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A Novel Method For evaluating Parameters Of Ongoing Calls In Low Earth Orbit Mobile Satellite System

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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 called Evaluation Parameters Method EPM which allows for such systems the evaluation of different information concerning a MS with a call in progress even if its location is unknown.

Keywords—Cellular layout, LEO mobile satellite system, mobility model, positioning system.

I. Introduction

THE trend in designing future global communication networks is to offer fast and integrated service to ubiquitous users on-demand, any time [1]- [3].

Providing a complete coverage to a diverse population, mobile satellite systems MSSs seam to be a useful choice for universal mobile telecommunication systems UMTS.

Satellite based communication networks can be broadly classified into three categories depending on the type of the satellites used [2]: Geostationary GEO, Medium MEO, and Low Earth Orbit LEO satellite systems [4], although mixed constellations exist.

Comparing with other systems, LEO satellite systems present different advantages for UMTS such as relatively low transmit power and short transmission delay [2].

LEO satellites are not stationary with respect to a fixed point on the Earth; this is due to the asynchronous movement of the satellite relative to the Earth. A user terminal in such systems can be served by a number of spot beams and satellites during a connection. The ground track speed of satellite V_{sat} is far greater than the earth rotation speed and the user speed [5], so that the relative motion mobile subscriber MS-satellite is dominated by the satellite motion. In those systems, it is possible at any instant to obtain an actual scenario of the satellite constellation, thus a simple mobility model.

This advantage allows the system to determine different important parameters such as maximum queuing time and the instant of subsequent handover request initializations for an ongoing call. In previous studies presented in literature, such parameters were determined by considering that the system estimates the position of the MS at the beginning of the call. This requires a positioning system to be integrated to the LEO MSS [6]-[8].

We demonstrate in this paper that it is possible, even if the exact location of a MS is unknown, to derive some of important information and that by taking advantage of both the deterministic behavior of the MS-Satellite relative motion and the regular cellular layout of the network.

Indeed, some 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. In fact, this period equal to the period separating two successive handover initializations. We will show in this paper, that this parameter can be used to derive important information and parameters concerning the related ongoing call.

This paper is organized as follow: in the second section the mobility model considered in the study is presented, then the problem of spotbeam handover in LEO MSS in addition of important parameters concerning MSs with ongoing calls in the system are introduced in the third section. In section four a novel method called Evaluation Parameters Method EPM for computing different important parameters is proposed. Finally, a conclusion is presented in section five .

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 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

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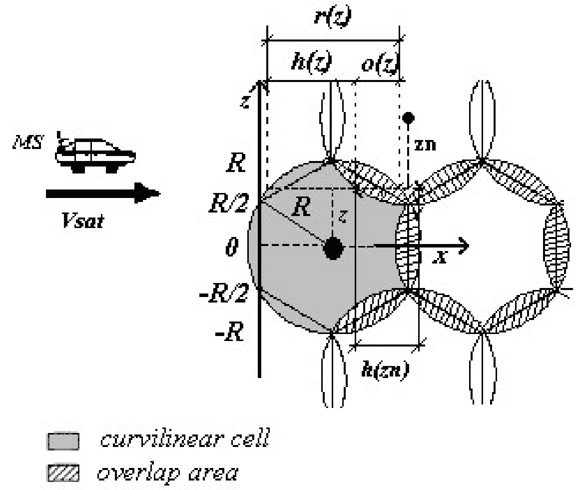

Fig. 1. Mobility model assumption

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.

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

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

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

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 [7]: the curvilinear cell and the overlap area. Let us consider an MS with a call in progress, 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 a MS with offset z in the overlap area:

$$o(z) = \begin{cases} 2\sqrt{R^2 - z^2} - \sqrt{3}R & \text{if } \mid z \mid \leq R/2 \\ \sqrt{R^2 - z^2} - \frac{\sqrt{3}}{2}R & \\ \quad + \sqrt{R^2 - |z| - \frac{3}{2}R^2} & \text{if } R \geq |z| > \frac{R}{2} \end{cases} \tag{4}$$

III. SPOTBEAM HANDOVER IN LEO MSS

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 [7] 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 [6]-[8]. Previous studies consider that the location of MS with call in progress has to be known in order to evaluate parameters concerning ongoing calls that need to be handed over in the system [6]-[8].

In [7] E Del Re et al. consider that the position can be estimated by the LEO-MSS using a suitable positioning system, and that by measuring the propagation delay and Doppler frequency shift for the MS transmissions. A fixed propagation delay circle is obtained on the Earth using the time delay measurement. Since the Doppler frequency shift is related to the angle between the satellite velocity vector and the MS-satellite direction vector, the Doppler measurement defines a cone making a fixed angle with the satellite velocity vector. 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.

Once the initial position of the call is estimated the system can easily tracks it by estimating position variations, since the relative MS-satellite motion is dominated by the satellite motion. This permits to derive different information.

A. The MS position in the cell

When the MS with the initialized call is located, its position in the cell can be determined with two coordinates z and x. Let us denote by z_i and x_i the coordinates of the MS at its initial position, that is at the beginning of the call.

Since the relative MS-satellite motion has a fixed orientation with respect to the cellular layout irradiated on the Earth by satellite (see Fig.1) the MS position in the cell will change only according to coordinate x and it can be determined by:

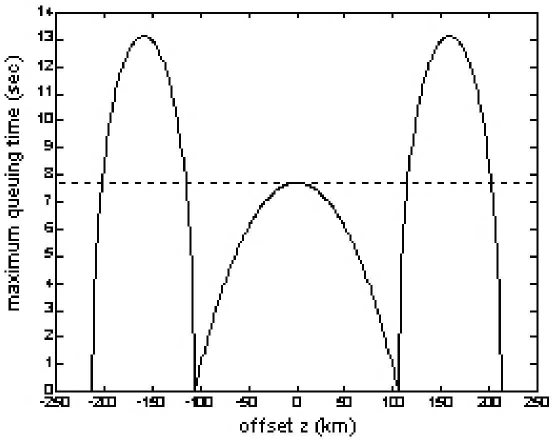

Fig. 2. Maximum queuing time according to z for the mobility model

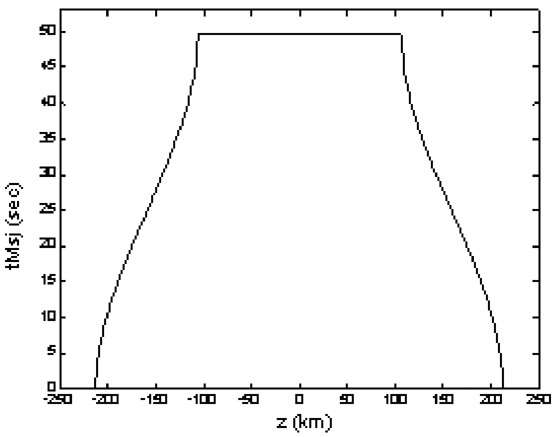

Fig. 3. Maximum sojourn time according to z

$$x = x_i + \frac{t_{cl}}{V_{sat}} \quad (5)$$

t_{cl} is the duration of the call in the cell.

B. Maximum queuing time

The maximum time a call may spend in queue waiting for an available channel in the transit cell represents the period necessary for a MS to cross the overlap area between the source and the transit cell where a call can be served by both of them (source and transit cell). This parameter is function of coordinate z only and equal to:

$$t_{qmax} = \frac{o(z)}{V_{sat}} \quad (6)$$

Figure 2 shows the variation of t_{qmax} according to z.

C. Instant of next handover request initialization

For a MS with a call in progress, it is possible to estimate the remaining time before it will perform a request if the system knows the position of the MS in the cell since this last has a deterministic motion over the cellular layout and the system knows the cellular coverage geometry.

Let us denote by T_{nxt} the instant of the forthcoming handover request for a call with coordinates (z, x) in a given cell. T_{nxt} is then given by:

$$T_{nxt} = \frac{h(z) - (x + \frac{o(z)}{2})}{V_{sat}} \qquad |z| \leq R/2 \quad (7)$$

$$T_{nxt} = \frac{h(z) - (x - \frac{\sqrt{3} - r(z)}{2})}{V_{sat}} \qquad R \geq |z| > R/2 \quad (8)$$

IV. Evaluation parameters method EPM

The relative motion MS-satellite is dominating by the satellite motion. that is a deterministic behavior of relative motion MS-Satellite. Thus, in LEO MSS, the handover destination cell will always be the neighboring cell in the direction of the relative motion MS-Satellite.

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) is equal to the period separating two successive handover initializations an MS performs.

This period, let us denote it by t_{Msj}, can be estimated for each MS with a call in progress from the second initialization of a handover request using a timer. t_{Msj} is equal to:

$$t_{Msj} = \frac{h(z)}{V_{sat}} \quad (9)$$

Different information and parameters can be derived using the value of t_{Msj} even if the MS location is unknown, as it is presented in following sections.

A. Seam or center area

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}).

Therefore, the estimated value of the maximum sojourn time allow us to determine if the call belongs to seam or center area; if t_{Msj} is equal to T_{sM} the call is in the center area otherwise, it belongs to the seam region of the cell.

B. Instant of the next handover initialization

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:

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

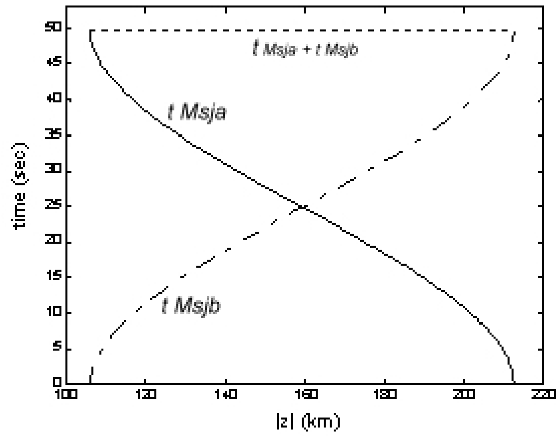

Fig. 4. Maximum sojourn time in source and transit cell according to —z—.

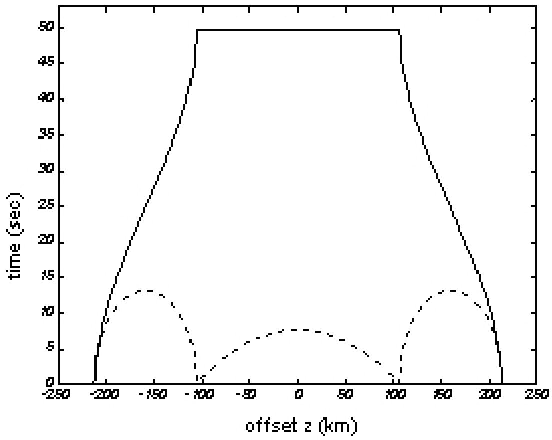

Fig. 5. Maximum queuing time and maximum sojourn time according to z.

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:

$$|z_n| = \frac{3}{2}R - |z| \tag{10}$$

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

$$t_{Msjb} = \frac{h(z_n)}{V_{sat}} \tag{11}$$

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:

$$t_{Msjb} = T_{Ms} - t_{Msja} \tag{12}$$

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: $T_{nxt} = t_{Msj} - t_{hr}$

C. Maximum queuing time

Fig.5 represents the variation of t_{Msj} and t_{qmax} according to z for the considered mobility model. We remark that for the seam area for each value of t_{Msj} there is an equivalent value of t_{qmax}. We also remark that due to the symmetry of the topology of the system, equal values of t_{Msj} in different areas (for z and $-z$) have the same value of t_{qmax}.

Let us represent the variation of t_{qmax} according to t_{Msj} and that using (6) and (9) [9], the result is presented by Fig. 6. Then referring to this result, it is possible for calls belonging to seam area to derive the maximum queuing time from the second initialization of a handover request using the value of t_{Msj}. For calls initialized in the center area of a cell, the available information is that $t_{qmax} \leq 7.706$, see Fig.2.

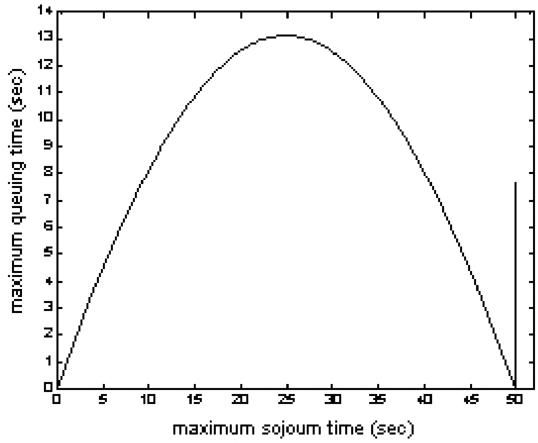

Fig. 6. Maximum queuing time according to maximum sojourn time.

Remark that due to both the regular cellular layout and the mobility assumptions, the maximum queuing time for the MS remains the same for any handover request, it does not matter if it is originates from a source or a transit cell [7].

V. Conclusion

A positioning system integrated to LEO MSS allows it to derive important parameters concerning MSs with ongoing calls that are necessary for strategies of resource management in order to improve QoS in those networks. However, the implementation of those systems (positioning systems) seams to be complex and presents some constraints.

In this paper a novel method is presented which permits to derive such parameters without using a positioning system. This method called Evaluation Parameters Method EPM, is essentially based on the deterministic behavior of the relative motion MS-satellite and the cellular coverage geometry. Using this method, parameters are available only from the second handover request initialization, but in such systems handover requests are very frequent. In the Iridium case, the average number of handover requests per call attempt is on average equal to 5 [7].

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