A Markov Model to Calculate New and Hand-off Call Blocking Probabilities in LEO Satellite Networks

A. Halim Zaim

Department of Computer Engineering
Istanbul University
Email: ahzaim@istanbul.edu.tr

We derive a Markov Model to calculate new call and hand-off call blocking probabilities in LEO satellite networks carrying voice calls. The model is used to define blocking conditions for new and hand-off calls. The satellite constellation is treated as a group of M/M/K/K queues effecting each other with a set of constraints.

Categories and Subject Descriptors: C.2.m (Computer Systems Organisation): Computer Communication Networks—Miscellaneous

Additional Keywords and Phrases: Low earth orbit satellite networks, call blocking probability, hand-offs

1. INTRODUCTION

Most of the studies on the performance of satellite systems rely on simple queueing models to evaluate call blocking probabilities, and focus on devising methods for improving the performance of calls during hand-offs (e.g., by assigning higher priority to hand-off calls, using guard channels, or making reservations ahead of a hand-off instant). Ganz *et al* (1994) expressed the system performance in terms of the *distribution of the number of hand-offs* occurring during a single transaction time and the *average call drop probability*. In their work, each cell is modeled as an M/M/K/K queue where K denotes the number of channels per cell, assuming that the number of hand-off calls entering a cell is equal to the number of hand-off calls leaving the cell. Del Re *et al* (1994; 1999) proposed an analytical model to analyse hand-off queueing strategies under fixed channel allocation. Their method is designed for satellite-fixed cell coverage. Pennoni and Ferroni (1994) described an algorithm to improve the performance of hand-offs in LEO systems. They defined two separate queues for new and hand-off calls. The hand-off queue has higher priority than the new calls queue. Dosiere *et al* (1993) used the same model to calculate the hand-off traffic rate over a street-of-coverage. Ruiz *et al* used a similar technique to the one used in Pennoni (1994). However, this time, they used some guard channels for hand-off calls and they distinguished between the new arrival rate and the hand-off attempt rate. Restrepo and Maral (1997) defined a guaranteed hand-off mechanism for LEO satellite systems with satellite-fixed cell configuration. In this method, channel reservation is performed according to the location of the user. The advantage of this method is that the reservation is done only on the next satellite instead of the whole call path.

This work was supported by the Research Fund of the University of Istanbul. Project number: 69/15052003
Author's address: A. Halim Zaim, Department of Computer Engineering, Istanbul University, Avcilar, 34850, Istanbul, Turkey

Manuscript received: 14 May 2002
Communicating Editor: John Roddick

With this approach, the amount of redundant circuitry is minimised and the hand-off success rate is as high as the static reservation technique. Wan *et al* (1999) defined a channel reservation algorithm for hand-off calls. In this algorithm, they keep three queues, one for hand-off requests, one for new call requests and one for available channels. Each request comes with the information indicating the position of the user within the footprint area. The position information is then used to calculate the time of the next hand-off. The aim of the algorithm is to match the available channels with the hand-off and new call request queues according to the time criteria. A similar approach is proposed by Obradovic and Cigoj (1999).

Zaim *et al* (2002) proposed an approximation method for calculating call blocking probabilities in a group of LEO/MEO satellites arranged in a single orbit. Both satellite-fixed and earth-fixed types of coverage with hand-offs were considered. In the model, it was assumed that each satellite has a single beam and that the arrival process is Poisson with a rate independent of the geographic area. The model was analysed using decomposition. Specifically, the entire orbit is decomposed into sub-systems, each consisting of a small number of satellites. Each sub-system is analysed exactly, by observing that its steady-state probability distribution has a product-form solution. An efficient algorithm was proposed to calculate the normalising constant associated with this product-form solution. The results obtained from each sub-system are combined together in an iterative manner in order to solve the entire orbit. However, this approach does not allow to evaluate blocking probabilities of new and hand-off calls individually.

In this paper, we define a new Markov Model to take into account hand-off call blocking. Instead of handling new and hand-off calls similarly, in this approach, we add the idea of guard channels. That way, a new call can consume the channels reserved for both type of calls, but can not use guard channels. However, a hand-off call would be able to use guard channels, reserved for hand-off calls, only. Therefore, the new Markov Model uses some guard channels for hand-off calls to decrease blocking probability of hand-off calls. Using this new Markov Model, we can evaluate hand-off and new call blocking probabilities separately.

The paper is organised as follows. In Section 2 we present the hand-off model, and in Section 3 we present how to adapt the exact Markov model proposed in Zaim (2002). We present numerical results in Section 4, and in Section 5 we conclude the paper.

2. PROPOSED MARKOV MODEL

Let us consider a satellite-fixed cell coverage. As a satellite moves, its footprint on the earth (the cell served by the satellite) also moves with it. As customers move out of the footprint area of a satellite, their calls are handed off to the satellite following it from behind. In order to model hand-offs in this case, we make the assumption that potential customers are uniformly distributed over the part of the earth served by the satellites in the orbit. This assumption has the following two consequences.

- The arrival rate λ of new calls to each satellite remains constant as it moves around the earth. Then, the arrival rate of calls between satellite i and satellite j is given by $\lambda_{ij}=\lambda r_{ij}$, where r_{ij} is the probability that a call originating by a customer served by satellite i is for a customer served by satellite j.
- The active customers served by a satellite can be assumed to be uniformly distributed over the satellite's footprint. As a result, the rate of hand-offs from satellite i to satellite j that is following from behind is proportional to the number of calls at satellite i.

Clearly, the assumption that customers are uniformly distributed (even within an orbit) is an approximation.

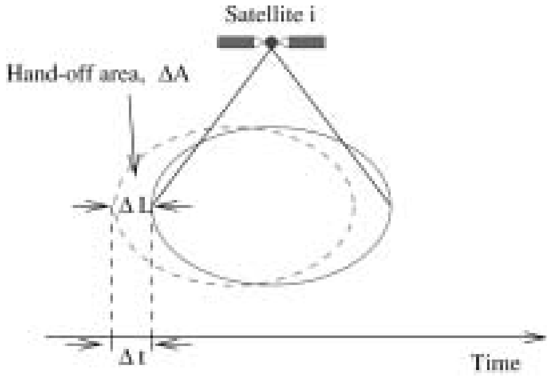

Figure 1: Calculation of the hand-off probability

Let A denote the area of a satellite's footprint and v denote a satellite's speed. As a satellite moves around the earth, within a time interval of length Δt, its footprint will move a distance of ΔL, as shown in Figure 1. Calls involving customers located in the part of the original footprint of area ΔA (the hand-off area) that is no longer served by the satellite are handed off to the satellite following it. Let $\Delta A = A\beta\Delta L$, where β depends on the shape of the footprint. Because of the assumption that active customers are uniformly distributed over the satellite's footprint, the probability q that a customer will be handed off to the next satellite along the sky within a time interval of length Δt is

$$q = \frac{\Delta A}{A} = \beta \Delta L = \beta v \Delta t \tag{1}$$

Define $\alpha = \beta v$. Then, when there are n customers served by a satellite, the *rate* of hand-offs to the satellite following it will be αn .

In this section we review the single-orbit model that was first proposed in Zaim (2002). This section is included here for completeness only.

Let us consider a single orbit of a constellation, and let us assume that the position of the satellites is fixed in the sky, as in the case of geostationary satellites. The analysis of such a system is simpler, since no calls are lost due to hand-offs from one satellite to another, as when the satellites move with respect to the users on the earth.

Each up-and-down link (UDL) of a satellite has capacity to support up to C_{UDL} bidirectional calls, while each inter-satellite link (ISL) has capacity equal to C_{ISL} bidirectional calls. We assume that call requests arrive at each satellite according to a Poisson process, and that call holding times are exponentially distributed. We now show how to compute blocking probabilities for the three satellites in the single orbit of Figure 2. The analysis can be generalised to analyse $k > 3$ satellites in a single orbit. For simplicity, we consider only shortest-path routing, although the analysis can be applied to any fixed routing scheme whereby the path taken by a call is fixed and known in advance of the arrival of the call request.

Let n_{ij} be a random variable representing the number of active calls between satellite i and satellite $j, 1 \leq i, j \leq 3$, regardless of whether the calls originated at satellite i or j . In other words, n_{ij} represents a bidirectional call between satellite i and satellite j. As an example, if $n_{12} = 1$, this means, there is a call using an ISL channel from satellite 1 to satellite 2 and an ISL channel from satellite 2 to satellite 1. Therefore, if there is a call between satellite 1 and satellite 1, two bidirectional channels are used. Let λ_{ij} (respectively, $1/\mu_{ij}$) denote the arrival rate (resp., mean holding time) of

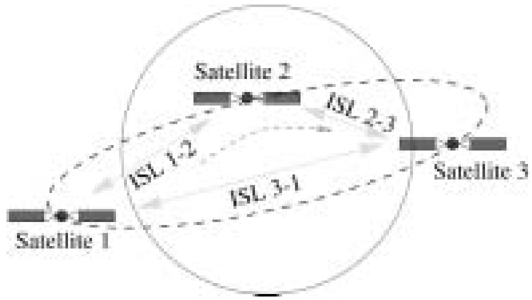

Figure 2: Three satellites in a single orbit

calls between satellites i and j. Then, the evolution of the three-satellite system in Figure 2 can be described by the six-dimensional Markov process:

$$\underline{n} = (n_{11}, n_{12}, n_{13}, n_{22}, n_{23}, n_{33}) \tag{2}$$

Also let $\underline{1}_{ij}$ denote a vector with zeros for all random variables except random variable n_{ij} which is 1. The state transition rates for this Markov process are given by:

$$r(\underline{n}, \underline{n} + \underline{1}_{ij}) = \lambda_{ij} \forall i, j \tag{3}$$

$$r(\underline{n}, \underline{n} - \underline{1}_{ij}) = n_{ij}\mu_{ij} \forall i, j, n_{ij} > 0 \tag{4}$$

The transition in (3) is due to the arrival of a call between satellites i and j, while the transition in (4) is due to the termination of a call between satellites i and j.

Let Ω denote the state space for this Markov process. Due to the fact that some of the calls share common up-and-down and inter-satellite links, the following constraints are imposed on Ω :

$$2n_{11} + n_{12} + n_{13} \leq C_{UDL} \tag{5}$$

$$n_{12} + 2n_{22} + n_{23} \leq C_{UDL} \tag{6}$$

$$n_{13} + n_{23} + 2n_{33} \leq C_{UDL} \tag{7}$$

$$n_{12} \leq C_{ISL} \tag{8}$$

$$n_{13} \leq C_{ISL} \tag{9}$$

$$n_{23} \leq C_{ISL} \tag{10}$$

Constraint (5) ensures that the number of calls originating (equivalently, terminating) at satellite 1 is at most equal to the capacity of the up-and-down link of that satellite. Note that a call that originates and terminates within the footprint of satellite 1 captures two channels, thus the term $2n_{11}$ in constraint (5). Constraints (6) and (7) are similar to (5), but correspond to satellites 2 and 3, respectively. Finally, constraints (8)–(10) ensure that the number of calls using the link between two satellites is at most equal to the capacity of that link. Note that, because of (5)–(7), constraints (8)–(10) become redundant when $C_{ISL} \geq C_{UDL}$. In other words, there is no blocking at the inter-satellite links when the capacity of the links is at least equal to the capacity of the up-and-down links at each satellite[1].

[1] When there are more than three satellites in an orbit, calls between a number of satellite pairs may share a given inter-satellite link. Consequently, the constraints of a k-satellite orbit, $k > 3$, corresponding to (8)–(10) will be similar to constraints (5)–(7), in that the left-hand side will involve a summation over a number of calls. In this case, blocking on inter-satellite links may occur even if $C_{ISL} \geq C_{UDL}$.

It is shown that this system has a closed-form solution which is given by (see Zaim, 2002):

$$P(\underline{n}) = P(n_{11}, n_{12}, n_{13}, n_{22}, n_{23}, n_{33}) = \frac{1}{G} \frac{\rho_{11}^{n_{11}}}{n_{11}!} \frac{\rho_{12}^{n_{12}}}{n_{12}!} \frac{\rho_{13}^{n_{13}}}{n_{13}!} \frac{\rho_{22}^{n_{22}}}{n_{22}!} \frac{\rho_{23}^{n_{23}}}{n_{23}!} \frac{\rho_{33}^{n_{33}}}{n_{33}!}, \underline{n} \in \Omega \quad (11)$$

where G is the normalising constant and $\rho_{ij} = \lambda_{ij} / \mu_{ij}, i,j = 1,2,3$, is the offered load of calls from satellite i to satellite j.

An alternative way is to regard this Markov process as describing a network of six M/M/K/K queues, one for each source/destination pair of calls between the three satellites. Since the satellites do not move, there are no hand-offs, and as a consequence customers do not move from one queue to another. Now, the probability that there are m customers in an M/M/K/K queue is given by the familiar expression $(\rho^m/m!)/\left(\sum_{l=0}^{K} \rho^l/l!\right)$, and therefore, the probability that there are $(n_{11},n_{12},n_{13},n_{22},n_{23},n_{33})$ customers in the six queues is given by (11). Unlike previous studies reported in the literature, our model takes into account the fact that the six M/M/K/K queues are not independent, since the number of customers accepted in each M/M/K/K queue depends on the number of customers in other queues, as described by the constraints (5)–(10).

3. AN EXACT MODEL TO CALCULATE NEW AND HAND-OFF CALL BLOCKING

Let us return to the 3-satellite orbit (see Figure 2) and introduce hand-offs. This system can be described by a continuous-time Markov process with the same number of random variables as the no-hand-offs model of Section 2 (i.e., $n_{11},\ldots,n_{33}$), the same transition rates (3) and (4), but with a number of additional transition rates to account for hand-offs. We will now derive the transition rates due to hand-offs.

Consider calls between a customer served by satellite 1 and a customer served by satellite 2. There are n_{12} such calls serving $2n_{12}$ customers: n_{12} customers on the footprint of satellite 1 and n_{12} on the footprint of satellite 2. Consider a call between customer A and customer B, served by satellites 1 and 2, respectively. The probability that customer A will be in the hand-off area of satellite 1 but B will not be in the hand-off area of satellite 2 is $q(1-q)=q-q^2$. But, from (1), we have that $\lim_{\Delta t \to 0} \frac{q^2}{\Delta t} = 0$, so the rate at which these calls experience a hand-off from satellite 1 to satellite 3 that follows it is αn_{12}. Based on the above discussion, we thus have:

$$r(\underline{n},\underline{n} - \underline{1}_{12} + \underline{1}_{23}) = \alpha n_{12},\ n_{12} > 0 \quad (12)$$

Similarly, the probability that customer B will be in the hand-off area of satellite 2 but A will not be in the hand-off area of satellite 1 is $q(1-q)=q-q^2$. Thus, the rate at which these calls experience a hand-off from satellite 2 to satellite 1 that follows it is again αn_{12}:

$$r(\underline{n},\underline{n} - \underline{1}_{12} + \underline{1}_{11}) = \alpha n_{12},\ n_{12} > 0 \quad (13)$$

On the other hand, the probability that both customers A and B are in the hand-off area of their respective satellites is q^2, which, from (1) is $o(\Delta t)$, and thus simultaneous hand-offs are not allowed. Now consider calls between customers that are both served by the same satellite, say, satellite 1. There are n_{11} such calls serving $2n_{11}$ customers. The probability that exactly one of the customers of a call is in the hand-off area of satellite 1 is $2q(1-q)$, so the rate at which these calls experience hand-offs (involving a single customer) to satellite 3 is $2\alpha n_{11}$

$$r(\underline{n},\underline{n} - \underline{1}_{11} + \underline{1}_{13}) = 2\alpha n_{11},\ n_{11} > 0 \quad (14)$$

As before, the probability that both customers of the call are in the hand-off area of satellite 1 is q^2, and again, no simultaneous hand-offs are allowed.

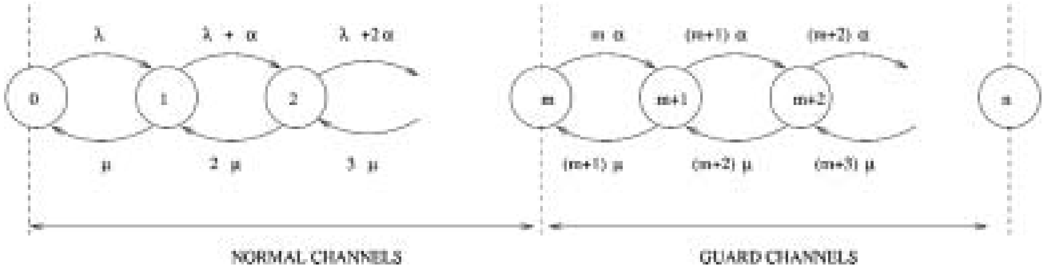

Figure 3: Markov Chain with Guard Channels

The transition rates involving the other four random variables in the state description (2) can be derived using similar arguments. For completeness, these transition rates are provided in (15)-(20).

$$r(\underline{n},\underline{n} - \underline{1}_{13} + \underline{1}_{12}) = \alpha n_{13},\ n_{13} > 0 \qquad (15)$$

$$r(\underline{n},\underline{n} - \underline{1}_{13} + \underline{1}_{33}) = \alpha n_{13},\ n_{13} > 0 \qquad (16)$$

$$r(\underline{n},\underline{n} - \underline{1}_{22} + \underline{1}_{12}) = 2\alpha n_{22},\ n_{22} > 0 \qquad (17)$$

$$r(\underline{n},\underline{n} - \underline{1}_{23} + \underline{1}_{13}) = \alpha n_{23},\ n_{23} > 0 \qquad (18)$$

$$r(\underline{n},\underline{n} - \underline{1}_{23} + \underline{1}_{2}) = \alpha n_{23},\ n_{23} > 0 \qquad (19)$$

$$r(\underline{n},\underline{n} - \underline{1}_{33} + \underline{1}_{23}) = 2\alpha n_{33},\ n_{33} > 0 \qquad (20)$$

From the queueing point of view, this system is the queueing network of M/M/K/K queues described in Section 2, where customers are allowed to move between queues according to (12)–(20). (Recall that in the queueing model of Section 2, customers are not allowed to move from node to node.)

In order to separate the blocking probability of new and hand-off calls, we define Guard Channels. That means, some percentage of the total number of channels used by each n_{ij} is reserved for hand-off calls only. Therefore, our Markov Chain differs. The new Markov chain is illustrated in Figure 3. As we changed the Markov Chain by adding some guard channels, we need to solve this new Markov Chain to calculate the new $P(n)$. For the sake of clarity, we will solve this Markov Chain for one of these queues in our queueing network and then will compute the total blocking probability using the formula found for one queue by generalisation.

Let us start solving the above Markov Chain. First, we will work on the Normal Channels, and solve the chain until m (where the arrival rate consists of new call arrival and hand-off call arrivals).

$$P_m = \frac{\lambda + (m-1)\alpha}{m\mu} P_{m-1} \qquad (21)$$

Using 21, we can solve the loop at the border of Normal and Guard Channel area to find P_{m+1} with P_m. This is given as

$$P_{m+1} = \frac{m\alpha}{(m+1)\mu} P_m \qquad (22)$$

If we continue working on the Guard Channel area, we can find

$$P_n = \frac{(n-1)\alpha}{n\mu} P_{n-1} \qquad (23)$$

Now, we can solve P_m in [REF:MC-1] iteratively to find it using P_0

$$P_m = \prod_{i=1}^{m} \frac{\lambda + (i-1)\alpha}{i\mu} P_0 \tag{24}$$

If we solve P_n in 23 iteratively to obtain P_n with P_m

$$P_n = \prod_{j=1}^{m} \frac{(n-j)\alpha}{(n-j+1)\mu} P_m \tag{25}$$

Then we replace P_m with P_m in 24

$$P_n = \prod_{j=1}^{m} \frac{(n-j)\alpha}{(n-j+1)\mu} \prod_{i=1}^{m} \frac{\lambda + (i-1)\alpha}{i\mu} P_0 \tag{26}$$

Let us now simplify P_n in 26

$$P_n = \prod_{i=1}^{m} \frac{(n-i)\alpha}{(n-i+1)\mu} \frac{\lambda + (i-1)\alpha}{i\mu} P_0 \tag{27}$$

where $n > m$ or in other words, the probability of being in a state greater than the number of normal state. Otherwise

$$P_n = \prod_{i=1}^{n} \frac{\lambda + (i-1)\alpha}{i\mu} P_0 \tag{28}$$

where $n <= m$ and

$$P_n = P_0 \tag{29}$$

where $n = 0$

Therefore we can calculate P_0 as the sum of all possible states

$$\sum_{i=0}^{N} P_n = 1 \tag{30}$$

$$\left(1 + \sum_{k=1}^{m} \prod_{i=1}^{k} \frac{\lambda + (i-1)\alpha}{i\mu} + \sum_{k=m+1}^{N} \prod_{i=1}^{m} \frac{(k-i)\alpha}{(k-i+1)\mu} \frac{\lambda(i-1)\alpha}{i\mu}\right) P_0 = 1 \tag{31}$$

So P_0 is

$$P_0 = \frac{1}{\left(1 + \sum_{k=1}^{m} \prod_{i=1}^{k} \frac{\lambda+(i-1)\alpha}{i\mu} + \sum_{k=m+1}^{N} \prod_{i=1}^{m} \frac{(k-i)\alpha}{(k-i+1)\mu} \frac{\lambda(i-1)\alpha}{i\mu}\right)} \tag{32}$$

Once *P*0 is found, we can easily define *G* as the sum of 32s for all *x*,*y* = 1,2,3 as shown in Zaim (2002).

$$
\begin{aligned}
G = \sum_{\underline{n}} & \left\{1+\sum_{k=1}^{m}\prod_{i=1}^{k}\frac{\lambda_{11}+(i-1)\alpha}{i\mu_{11}}+\sum_{k=m+1}^{N}\prod_{i=1}^{m}\frac{(k-i)\alpha}{(k-i+1)\mu_{11}}\frac{\lambda_{11}(i-1)\alpha}{i\mu_{11}}\right\}\times \\
& \left\{1+\sum_{k=1}^{m}\prod_{i=1}^{k}\frac{\lambda_{12}+(i-1)\alpha}{i\mu_{12}}+\sum_{k=m+1}^{N}\prod_{i=1}^{m}\frac{(k-i)\alpha}{(k-i+1)\mu_{12}}\frac{\lambda_{12}(i-1)\alpha}{i\mu_{12}}\right\}\times \\
& \left\{1+\sum_{k=1}^{m}\prod_{i=1}^{k}\frac{\lambda_{13}+(i-1)\alpha}{i\mu_{13}}+\sum_{k=m+1}^{N}\prod_{i=1}^{m}\frac{(k-i)\alpha}{(k-i+1)\mu_{13}}\frac{\lambda_{13}(i-1)\alpha}{i\mu_{13}}\right\}\times \\
& \left\{1+\sum_{k=1}^{m}\prod_{i=1}^{k}\frac{\lambda_{22}+(i-1)\alpha}{i\mu_{22}}+\sum_{k=m+1}^{N}\prod_{i=1}^{m}\frac{(k-i)\alpha}{(k-i+1)\mu_{22}}\frac{\lambda_{22}(i-1)\alpha}{i\mu_{22}}\right\}\times \\
& \left\{1+\sum_{k=1}^{m}\prod_{i=1}^{k}\frac{\lambda_{23}+(i-1)\alpha}{i\mu_{23}}+\sum_{k=m+1}^{N}\prod_{i=1}^{m}\frac{(k-i)\alpha}{(k-i+1)\mu_{23}}\frac{\lambda_{23}(i-1)\alpha}{i\mu_{23}}\right\}\times \\
& \left\{1+\sum_{k=1}^{m}\prod_{i=1}^{k}\frac{\lambda_{33}+(i-1)\alpha}{i\mu_{33}}+\sum_{k=m+1}^{N}\prod_{i=1}^{m}\frac{(k-i)\alpha}{(k-i+1)\mu_{33}}\frac{\lambda_{33}(i-1)\alpha}{i\mu_{33}}\right\}
\end{aligned} \tag{33}
$$

Finally $P(\underline{n})$ is

$$
\begin{aligned}
& P(\underline{n}) = P(n_{11}, n_{12}, n_{13}, n_{22}, n_{23}, n_{33}) = \frac{1}{G}\times \\
& \left\{\begin{array}{ll} 1, & n_{11}<1 \\ \prod_{i=1}^{n_{11}}\frac{\lambda_{11}+(i-1)\alpha}{i\mu_{11}}, & 0<n_{11}<=m \\ \prod_{i=1}^{m}\left(\frac{(n_{11}-i)\alpha}{(n_{11}-i+1)\mu_{11}}\right)\left(\frac{\lambda_{11}(i-1)\alpha}{i\mu_{11}}\right), & n_{11}>m \end{array}\right\}\times \\
& \left\{\begin{array}{ll} 1, & n_{12}<1 \\ \prod_{i=1}^{n_{12}}\frac{\lambda_{12}+(i-1)\alpha}{i\mu_{12}}, & 0<n_{12}<=m \\ \prod_{i=1}^{m}\left(\frac{(n_{12}-i)\alpha}{(n_{12}-i+1)\mu_{12}}\right)\left(\frac{\lambda_{12}(i-1)\alpha}{i\mu_{12}}\right), & n_{12}>m \end{array}\right\}\times \\
& \left\{\begin{array}{ll} 1, & n_{13}<1 \\ \prod_{i=1}^{n_{13}}\frac{\lambda_{13}+(i-1)\alpha}{i\mu_{13}}, & 0<n_{13}<=m \\ \prod_{i=1}^{m}\left(\frac{(n_{13}-i)\alpha}{(n_{13}-i+1)\mu_{13}}\right)\left(\frac{\lambda_{13}(i-1)\alpha}{i\mu_{13}}\right), & n_{13}>m \end{array}\right\}\times \\
& \left\{\begin{array}{ll} 1, & n_{22}<1 \\ \prod_{i=1}^{n_{22}}\frac{\lambda_{22}+(i-1)\alpha}{i\mu_{22}}, & 0<n_{22}<=m \\ \prod_{i=1}^{m}\left(\frac{(n_{22}-i)\alpha}{(n_{22}-i+1)\mu_{22}}\right)\left(\frac{\lambda_{22}(i-1)\alpha}{i\mu_{22}}\right), & n_{22}>m \end{array}\right\}\times \\
& \left\{\begin{array}{ll} 1, & n_{23}<1 \\ \prod_{i=1}^{n_{23}}\frac{\lambda_{23}+(i-1)\alpha}{i\mu_{23}}, & 0<n_{23}<=m \\ \prod_{i=1}^{m}\left(\frac{(n_{23}-i)\alpha}{(n_{23}-i+1)\mu_{23}}\right)\left(\frac{\lambda_{23}(i-1)\alpha}{i\mu_{23}}\right), & n_{23}>m \end{array}\right\}\times \\
& \left\{\begin{array}{ll} 1, & n_{33}<1 \\ \prod_{i=1}^{n_{33}}\frac{\lambda_{33}+(i-1)\alpha}{i\mu_{33}}, & 0<n_{33}<=m \\ \prod_{i=1}^{m}\left(\frac{(n_{33}-i)\alpha}{(n_{33}-i+1)\mu_{33}}\right)\left(\frac{\lambda_{33}(i-1)\alpha}{i\mu_{33}}\right), & n_{33}>m \end{array}\right\}
\end{aligned} \tag{34}
$$

As we can see, the solution is the product of six terms defined in 27–29[2] each corresponding to one of the six different source/destination pair of calls. Therefore, it is easily generalisable to a *k*-satellite system, $k > 3$.

Due to the fact that the limits for the new and hand-off calls are not the same any more, we need to redefine the following contraints for new calls[3]:

[2] Each formula is applicable according to the value of n_{ij}.

3 The constraints 5–10 used for the old Markov Process are still valid for hand-off calls.

$$2n_{11} + n_{12} + n_{13} \leq C_{UDL} - GC_{UDL} \quad (35)$$

$$n_{12} + 2n_{22} + n_{23} \leq C_{UDL} - GC_{UDL} \quad (36)$$

$$n_{13} + n_{23} + 2n_{33} \leq C_{UDL} - GC_{UDL} \quad (37)$$

$$n_{12} \leq C_{ISL} - GC_{ISL} \quad (38)$$

$$n_{13} \leq C_{ISL} - GC_{ISL} \quad (39)$$

$$n_{23} \leq C_{ISL} - GC_{ISL} \quad (40)$$

where GC_{UDL} and GC_{ISL} are the number of guard channels reserved for UDL and ISL links, respectively.

Now the probability of a new call originating or terminating at satellite 1 will be blocked on the up-and-down link of that satelite is given by:

$$P^{new}_{UDL_1} = \sum_{2n_{11}+n_{12}+n_{13}=C_{UDL}-GC_{UDL}} P(\underline{n}) \quad (41)$$

While the probability of a hand-off call generating a hand-off call between satellite 1 and j, j = 1,2,3 will be blocked on the up-and-down link of that satellite is given by:

$$P^{hand-off}_{UDL_1} = \sum_{2n_{11}+n_{12}+n_{13}=C_{UDL}} P(\underline{n}) \quad (42)$$

Once the blocking probabilities on all up-and-down and intersatellite links have been obtained using expressions similar to 41 and 42, the blocking probability of calls between any two satellites can be easily obtained.

4. TEST RESULTS

In this section we verify the accuracy of the Markov Model by observing the new and handoff call blocking probabilities under different load and resources with different traffic types. In the figures presented, simulation results are plotted along with 95% confidence intervals estimated by the method of replications. The number of replications is 30, with each simulation run lasting until each type of calls has at least 15,000 arrivals.

We obtained results using a 3-satellite orbit with two different traffic patterns. Let $r_{i,j}$ denote the probability that a call originating by a customer served by satellite i is for a customer served by satellite j. The first pattern is the uniform traffic pattern, that is:

$$r_{i,j} = \frac{1}{K} \forall i, j (\text{uniform\_pattern}) \quad (43)$$

where K is the number of satellites.

The second traffic pattern is the hot spot pattern in which one of the satellites, satellite X, carries most of the traffic. If we let $r_{i,j}$ represent calls originating from satellite i and terminating at satellite j, then this pattern is such that:

$$r_{i,j} = \begin{cases} 0.7, & i = 1, \cdots, K, j = X (\text{hot\_spot\_pattern}) \\ \frac{0.3}{K-1}, & i, j \neq X \end{cases} \quad (44)$$

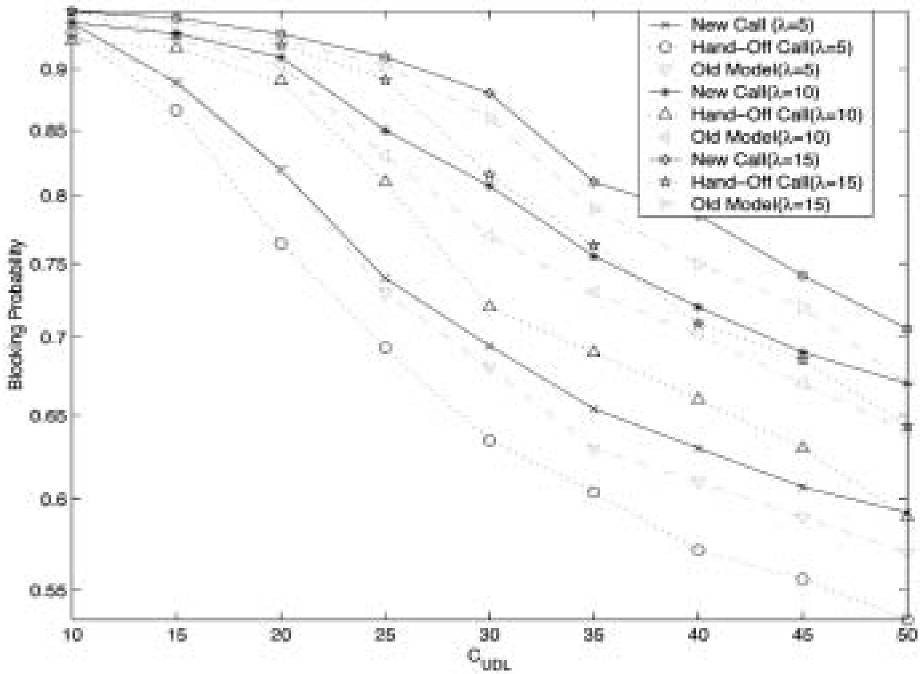

Figure 4: Uniform Traffic Pattern with C.ISL=10, GC=10%, comparing with Old Model

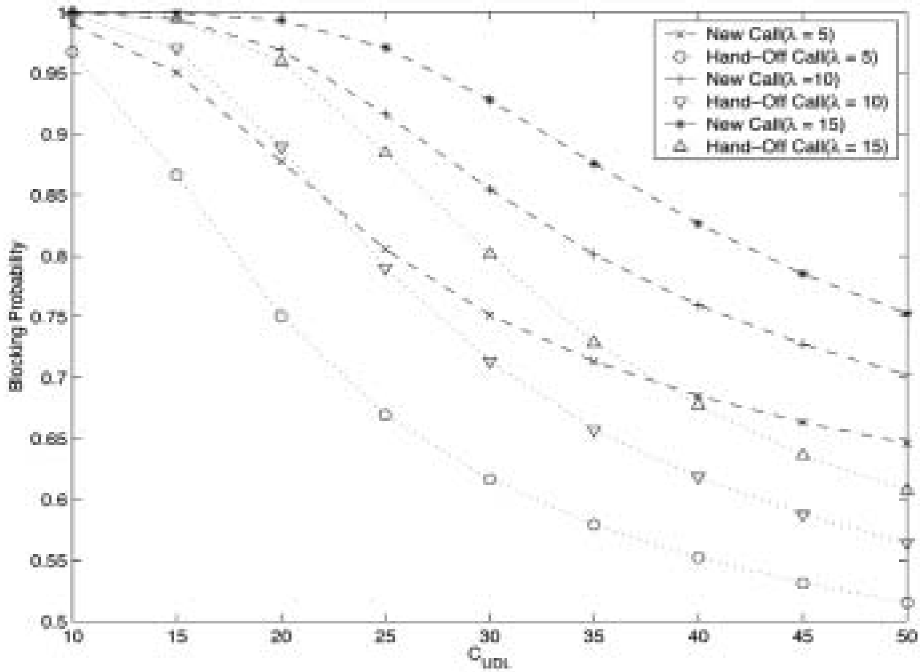

Figure 5: Uniform Traffic Pattern with C_ISL=10, GC=20%

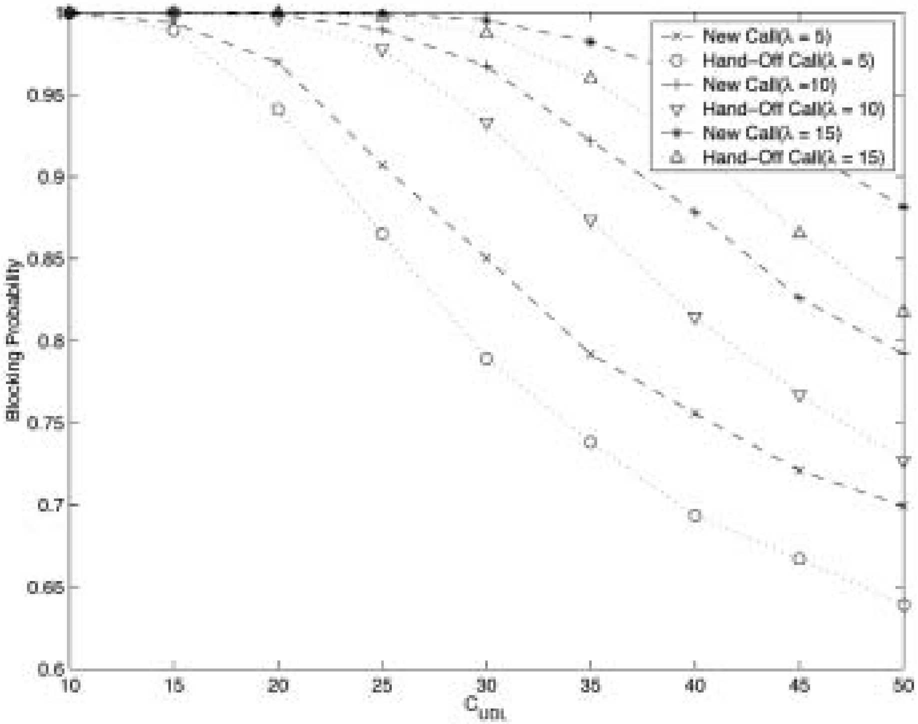

Figure 6: Hot Spot Traffic Pattern, GC=10%

Figure 4 corresponds to satellite systems with intersatellite link capacities C_{ISL} equal to 10, and plot the call blocking probability against the capacity C_{UDL} of up-and-down links, when the number of guard channels are 10% of the total channel capacities, for uniform traffic pattern. The blocking probabilities we are witnessing in these figures are the new and hand-off call blocking probabilities at up-and-down link of satellite 1 and total blocking probability at satellite 1 calculated using the method proposed in Zaim (2002). As shown in this figure, although the old results are near to new and hand-off call blocking probabilities calculated using the new model, their accuracy is less then the new results. Taking into account the fact that all figures use logarithmic y-axis, the improvement with the new model becomes more obvious. Once compared with the old model, and showed that our new model performs better, we will not use the old model in the following results.

Figure 5, on the other hand, uses 20% of the total available channels as guard channels to give more priority to hand-off calls againts new calls. As shown in this figure, the blocking probabilities of hand-off calls are less than the blocking probabilities of hand-off calls in Figure 4 as we are reserving more channels to hand-off calls in Figure 5. Conversely, blocking probabilities of new calls increase due to more restricted number of available channels for new calls. Therefore, we observe exactly the expected results in Figures 4 and 5.

Figures 6 and 7, on the other hand, correspond to the same satellite system using the hot spot traffic pattern again with 10 and 20% guard channels, respectively. Similar behaviours are also observed for this traffic type with increased blocking probabilities because the loading in satellite 1 is increased in this scheme.

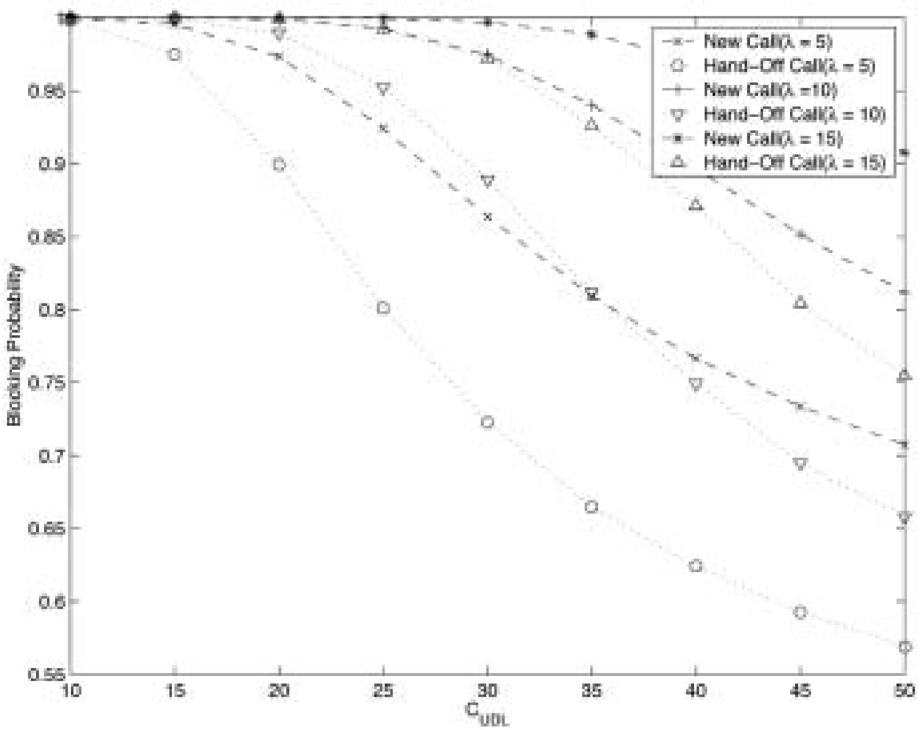

Figure 7: Hot Spot Traffic Pattern, GC=20%

5. CONCLUDING REMARKS

We have defined a new Markov Model to calculate the call blocking probabilities for new and hand-off calls. The model is an extension of the study proposed in Zaim (2002). The model proposed in Zaim (2002) suffered from the fact that, it was not possible to use that model to differentiate a call blocking due to new call arrival or a hand-off. The newly proposed model, on the other hand gives us the flexibility of calculating the new and hand-off calls separately. As explained in Karafolas (2000), design of a LEO satellite system has two important factors such as Network Physical Topology and Network Traffic Demand. Taking into account the future systems with onboard processing capabilities, we need an analytical model to estimate onboard proccessing load. In Karafolas (2000) it is shown that the calculation of the total traffic is based on the sum of the number of new and hand-off calls. Therefore, it is important for the design of future satellite systems to know the new and hand-off call blocking so that the up and down link and transit capacities could be estimated correctly.

Another practical use of this study is related with the guard channels. Therefore, it is possible as a future work to add some guard channels to be used for the hand-off calls. That way, the quality of service of ongoing calls will be increased. The method proposed in this study may also be used as the core of such a study to adjust the number of guard channels necessary to improve both the new call and hand-off call blocking probabilities.

REFERENCES

DOSIERE, F., ZEIN, T., MARAL, G. and BOUTES, J.P. (1993): A Model for the handover traffic in low earth-orbiting satellite networks for personal communications. *IEEE Globecom*.

GANZ, A., GONG, Y. and LI, B. (1994): Performance study of low earth orbit satellite systems, *IEEE Transactions on Communications*, 42(2,3,4).

LUTZ, E., WERNER, M. and JAHN, A. (2000): *Satellite Systems for Personal and Broadband Communications*, Springer, Germany.

OBRADOVIC, V. and CIGOJ, S. (1999): Performance evaluation of prioritized handover management for (LEO) mobile satellite systems with dynamic channel assignment, *Global Telecommunications Conference*, volume 1a.

PENNONI, G. and FERRONI, A. (1994): Mobility management in (LEO/ICO) satellite systems: Preliminary simulation results, *PIMRC*, 1323–1329.

FANTACCI R. and GIAMBENE, G. (1995): Efficient dynamic channel allocation techniques with handover queueing for mobile satellite networks, *IEEE Journal in Selected Areas in Communications*, 13(2).

FANTACCI, R. and GIAMBENE, G. (1999): Different queueing policies for handover requests in low earth orbit mobile satellite systems, *IEEE Transactions on Vehicular Technology*, 48(2): 448–458.

KARAFOLAS, N and BARONI, S. (2000): Optical Satellite Networks, *Journal of Lightwave Technology*, 18(12): 1792–1806.

RESTREPO, J. and MARAL, G. (1997): Guaranteed handover (GH) service in a non-geo constellation with "satellite-fixed-cell" (SFC) systems, *International Mobile Satellite Conference*.

RUIZ, G., DOUMI, T.L. and GARDINER, J.G. (1998): Teletraffic analysis and simulation of mobile satellite systems, *IEEE Transactions of Vehicular Technology*, 47(1): 311–320.

WAN, P.J., NGUYEN, V. and BAI, H.(1999): Advanced handovers arrangement and channel allocation in (LEO) satellite networks, *Global Telecommunications Conference*, volume 1a.

ZAIM, A.H., ROUSKAS, G.N. and PERROS, H.G. (2002): Computing call blocking probabilities in (LEO) satellite networks: The single orbit case, *IEEE Transactions on Vehicular Technology*, 51(2).

ZAIM, A.H., PERROS, H.G. and ROUSKAS, G.N.(2002): Performance Analysis of (LEO) satellite networks, *Networking 2002*.

BIOGRAPHICAL NOTES


Abdul Halim Zaim

Abdul Halim Zaim received his B.Sc. degree (Honours) in computer science and engineering from Yildiz Technical University, Istanbul, Turkey, in 1993; his M.Sc. degree in computer engineering from Bogazici University, Istanbul, Turkey, in 1996 and a Ph.D. degree in electrical and computer engineering from North Carolina State University, Raleigh, NC, USA, in 2001.

As a teaching assistant and lecturer, he taught several courses in Istanbul and Yeditepe Universities between 1993–1997. In 1998–1999 he was with Alcatel, Raleigh. He worked as a Postdoctoral Research Assistant at North Carolina State University (working at MCNC under contract with NCSU) and an Adjunct Professor at North Carolina State University during 2001–2002.

He is currently an Assistant Professor at Istanbul University, Turkey. His research interests include computer performance evaluation, satellite and high-speed networks, network protocols, optical networks and computer network design.