover request every one minute [3] that is due to the high speed movement of satellites, nearly 7 km /s.

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].

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In [3] different queuing policies for handover requests were proposed. The handover requests, queued up to a maximum time interval, are served in a first-input-first-output (FIFO) scheme or in a last useful instant (LUI) scheme (that is, a handover request is queued ahead of any other requests already in the queue that have a longer residual queuing time). The maximum queuing time is a function of the overlap area between contiguous cells in the same direction.

The LUI scheme is regarded as an ideal scheme because it is based on an exact estimate of the maximum time a call may spend in the queue waiting for a free channel. It is quoted (LUI scheme) in recent studies as an example of queuing handover schemes [8], [9].

If comparing with First In First Out FIFO, LUI scheme allows a high system capacity, it however requires a greater implementation complexity. Indeed, a positioning system integrated into the MSS is necessary in order to estimate the position of an MS initializing a call and to track it during call life time [3].

Trying to reach a compromise between these two strategies, we propose in this paper a new queuing strategy combining the simplicity of the FIFO implementation and the effectiveness of the LUI scheme. This strategy, named Pseudo Last Useful Instant PLUI scheme, is essentially based on the geometry of the network and the deterministic behavior of relative motion MS-satellite.

This paper is organized as follow: in the second section the mobility model considered in the study is presented, queuing strategies are discussed in section 3, followed, in section 4, by an analytical study for a Fixed Channel Allocation technique with different queuing disciplines. Simulations and results for Dynamic Channel Allocation with different queuing strategies DCA-QH are presented and discussed in section 5.

II. Mobility Model for LEO MSS

The evaluation of the impact of handover strategies on the performance of resource management techniques necessitates modeling the user mobility.

The mobility model used 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 [10]. This means that the relative motion has a fixed orientation with respect to the cellular layout irradiated on the earth by satellites.

MSs and calls they generate are considered uniformly distributed over the simulation area.

The user mobility is characterized by the parameter α, defined as:

$$\alpha = \frac{\sqrt{3}R}{V_{sat}T_m} \cdot \tag{1}$$

R and T_m are the hexagonal cell side and the average call duration respectively. In the Iridium case $\alpha \approx 0.27$.

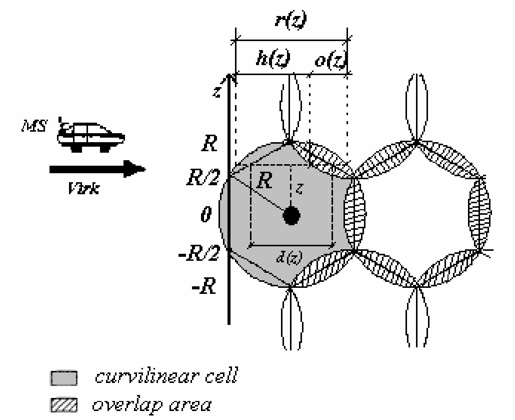


Fig. 1 Mobility model assumption

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. The circular cell is divided into two regions [3]: the curvilinear cell and the overlap area. Let us consider an MS crossing a cell at a height: $z \in [-R,\ R]$

From the call arrival in a cell, where z is the offset of the related MS according to Fig. 1, the related MS travels a distance in this cell which is

- Uniformly distributed between zero and $h(z)$ if the cell is the source cell of the call.
- Deterministically equal to $h(z)$ if the cell is a transit cell of the call.

With $h(z)$ equal to:

$$h(z) = r(z) - o(z). \tag{2}$$

$r(z)$ is the length of the circular cell with radius R at a height z, it is equal to:

$$r(z) = 2\sqrt{R^2 - z^2} \tag{3}$$

$o(z)$ is the distance crossed by an MS with offset z in the overlap area:

$$o(z) = \begin{cases} 2\sqrt{R^2 - z^2} - \sqrt{3}R & \text{if } |z| \le R/2 \\ \sqrt{R^2 - z^2} - \frac{\sqrt{3}}{2}R + \sqrt{R^2 - \left(|z| - \frac{3}{2}R\right)^2} & \text{if } R \ge |z| \rangle \frac{R}{2} \end{cases} \tag{4}$$

So an MS with offset z, crosses the overlap area during a period t_{qmax} called the maximum queuing time and equal to:

$$t_{qmax} = o(z) / V_{sat}. \tag{5}$$

III. Queuing Disciplines

The most common queuing discipline for telecommunication networks is FIFO. In this scheme, handover requests are queued according to their arrival instants, and the first who enters the queue is the first served when a channel is released in the destination cell.

In LUI, the system tries to serve the most urgent handover request, it relies on the fact that when a handover request is queued, the system exactly estimates its t_{qmax}, it is stored in a queue position before (after) all handover requests having a greater (lower) residual value of t_{qmax}.

LUI scheme out performs FIFO one, but the integration of a suitable positioning system to LEO MSS makes its implementation more complex.

The Pseudo Last Useful Instant PLUI is an alternative scheme that is based on the relative MS satellite motion which has a deterministic orientation and a constant velocity, and on the cellular coverage geometry, as it is explained below.

A. Pseudo Last Useful Instant PLUI Scheme

The aim of the Pseudo Last Useful Instant PLUI scheme is to evaluate approximately the maximum queuing time of a MS entering the queue and that using the deterministic relative motion MS-satellite and the topology of the network instead of the integration of positioning system, which is the principal disadvantage of the LUI scheme.

Indeed, due to both the regular cellular layout and the mobility assumptions, the distance $o(z)$ covered by the MS in the overlap area remains the same for any handover request, it does not matter if it is originates from a source or a transit cell [3]. So one need to derive the maximum queuing time for an ongoing call for once, and then use it for any subsequent handover. This is possible for any call, from the second initialization of a handover request.

In fact, the period separating two successive handover initializations, let denote it by t_{sH}, can be estimated for each MS with a call in progress using a timer. This period represents the necessary time 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_{sH} is equal to:

$$T_{sH} = h(z) / V_{sat}. \tag{6}$$

Fig. 2 represents the variation of t_{sH} and t_{qmax} according to z. We remark that, except for the center area of cells, for each value of t_{sH} there is an equivalent value of t_{qmax}.

Let us represent the variation of t_{qmax} according to t_{sH} and that using (5) and (6), the result is presented by Fig. 3. (Due the symmetry of the topology of the system, equal values of t_{sH} in different areas (for z and $-z$) have the same value of t_{qmax}.)

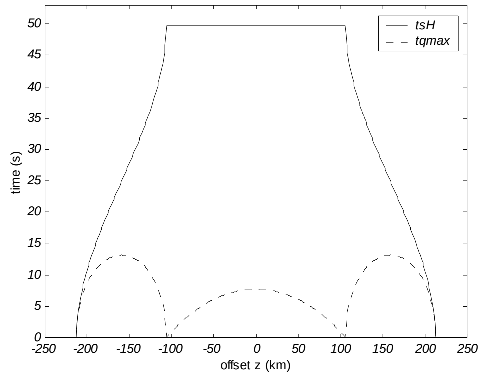


Fig. 2 Maximum queuing time t_{qmax}, and maximum sojourn time t_{sH} according to z

We notice from those results, that it is possible to derive values of t_{qmax} using t_{sH} values. Indeed Fig. 3 represents the graph of the function $a\,x^2 + b\,x$. Using values of t_{qmax} and t_{sH}, we can obtain values of a and b:

$$t_{qmax}(t_{sH}) = a(t_{sH})^2 + b\,(t_{sH}). \qquad a \approx -0.0212 \quad b \approx 1.0551 \quad (7).$$

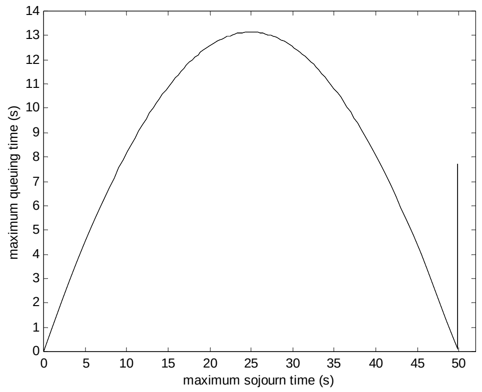


Fig. 3 Maximum queuing time t_{qmax}, according to maximum sojourn time t_{sH}

In result, in the PLUI scheme the system estimates the value of t_{sH} for each call initializing a handover request for the second time, and uses it to evaluate the maximum queuing time for the call. This value is registered in order to be used if the call needs to be handed over other time.

We propose for the problem of the center area $-R/2 < z < R/2$ (where the period separating two successive initializations of handover requests t_{sH} remains the same for different values of t_{qmax}) to consider the period that such calls spent in the queue in previous times and use the maximum one, let us denote it by t_{mxqp}, to estimate the real maximum queuing time using the following formula:

$$t_{q\max} \cong t_{mxqp} + \left(\left(t_{mxc} - t_{mxqp}\right)/5\right) \qquad (8)$$

$t_{mxc} \approx 7.706\,s$ is the maximum value of t_{qmax} in this region, see Fig. 4. This period is used in the following handover request to queue the call following the LUI scheme.

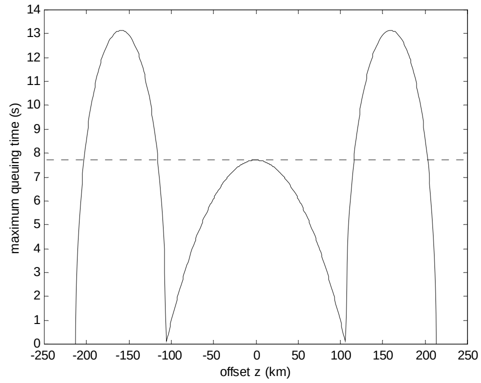


Fig. 4 Maximum queuing time according to z for the mobility model

It is important to note that the number of those calls presents a minority among queued requests. Indeed, in [11] Markoulidakis *et al.* give an estimation of the average number of handovers per call for such mobility model. The study shows that, the average number of handover requests a call belonging to this area performs is about a half of that performed by a call initialized in seam areas. So we suppose that this problem will have a limited impact on the effectiveness of the proposed scheme.

New calls with first handover requests are queued following the FIFO scheme and are queued before all those calls that have already being handed over for at least one time, and need to be handover again.

IV. Analysis of FCA-QH with FIFO, LUI and PLUI

We consider in this section the same analytical approach out lined in [3], [12], in order to evaluate the performance of Fixed Channel Allocation technique with the queuing of handover requests denoted by FCA-QH.

Each cell can be modeled as an M/M/S queuing system (M: Poisson arrival process/ M: service time exponentially distributed/ S: number of assigned channels per cell). Fig. 5 shows the state transition of the Markov chain; it is valid for all FIFO, LUI and PLUI schemes.

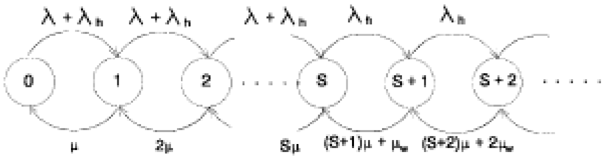


Fig. 5 The queuing system for FCA-QH

Let us denote by:

- λ: the average arrival rate of new call attempts in a generic cell of the system.
- λ_h: the average handover arrival rate toward a cell.
- $1/\mu$: the mean value of the channel holding time in a cell.
- $1/\mu_\omega$: the expected value of maximum waiting time in queue.

The probability of state n P_n is

$$P_n = \begin{cases} \dfrac{(\lambda+\lambda_h)^n}{n!\,\mu^n} P_0, & 1 \le n \le S-1 \\ \dfrac{(\lambda+\lambda_h)^S \lambda_h^{n-S}}{S!\,\mu^S \prod_{j=1}^{n-S}\left((S+j)\mu + j\mu_\omega\right)} P_0, & n \ge S \end{cases} \tag{9}$$

Where P_0 is the probability that all channels of one cell are idle and given by:

$$P_0 = \left\{ \sum_{n=0}^{S-1} \left[\frac{(\lambda+\lambda_h)^n}{n!\,\mu^n} \right] + \sum_{n=S}^{\infty} \left[\frac{(\lambda+\lambda_h)^S \lambda_h^{n-S}}{S!\,\mu^S \prod_{j=1}^{n-S}\left((S+j)\mu + j\mu_\omega\right)} \right] \right\}^{-1} \tag{10}$$

Therefore, the probability that new call arrivals are blocked is:

$$P_{b1} = \sum_{n=S}^{\infty} P_n \tag{11}$$

P_{b1} does not depend on the queuing discipline [3]

In FIFO the handover failure probability P_{b2} is given by taking into account:

1. P_{b2} must contain, as a multiplying factor, the probability that the call, with a queued handover request, does not end before t_{qmax} has expired, P_{uh}. According to the exponential distributions for the maximum queuing time and the channel holding time, P_{uh} is

$$P_{uh} = \frac{\mu_\omega}{\mu + \mu_\omega} \tag{12}$$

2. state probabilities are given by (9), (10).
3. we consider the additional departure rates $i\mu$ for states $S+i$ with $i=1,2,\ldots.$, due to calls that end in the overlap area before accomplishing the related handover procedures.

Hence P_{b2} equal to:

$$P_{b2} = \frac{\mu_\omega}{\mu+\mu_\omega} \sum_{n=S}^{\infty} P_n \left\{ 1 - \frac{S\mu}{S\mu+\mu_\omega} \cdot \prod_{j=1}^{n-S} \left[1 - \frac{\mu_\omega}{S\mu+\mu_\omega} \left(\frac{\mu_\omega}{\mu+\mu_\omega} \frac{1}{2} \right)^j \right] \right\} \tag{13}$$

In LUI strategy the failure probability for a handover request does not depend on its position in the queue because only the request at the head of the queue may fail.

So:

$$P_{b2} = P_{b2|S} P_{b1}. \tag{14}$$

$P_{b2|S}$ here takes into account two events:

1. the call, whose handover request is at the head of the queue, does not end before its maximum queuing time has expired; the probability of this event is P_{uh}.
2. none of the S channels of the cell becomes free before the maximum queuing time has expired. Let us denote the probability of this event by P_f. according to the exponential distributions for the maximum queuing time and the channel holding time, we have:

$$P_f = \frac{\mu_\omega}{S\mu + \mu_\omega}. \tag{15}$$

P_{b2} for LUI is then given by:

$$P_{b2} = P_{b1} \frac{\mu_\omega}{\mu+\mu_\omega} \frac{\mu_\omega}{S\mu+\mu_\omega} \tag{16}$$

For PLUI the problem discussed in the previous section for those calls belonging to the central area is ignored here.

We also suppose that the i[th] request entering the queue is one that have already been handed over and need to be handed over another time.

Since calls queued following the FIFO scheme have the priority, and among calls queued following the LUI scheme only the request at the head of the queue may fail, the probability that the i^{th} request entering the queue is blocked is:

$$P_{b2}=\frac{\mu_\omega}{\mu+\mu_\omega}\sum_{\mathrm{n=S}}^{\infty}P_n\sum_{nf=0}^{n-S}\left\{\left(1-\frac{S\mu}{S\mu+\mu_\omega}\cdot\prod_{\mathrm{j=1}}^{nf}\left[1-\frac{\mu_\omega}{\mathrm{S}\mu+\mu_\omega}\left(\frac{\mu_\omega}{\mu+\mu_\omega}\frac{1}{2}\right)^j\right]\right)\left(\frac{\mu_\omega}{S\mu+\mu_\omega}\right)^{\left(1-0^{n-s-nf}\right)}\right\} \quad (17)$$

A recursive approach is necessary to compute P_{b1} and P_{b2} for the three queuing strategies. The iterative method is based on parameter $n_h=\lambda_h/\lambda$, which is a function of P_{b1} and P_{b2}[3]. The unsuccessful call probability P_{ns} can be derived as [10]:

$$P_{ns}=P_{b1}+\left(1-P_{b1}\right)\frac{n_h}{1-P_{b1}}P_{b2}. \quad (18)$$

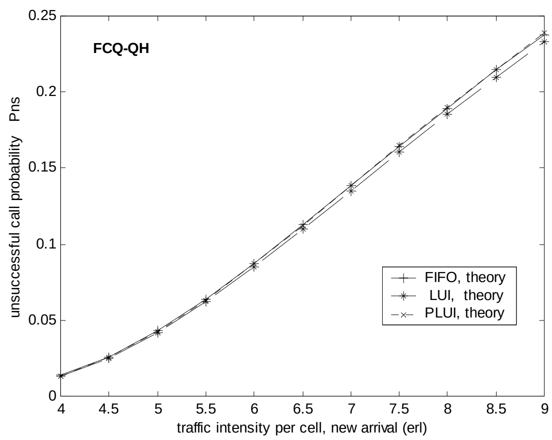


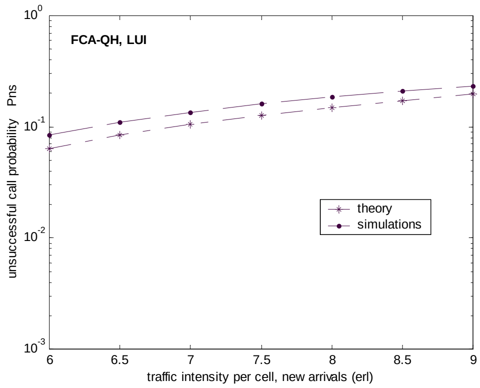
Fig. 6 Theoretic comparison between the performance of FIFO, LUI and PLUI queuing disciplines for FCA-QH in terms of P_{ns} (IRIDIUM case, $S=10$.)

Fig. 6 presents the analytical results concerning FCA-QH with the three different queuing schemes. As it is explained in [3] there is not a significant difference in performance between different queuing strategies LUI, PLUI & FIFO with FCA-QH, since the time spent in the overlap area by an MS is so small and for this allocation technique each cell has its own queue, whereas a Dynamic Channel Allocation technique DCA-QH requires that the system manages a virtual global queue formed by handover requests waiting for service in all the cells. That is why the simulation results in the next section highlight better the difference between those queuing schemes while considering DCA-QH.

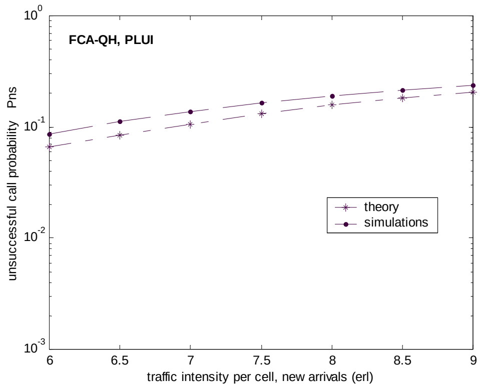
V. Simulation Results

The following assumptions have been made in simulation:

- The dimension of the network used in the simulation is the common choice in literature, 7 cells per side total 49 folded onto its self [13].
- The average call duration is T_m =180 s.
- Belt of interfering cells is formed by two tiers of cells.
- A number of 70 channels are available to the system.
- Call arrival process is Poisson independent from cell to cell with average call arrival rate per cell equal to λ .
- An infinite queue capacity is assumed.



(a)



(b)

Fig. 7 (a) FCA-QH with LUI queuing discipline: comparison between simulation and analytical predictions (IRIDIUM case, $S=10$)
(b) FCA-QH with PLUI queuing discipline: comparison between simulation and analytical predictions (IRIDIUM case, $S=10$)

In order to verify the system model and simulation methods, comparisons between analytical predictions and simulation results are given by Fig. 7. Simulation performances agree well with the analytical results, the small difference observed is due to the simplifications assumed in the analysis.

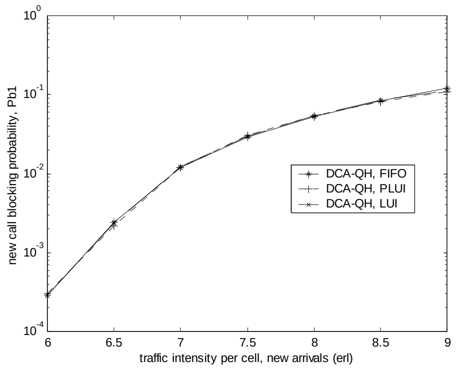


Fig. 8 New call blocking probability for DCA-QH with FIFO, LUI, and PLUI (IRIDIUM case)

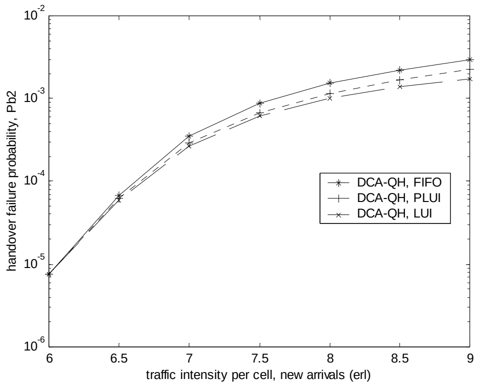


Fig. 9 Handover failure probability for DCA-QH with FIFO, LUI, and PLUI (IRIDIUM case)

From Fig. 8 it is clear, as explained in the previous section, that P_{b1} is independent of the adopted queuing scheme (i.e. FIFO, LUI, or PLUI).

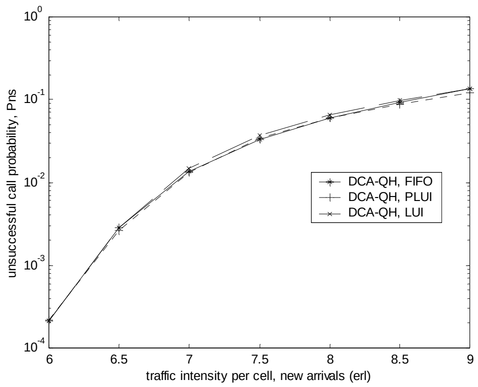


Fig. 10 Unsuccessful call probability for DCA-QH with FIFO, LUI, and PLUI (IRIDIUM case)

Let us refer to the handover failure probability P_{b2}. From Fig. 9 we remark that LUI achieves better performance than FIFO and PLUI, however this last permits the reduction of P_{b2} as regards the FIFO policy. We also remark that performance of PLUI is close to LUI one. The reason of that has to be searched on the fact that the average number of handover requests per call attempt in the Iridium mobility case is on average equal to 5 [3], so the majority of queued calls are those that have already been handed over, and need to be handed over another time, so those that are queued, in the PLUI strategy, following the LUI scheme.

As expected, the problem of the center area of cells has a limited impact in the effectiveness of the PLUI scheme, since this last achieves good performance. Without this problem, the difference between performances of PLUI and LUI schemes would be smaller.

VI. Conclusion

This paper has proposed a compromise between the common FIFO scheme and the ideal LUI strategy for queuing handovers in LEO MSSs. Indeed the proposed strategy PLUI combines the simplicity of the first and the effectiveness of the second.

Essentially based on topology and geometry of the network and the deterministic orientation and speed of users in such networks, this scheme allows the system to evaluate the value of the maximum queuing time for each call in a transit cell that needs to be handed over, and use it to queue the request according to LUI scheme. Calls that are in their source cell and need to be handed over are queued according to FIFO strategy.

Performance evaluations and comparisons carried out for Iridium mobility model shows that the PLUI scheme achieves performance that are close to those achieved by LUI strategy.

PLUI scheme is an attractive choice for LEO MSSs since it achieves good performance with a simple implementation.

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