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Satellite Handover Techniques for LEO Networks Serving Air Traffic Control Communication

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Abstract

Satellite systems are a perfect alternative system to cover wide areas on the earth, especially oceans and desert areas, and to provide broadband communications to all aircraft. Low earth orbit (LEO) satellite constellations are important in future air traffic control (ATC) communication networks due to their advantages, such as whole global coverage and low propagation time. However, the satellites are not stationary; a contact between aircraft and satellite may be subjected to handovers. Many techniques have been proposed in order to deal with the cell handover issue. In this paper, the Handover procedure implication in the communication blocking probability is estimated via simulation. To reduce the high number of Handovers, some strategies are used to cope with. Simulation models have been developed to improve all the features evaluated in this paper.

Keywords: *Air Traffic Control, Handover, satellite constellation, the queue, guard channel*

1. Introduction

The use of satellite systems provides permanent relays between ground stations and aircraft throughout the entire globe. To handle the increasing aircraft number, the International Civil Aviation Organization (ICAO) proposes a system of air traffic navigation reliable presented in Figure 1, capacitive and global based on a concept called Communication Navigation Surveillance (CNS), a system of data link: Aeronautical Telecommunication Network (ATN). The current Air Traffic Management (ATM) procedures [1] are still based on VHF communications and claims for an improvement of ATM concepts. These challenges require the development of satellite communication, navigation and surveillance systems, aiming at providing high reliability and availability system.

The increasing number of disasters [2], natural or man-made, occurred during the last years, in the first hours after the disaster, the existing solutions to overcome communication problems when terrestrial infrastructures are not available are the use of satellite communication systems.

Many LEO constellations have been proposed in the literature (Iridium [3], Globalstar, etc.), while the operation of the Iridium system has given a very important experience for the study of the serious issues of these systems.

The visibility period of a satellite in LEO systems [4] can be about 5 min due to the high speed of satellites. This leads to a remarkable probability of communication interruption and the handover mechanism becomes important for the global performance of the system. There are two types of handover events, as is the case in land mobile systems, the cell handover [5] and the satellite handover. The first one refers to the transfer of an ongoing contact from one cell to the next one in the same satellite footprint while the second one describes the transfer of an ongoing contact from a satellite to another one.

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Few studies have been carried out on the issue of satellite handover, investigating channel allocation policies for new and handover contacts using mainly fixed channel allocation (FCA) techniques. In this paper different queuing policies for handover requests were investigated in order to enhance them in air navigation satellite communication.

This paper is organized as follows: Section 2 presents the data model and lists the assumptions and some preliminary notions. Section 3 presents the priority strategies, Section 4 presents the simulations and discussions and the last Section will be the conclusion.

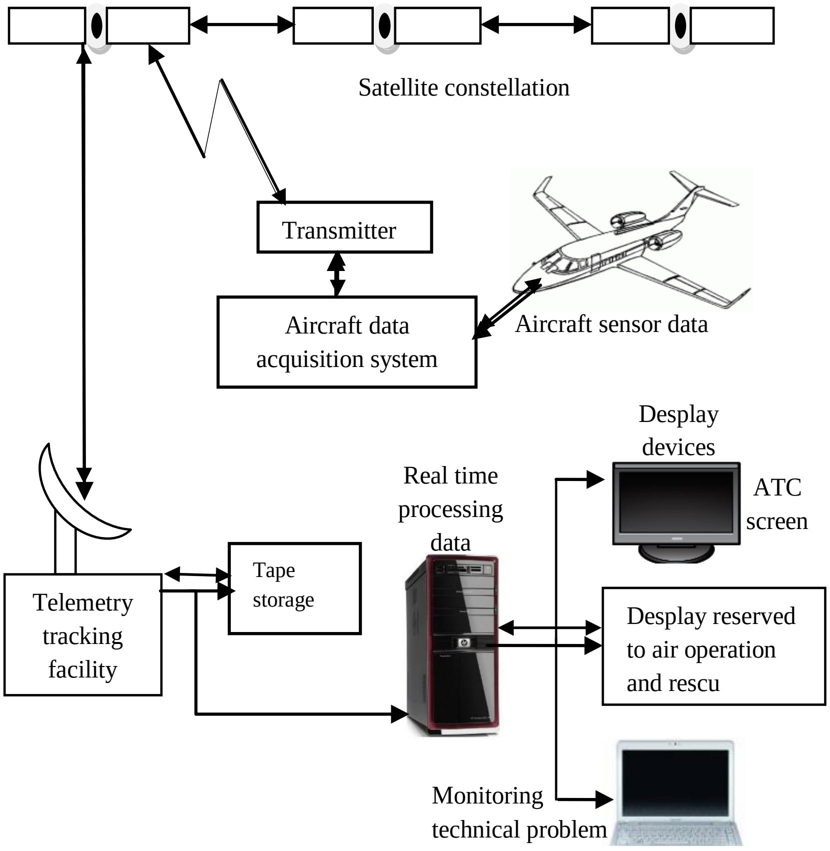
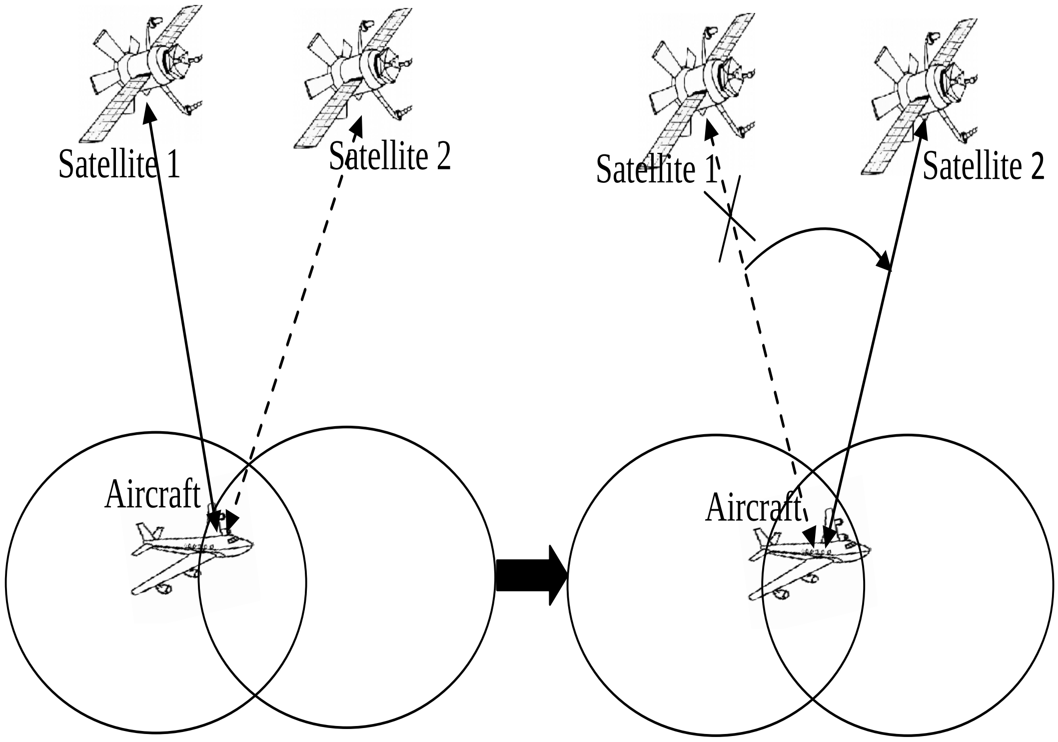


Figure 1. Simplified Block Diagram of Satellite air Communication System

2. Data Model and Preliminary

For the consistence with previous literatures [6] and its operational availability, the Iridium system is adopted as the basic system model. The satellite ground-track speed is approximately 26600 km/h, the Iridium satellite network is modeled as a one-dimensional environment in which mobile users move in straight lines and at constant speed.

We assume that the arrival of new contacts forms a Poisson process with an average λ and its intensity service is μ. The arrivals of handover requests, presented in Figure 2, form a Poisson process of average λh. If an aircraft is in the satellite cell, the contact duration (with mean $1/\mu$) is equal to the time during which the contact is in progress.



a. Before handoff

b. After handoff

Figure 2. Hard Handoff Between the Aircraft and Satellites

2.1. Traffic Model

Many traffic models have been established based on various assumptions about user mobility. In the coming subsection, we briefly introduce some of these traffic models.

2.1.1. Hong and Rappaport's Traffic Model (Two-Dimensional): Hong and Rappaport [7] have proposed a traffic model. They assume that the aircraft are spread evenly over the service area; thus, the location of an aircraft when a contact is initiated by the user is uniformly distributed in the cell.

They also assume that an aircraft initiating a contact moves from the current location in any direction with equal probability and that this direction does not change while the aircraft remains in the cell.

From these assumptions the arrival rate of handoff contacts is given by:

$$\lambda_H = \frac{P_h\left(1 - B_O\right)}{1 - P_{hh}\left(1 - P_{f'}\right)}\lambda_O \qquad (1)$$

Where:

- P_h = the probability that a new contact that is not blocked would require at least one handoff
- P_{hh} = the probability of a contact that has already been handed off successfully would require another handoff
- B_O = the blocking probability of originating contacts
- $P_{f'}$ = the probability of handoff failure
- λ_O = the arrival rate of originating contacts in a cell

2.1.2. Zeng et al.'s Approximated Traffic Model (Any Dimensional): Zeng et al.'s model [8] using simple formula, when the blocking probability of originating contacts and the forced termination probability of handoff contacts are small, the average numbers of occupied channels E[C] is approximated by:

$$E(C) \approx \frac{\lambda_O + \lambda_H}{\mu} \tag{2}$$

$E[C]$ is the average number of contacts in a cell

If a channel has been allocated to an aircraft, it will be released at the end of the contact is due to a handover to a neighboring cell. So the channel occupation time is the minimum duration of the contact.

We denote by:

- Pb: probability that a new user finds all channels busy in a cell.
- Ph: probability of failure of the handover. Is the probability that a handover contact finds all channels occupied on his arrival in the neighboring cell.
- Pf: the probability of forced termination of the contact. Is the probability that a contact has been accepted by the system is interrupted due to failure of handover.

3. Handoff Schemes in Single Traffic Systems

In the coming section, we introduce nonpriority, priority, and queuing handoff schemes for a single traffic system such as a voice or a data system. We assume that a system has many cells, and each has S channels. The channel holding time having an exponential distribution with mean rate μ. Both originating and handoff contacts are generated in a cell, respectively with mean rates λ_O and λ_H. We assume the system with a homogeneous cell. We concentrate our interest on a single cell (called the marked cell).

3.1. No Priority Strategy (NPS)

In this case, all S channels are used by both originating and handoff request contacts [9], the Handover requests are handled exactly in the same way as an originating contact. So, the blocking probability of handover is equal to the probability of blocking new contacts. The NPS model is presented in Figure 3, where S is the number of channels present in the satellite cell.

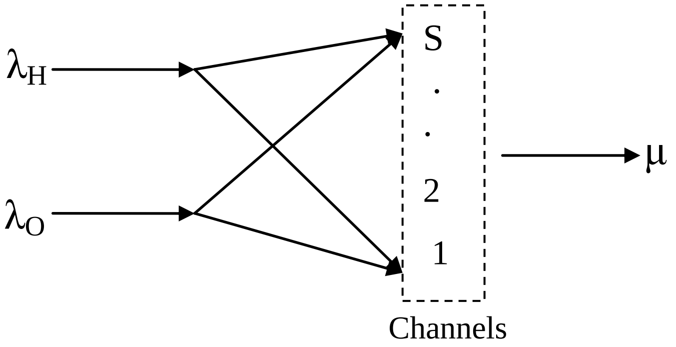


Figure 3. No Priority Strategy Scheme

When the S channel are free, they will be used by new aircraft contact or Handover. If all channels are busy the new contact will be blocked.

$$Pb = Ph = Ps = \frac{\dfrac{\left(\dfrac{\lambda + \lambda hi}{\mu}\right)^{s}}{s!}}{\displaystyle\sum_{k=0}^{s} \dfrac{\left(\dfrac{\lambda + \lambda hi}{\mu}\right)^{k}}{k!}} \tag{3}$$

3.2. Priority Strategy

3.2.1. Handoff Call Queuing Prioritizing Scheme (QPS): If no free channels in the neighboring cell, the handover request is inserted into a queue. The mobile continues to use the channel in the current cell. If a channel in the neighboring cell becomes available before the end of the range of degradation, the handover takes place.

If the mobile crosses the surface of the handover and finds no channel available, it is forced termination of the contact and releases the channel.

If the queue is empty, the released channel is idle. Otherwise, it is assigned to a handover's contact in the queue (Figure 4). The Handover's contact is served according to the method of queue.

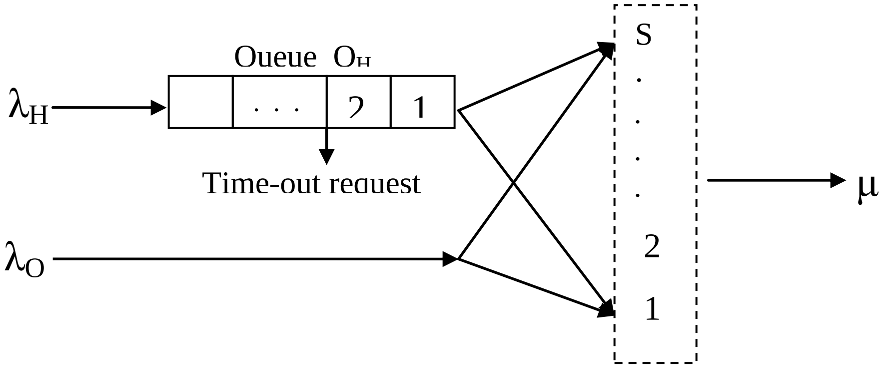


Figure 4. System Model with Priority and Queue for Handoff Contact

$$P_n \begin{cases} \frac{(\lambda+\lambda h)^n}{n!\,\mu^n} P_0 & 1 \le n \le s-1 \\ \frac{(\lambda+\lambda h)^s \lambda h^{n-s}}{s!\,\mu^s \prod_{j=1}^{n-s}(s\mu + j\mu_w)} P_0 & n \ge s \end{cases} \tag{4}$$

New contacts are blocked if all channels available in the satellite cell are occupied. We get:

$$Pb = \sum_{n=s}^{\infty} P_n \tag{5}$$

In the state n, the failure probability of handover is given by :

$$P_{b2|n} = 1 - \prod_{j=0}^{n-s}\left[1 - \frac{\mu_w}{(s\mu+\mu_w)^{2j}}\right] \tag{6}$$

Therefore Ph is given by:

$$Ph = \sum_{n=s}^{\infty} P_{b2|n} P_n \tag{7}$$

3.2.2. Reservation Channels Strategy (RCS) : Guard channels improve the probability of success of the handover by reserving a fixed number of guard channels reserved exclusively for Handover (Figure 5). The remaining channels are used for Handover and new contacts.

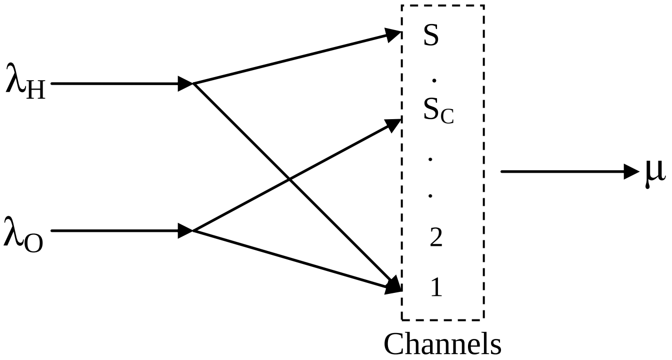


Figure 5. System Model with Priority and Reservation Channel for Handoff Contact

$$P_0 = \left[\sum_{j=0}^{n} \frac{\left(\frac{\lambda+\lambda h}{\mu}\right)^j}{j!} + \sum_{j=n+1}^{s} \frac{(\lambda h)^{j-n}(\lambda+\lambda h)^n}{j!\,\mu^j}\right]^{-1} \tag{8}$$

Or $a = \left(\dfrac{\lambda + \lambda h}{\mu} \right), \quad r = \dfrac{\lambda}{a\mu}$

The blocking probability of new contacts is equal to:

$$P = 1 - \sum_j \frac{(a)^j}{j!} P_0 \tag{9}$$

The blocking probability of handover is equal to:

$$Ph = P_0 \frac{a^s}{s!} (1 - r)^n \tag{10}$$

3.2.3. Guard Channels with Queue for Handoff contact (QPS +RCS): It is a combination of the two previous techniques queuing requests and guard channels strategy reserved exclusively for guards Handover [7]. The state transition diagram is shown in Figure 6.

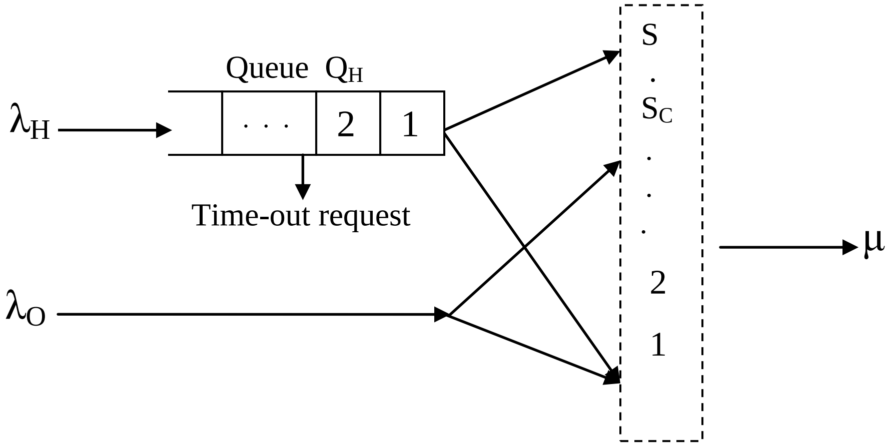


Figure 6. System Model with Reservation Channel and Queue for Handoff Contact

$$P(i) = \begin{cases} \dfrac{(\lambda + \lambda h)^i}{i!\,\mu^i} P(0) & 0 \le i \le s_C \\[2ex] \dfrac{(\lambda + \lambda h)^{s_C} \lambda h^{i - s_C}}{i!\,\mu^i} P(0) & s_C < i \le s \\[2ex] \dfrac{(\lambda + \lambda h)^{s_C} \lambda_H^{i - s_C}}{s!\,\mu^s \prod_{j=1}^{i-s} [s\mu + j(\mu_w)]} P(0) & s < i < \infty \end{cases} \tag{11}$$

Where:

$$P(0)=\left\{\sum_{i=0}^{S_C}\frac{(\lambda+\lambda h)^i}{i!\mu^i}+\sum_{i=S_C+1}^{S}\frac{(\lambda+\lambda h)^{S_C}\lambda h^{i-S_C}}{i!\mu^i}+\sum_{i=S+1}^{\infty}\frac{(\lambda+\lambda h)^{S_C}}{S!\mu^S}\frac{\lambda h^{i-S_C}}{\prod_{j=1}^{i-S}[S\mu+j(\mu_w)]}\right\}^{-1} \quad (12)$$

So we obtain:

$$Pb=\sum_{i=S_C}^{S}P(i) \quad (13)$$

$$Ph=\sum_{k=0}^{\infty}P(S+k)P_{fh|k} \quad (14)$$

$$P_{fh|k}=1-\left(\frac{\mu_w}{\mu S+\mu_w}\right)\prod_{i=1}^{k}\left\{1-\left(\frac{\mu_w}{\mu S+\mu_w}\right)\frac{1}{(2)^i}\right\} \quad (15)$$

Where $P_{fh|k}$ *is* a probability that a handoff request fails after joining the queue in position k+1.

3.2.4. Originating and Handoff Contacts Queuing Scheme [QPS (H+N) +RCS(H)]: We consider a system with many cells [7], each has S channels. There are two queues, Q_H and Q_O for Handover and new contacts, respectively. Capabilities for Q_H and Q_O are M_H and M_O, respectively. Handover's contact is inserted in Q_H if it finds no free channel. On the other hand, a new contact is put into Q_O if the channels available are less than or equal to (S-Sc), otherwise, the contact is blocked. Handover's contact placed in the queue is blocked when it moves out of the cell before obtaining a channel (forced termination).

So this technique is modeled by a two-dimensional Markov process. The state transition diagram is shown in Figure 7.

$$Pb=\sum_{i=S_C}^{S+MH}P(i,MO) \quad (16)$$

$$Ph=\sum_{j=0}^{MO}P(S+MH,j)$$
(17)

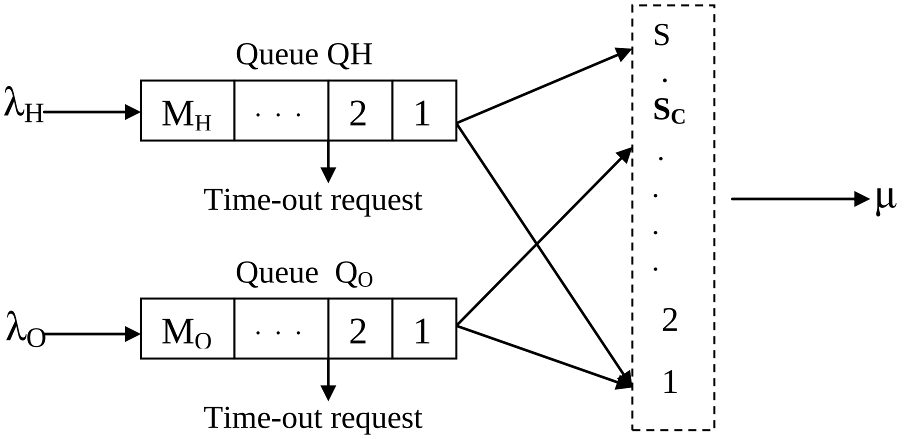


Figure 7. System Model with Priority and Queue for Handoff Contact and New Contact

4. Simulation Results

The traffic in the cells follows a Poisson distribution, so we suppose that:

- Contact duration is exponentially distributed with a mean of 1 min.
- The average waiting time in the queue is exponentially distributed with a mean of 5 min.
- Blocked contacts are lost and cleared.
- The system has a total of 10 available channels per cell.
- The queue length is infinite.
- The simulation results obtained are taken after 10 000s

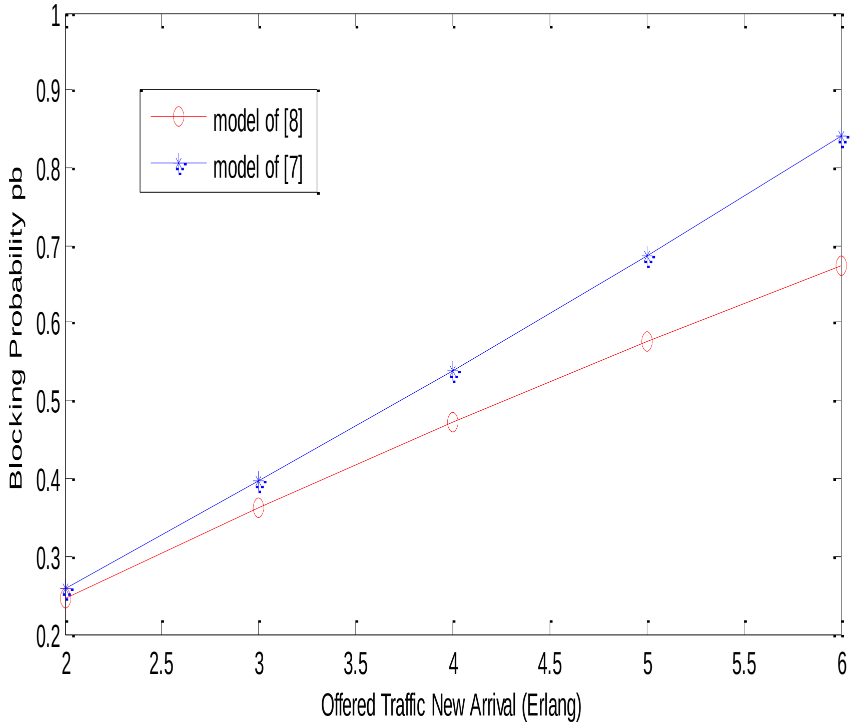


Figure 8. New Contact Probability Failure as Function of Traffic Intensity for Two Models

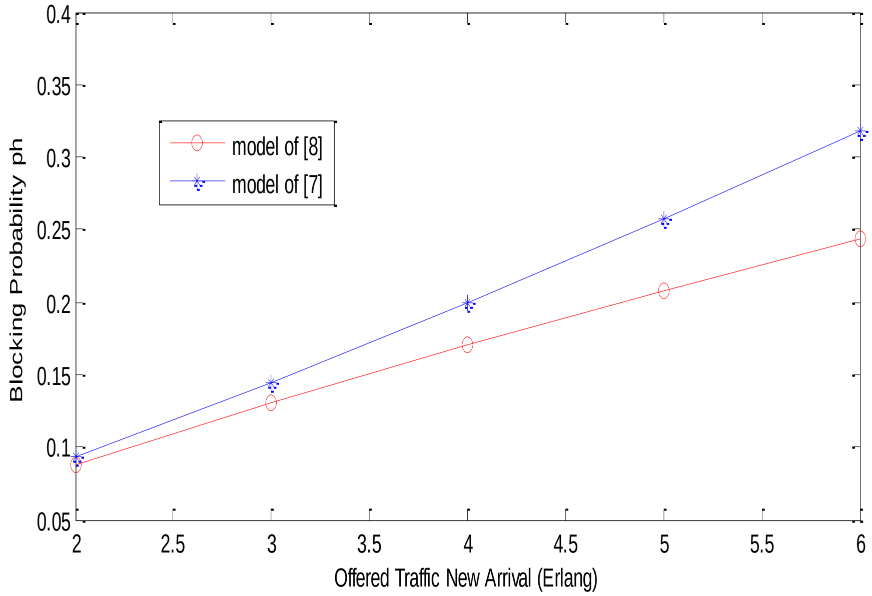


Figure 9. Handover Probability Failure as Function of Traffic Intensity for Two Models

We have made a comparison between two models in order to choose the one which gives best result. Figure 8 and Figure 9 show the blocking probability Pb and the Handoff failure Ph as function of traffic offered respectively, we observe that the model of Zeng gives best result comparing with the model of Hong and Rappaport.

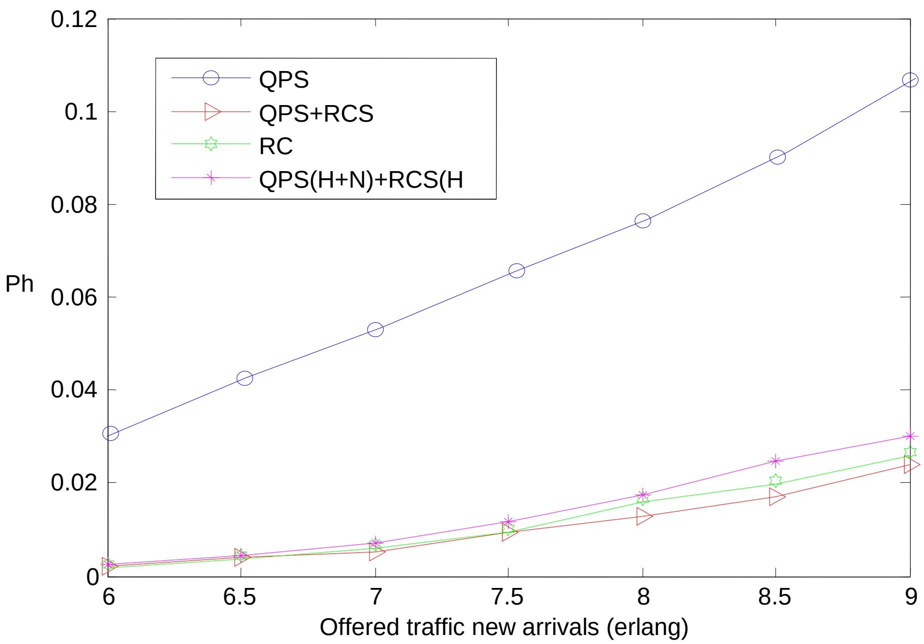


Figure 10. Handover Probability Failure as Function of Traffic Intensity for Different Models

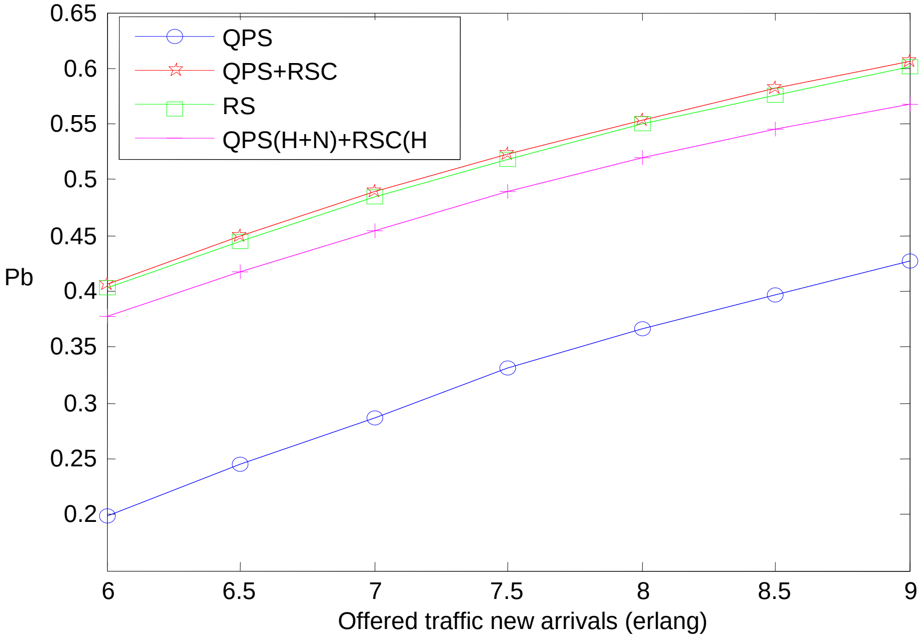


Figure 11. New Contact Probability Failure as Function of Traffic Intensity for Different Models

Figure 10 and Figure 11 show the blocking probability of handover requests and new contacts respectively for different models depending on the traffic density. We note that the blocking probability of new contacts is important for RCS and RCS+QPS techniques. The blocking probability of new contacts is noticeably reduced for the SCR(H)+QPS(N+H) technique, this reduction becomes important for the QPS model.

Regarding the probability of blocking handover requests, Figure 10 shows that using RCS and RCS +QPS techniques gives the best reduction of this probability which justifies the increasing of the CDP and it increases significantly using QPS technique.

A comparison of performance has been made between non-priority and priority techniques and has been evaluated. Reducing the blocking probability of handover is realised depending on all channels reserved exclusively to serve handover requests.

5. Conclusion

The handover is one of the critical procedures of communication in LEO satellite networks, the management of this mechanism must be set appropriately in order to maintain communication between pilots and controllers, and thus ensure an acceptable level of quality of communication.

About CBP (contact blocking probability), the results show that the value of this parameter varies from one technique to another. Therefore, it becomes important for techniques using guard channels and the queue exclusively for handover (RCS and RCS + QPS technique) and it decreases significantly for the QPS technique. This decreasing was improved when using the queue technique (RCS (H) + QPS (H + N)) for the original contact.

In terms of CDP (Contact dropping probability), the results show that the value of this parameter is minimized for the RCS technique, this minimization is improved when using (RCS + QPS) technique.

Furthermore, this value increases for (RCS (H) + QPS (H+N)) technique and continues to increase for the QPS technique.

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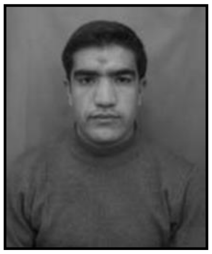
From 2003 to 2013 he has occupied the post of President of Scientist Comity of the Electronic Department of Batna University. His research interests are: the propagation of acoustic microwaves in piezoelectric material and the transmission by satellite.



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