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A Handover Management in LEO Satellite Network using Angular and Distance Based Algorithm

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ABSTRACT
In satellite communication networks, low propagation delay and power requirements increase the plausibility of Low Earth Orbit (LEO) satellites over geostationary Earth Orbit (GEO) satellites. High relative speed and random direction of motion of LEO satellites provide a serious barrier for their applicability in global wireless communication. The spot beam dynamics of LEO satellites brings about frequent handover of connections between spot-beams for the Mobile Stations (MS). This paper introduces two handover initiation algorithms with connection control. The angle and the distance between the MS and satellite after a defined sample interval serves as a data set for decision making in these two algorithms. A threshold limit is set in each algorithm (threshold angle and threshold distance) which when crossed results in handoff initiation. The simulations were performed in MATLAB 7.8 where a virtual coded scenario with aid of available data was created and the algorithm was executed in it.

Keywords
Threshold Angle, LEO, Iridium-Like Satellite, Global Star-Like Satellite, Spot beam Handover, Foot beam

1. INTRODUCTION
Satellite communication has become an essential criterion in mobile communication due to their coverage superiority. As cellular networks can provide mobile communication services with only a limited geographical coverage area, satellite communication network coexists with cellular networks to provide a global coverage to heterogeneously distributed user population. The information to be transmitted from a MS must be correctly received by a satellite and forwarded to one of the Base Station (BS) from the satellite. The BS keeps track of all Mobile Stations within its coverage range, controls the allocation and de-allocation of radio channels and performs most of the intelligent and decision making process to reduce the computational effort and the weight of the satellites. The architecture of Satellite communication is reflected in Figure 1.

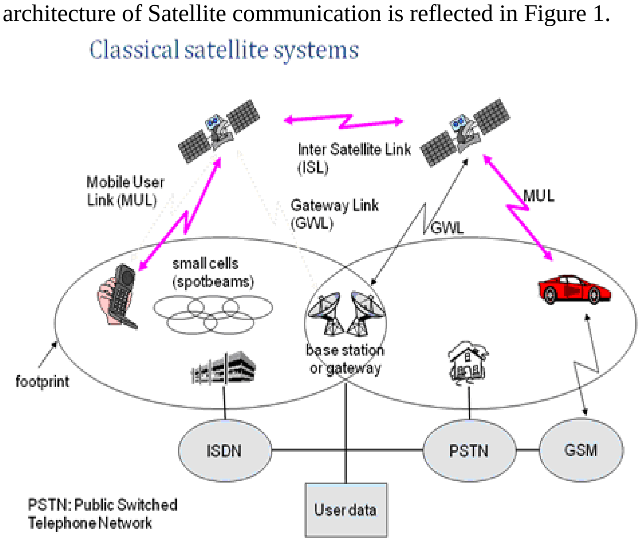

Figure1. Satellite Communication Architecture

The satellites are controlled by the BS located at the surface of the earth, which serves as gateway. Inter-satellite links can be used to relay information from one satellite to another, but they are still controlled by the ground BS. For an originating call from MS, the MS at first connect itself with the overhead satellite. The satellite informs the nearest BS for the authentication of the MS. The BS then allocates the channel for the MS via the satellite and informs the gateway about additional control information. For an incoming call from the Public Switched Telephone Network (PSTN), the gateway helps to reach the closest BS which, in turn, indicates the satellite serving the most recently known location of MS. The satellite informs the MS about an incoming call by employing a paging channel to the MS and radio resources to use for the uplink channel (Uplink: connection between base station and satellite).

Some of the terminologies related to satellite communication are elaborated below.

a) **Foot print**: Footprint is the area within which a mobile user can communicate with satellites.
b) **Spot beam**: To increase the capacity of the overall system, the coverage area of every satellite is divided into slightly overlapping cells, which are called spot beams. Figure 2 shows the spot beams created by a moving satellite with approximation of the spot beams for ease in calculations

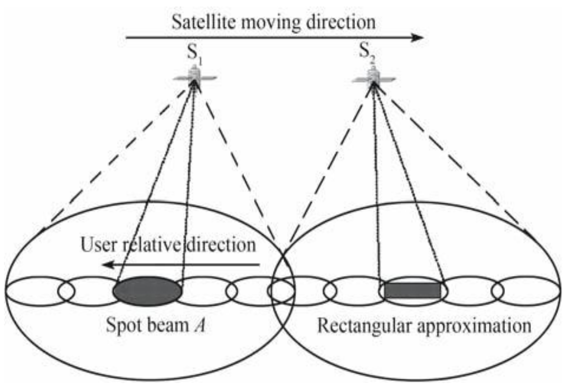

Figure 2. **Spot Beams of Moving Satellie and its Rectangular Approximation**

1.1. Handoff

Whenever an MS moves from one satellite coverage area to a new area served by another satellite, the MS needs to be connected with the new satellite via BS rejecting the connection of old satellite. Several handoff phenomena can occur within the satellite communication area.
d) **Intra-satellite handover**: Intra satellite handover occurs when the mobile station (MS) moves from one spot-beam to another spot-beam in the same footprint of the satellite due to its relative motion with respect to the satellite.
e) **Inter-satellite handover**: Inter satellite handover occurs when the MS leaves the footprint of the current satellite and enters into the footprint of another satellite.
f) **Gateway handover**: This is the handover of connection from one gateway to another gateway i.e. the mobile station (MS) remains in the footprint of the satellite, but gateway leaves the footprint.
g**) Inter system handover**: This is the handover of connection from the satellite network to a terrestrial cellular network which is cheaper and of lower latency.

Four different types of satellite orbits can be identified depending on the shape and diameter of the orbit (also shown in Figure 3). The Geostationary Orbit satellites (GEO) revolve between 36000 km above earth surface, Low Earth Orbit (LEO) satellite revolve between 500 - 1500 km above the earth surface, Medium Earth Orbit (MEO) or Intermediate Circular Orbit (ICO) satellites revolve between 6000 - 20000 km above earth surface and Highly Elliptical Orbit (HEO) satellites which follow elliptical orbits and stay at over 35,786km.

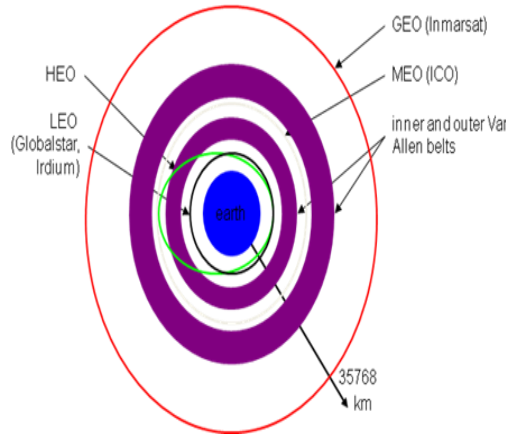

Figure 3. **Diagrammatic Representation of Satellite Orbit**

In low earth orbit (LEO) satellite networks, the spot beam handover is the most frequently encountered network function because of the relatively small spot beam areas of LEO satellite networks and the relatively high speed of the satellites (Akyildiz, Uzunalioglu and Bender, 1999).

The rest of the sections are classified as follow. Section 2 investigates the related works that had been done in this field of research. Section 3 introduces the angle estimation and distance evaluation algorithm. This is followed by performance evaluation in Section 4 with future work prospects and conclusions in Section 5.

2. RELATED WORKS

A lot of researches have been dedicated to enhance the performance of handover in satellite networks. Recently a number of channel allocation techniques have been proposed in different research papers.
Blocking a handoff call is generally considered less desirable from user's point of view than blocking a new call request since dropping a call in progress breaches quality of service (QoS) requirements (Naghshineh and Schwartz, 1996).In research paper (Maral et. al, 1998) a Guaranteed Handover (GH) scheme have been proposed where a system with two classes of users is addressed and the problem of cell handoff is addressed. The first class of users requires the elimination of forced termination during handoff, while the second class has no specific requirements. For users of class 2 no specific reservation mechanism is proposed, in (Maral et. al, 1998). According to the proposed method in (Xu, Ding and Ko, 2000), the time of channel blocking is decided based on the forced termination requirements, by using a complex Markovian model. The Time-based Channel Allocation Algorithm (TCRA) algorithm, presented in (Boukhatem et. al, 2003), improves on GH by taking advantage of the user positions to delay channel blocking. On the contrary, both the method for cell handoffs proposed in (Todorova, Olariu and Nguyen, 2003) and the method for satellite handoffs proposed in (Karapantazis, Todorova and Pavlidou, 2006) reserve resources in the next cell/satellite when the handoff occurs for both classes of users. Another prioritization technique proposed is handover with guard channel (HG) scheme (Hong and Rappaport, 1986) where the guard channels are used to ensure that certain numbers of channels are reserved for handover calls even when the new call

arrival rate is high. With the above techniques, various solutions have been proposed to minimize the blocking probabilities in wireless networks (Tekinay and Jabbari, 1991). Most of these studies focus on the channel allocation algorithms where they try to maximize the channel utilization efficiency. This approach, however, does not provide connection-level quality of service (QoS) (Naghshineh and Schwartz, 1996). The technique proposed in (Naghshineh and Schwartz, 1996) considers only fixed channel allocation (FCA) scheme which may lower the channel utilization efficiency. A handover method for multiservice non-geo satellite systems has been proposed in (Tian and Ji, 1998) which can be used for satellite handover as well as for cell handover when a fixed amount of channels is allocated to each cell. Due to scarcity of channels, connection admission control (CAC) policies are important for a network's capability to guarantee connection-level quality of service (QoS). Recently, several connection admission control (CAC) techniques have been proposed in research papers (Naghshineh and Schwartz, 1996) and (Tian and Ji, 1998). In (Tian and Ji, 1998), the overload probability metric is restricted to a simple one dimensional model which does not fit into the realistic situations. An important prioritization scheme is handoff with queuing (HQ) technique (Re, Fantxci and Giambene, 1995). Also, a connection admission control (CAC) technique in Non-GEO satellite networks has been proposed in (Mertzanis, Tafazolli and Evans, 1997) where admission decision is based upon so-called *mobility reservation status.* However, this technique has the problem of determining threshold point and does not take the QoS issues into account. In (Efthymiou et. al, 1998), the geographical connection admission control (GCAC) algorithm is introduced for low earth orbit LEO) satellite networks which estimates the future handover blocking probability of a new call attempt based on the user location database, in order to decrease the handover blocking. Several dynamic channel allocation techniques have been proposed in (Hu et al, 1998; Cheng and Chuang, 1996; Re, Fantacci and Giambene, 1999). Finally, in (Papapetrou and Pavlidou, 2002, 2005), the Dynamic Doppler-Based Handover Prioritization (DDBHP) algorithm is proposed for both cell and satellite handovers which takes the advantage of user locations and system characteristics to decide the time to delay channel blocking. Both TCRA and DDBHP manage to eliminate the forced termination probability. In (Lee et. al, 2002), a DCA technique has been proposed which utilizes frequency spectrum efficiently, and can also provide users a high-quality premium service that guarantees the success of each handover procedure, called guaranteed handover service. This is based on position measurement.

Compare to these channel allocation technique, a very few connection control technique have been proposed. In (Efthymiou et. al, 1998), the authors suggested a hard handover scheme where the current link is released before the next link is established, which may cause connection block during handover. NASA is using mobile IP (Re, Fantacci and Giambene, 1999) which uses hard handover, for future space communication networks. In paper (Koh, Chang and Lee, 2004), many soft handover schemes have been proposed where the current connection is not released until the next connection is firmly established. A new handover management technique, SIGMA (Seamless IP Diversity Based Generalize Mobility Architecture) is proposed in paper (Fu and Atiquzzaman, 2005) which uses the signal diversity based scheme.

3. PROPOSED WORK

As LEO satellites move with high velocity, the user mobility and speed of rotation of the earth have been neglected in the following discussion. Since the movement of a satellite is deterministic, all the information regarding the time of sweeping over a particular area is known i.e. the radius of the footprint region, the areas to be covered etc. The two algorithms are elaborated in the discussion to follow.

3.1. The Angle Estimation Algorithm

3.1.1. Angle between Satellite and MS

The angle (α) between mobile station (MS) and the satellite is calculated by establishing a three dimensional coordinate system at the current footprint (where the MS is present) with the origin at the center of the footprint, as shown in Figure 4.

The exact position of MS at the footprint can be found with aid of Global Positioning System (GPS). We can consider the coordinate of the MS in three dimensions (considering level surface) as (x, y, 0). Owing to location of the satellites at very high altitude from earth surface neglecting the height of the MS would result in minimum error with simplistic calculations.

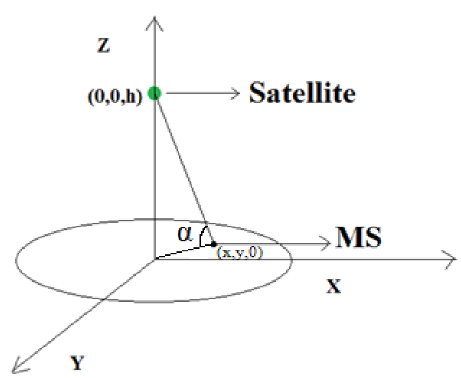

Figure 4. A simplistic situation showing the angle between the satellite and MS

From Figure 4, we can write the distance of the MS from the centre of the footprint 's' as

$s^2 = x^2 + y^2$ (1)

So, $s = \sqrt{(x^2 + y^2)}$ (2)

Now we can find out the angle α with help of trigonometry.

$\tan \alpha = \frac{h}{s}$ (3)

Or, $\tan \alpha = \frac{h}{\sqrt{x2 + y2}}$

So, $\alpha = \tan^{-1}(\frac{h}{\sqrt{x2 + y2}})$ (4)

Now the angle α between MS and the satellite can be calculated easily if the values of h, x and y is known which as stated is provided by GPS but at certain cost.

3.1.2. Threshold Angle

Threshold angle i.e. the angle after which the handoff will be initiated, is the angle between the satellite and the inner circle (which is determined by the footprint at which when handoff is initiated has the minimum most probability to suffer call blocking) of the footprint region. The height (h) of the satellite from the earth surface and the radius (r) of defined inner circle of the footprint is estimated by the GPS as stated earlier. From these two parameters, the threshold angle can be calculated. Figure 5 show the diagram based on which the necessary calculations are performed for calculation of threshold angle.

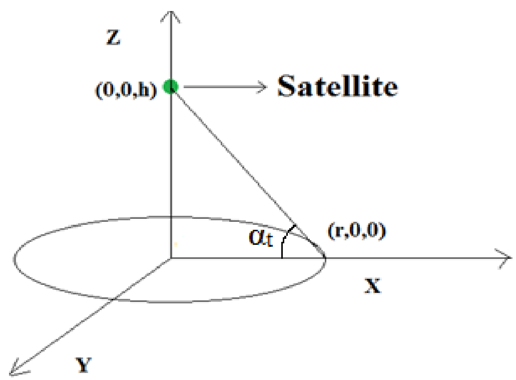

Figure 5. **Simplistic situation showing the threshold angle between the satellite and MS**

From Figure 5 the threshold angle can be written as,

$$\tan \alpha_t = \frac{h}{r}$$

$$\text{So, } \alpha_t = \tan^{-1} \frac{h}{r} \qquad (5)$$

α_t is the threshold angle which we can easily calculate if the values of h and r is known. Threshold value of a satellite is constant as the height of satellite and the radius of footprint, both are constant.

3.1.3. Handoff initiation

Handoff is only initiated when the MS moves out of the satellites footprint. Thus to initiate the handoff we have to check whether the angle between the MS and the satellite exceeds its threshold value. A particular sampling period t_{samp} is chosen to check the angle and judgment can be made based on the following relations:

If $\alpha_t < \alpha$, handoff is required
If $\alpha_t > \alpha$, no handoff is required

The mathematical model of the proposed model is expressed in algorithmic format below.

Input: The co-ordinate of MS and satellite in 3D space, sampling time, threshold angle

Output: Handoff initiation signal.

1 Set newconnection ( )// New connection between a satellite and MS//
2 Set sampling time= input sampling time
3 Set 3D co-ordinate of MS= input co-ordinate of MS
4 Set 3D co-ordinate of satellite = input co-ordinate of satellite
5 Set threshold angle = input threshold angle
6 While hanoff_initiation=null //variable that keeps check of handoff initiation//
6.1 After time=sampling time
6.2 Calculate angle between the MS and satellite
6.3 If angle between satellite and MS < threshold angle
6.3.1 Set handoff_initiation = 1 // Escape from the loop and starts handoff initiation//
6.4 End While Loop
7 oldconnection() = newconnection
8 If a new connection is successful Set newconnection() and continue from line 1

3.2. Handoff Management by Distance Evaluation Method

The spot beams formed by the satellite can be considered static relative to the motion of it. A seven cell cluster assumption for the spot beams can be considered with satellites in centre to it as shown in Figure 6. From the procedure used in the previous algorithm, the data regarding the location of the MS with respect to its serving satellite can be ensured through GPS. Inter satellite links enables intra MS knowledge for other satellites which is utilized in framing this algorithm. Initially the satellite measures the MS's Euclidean distance form itself. Considering a seven cell cluster formation by the spot beams (as shown in Figure 6) the distance between the MS and its parent satellite along with the surrounding six satellites can be known. This process is continued in a similar fashion as in the above algorithm after regular samples t_{samp}. When the distance between the MS and its serving satellite falls above a certain threshold distance (the threshold distance is specified as the maximum distance between the satellite and the MS after which handoff initiation will occur with minimum probability failure) handoff initiation occurs. Moreover, the distance between the MS and the other six satellites provides an added advantage in handing over the call in progress with minimum delay as the satellite which has minimum Euclidian distance with the MS during handover period has the highest probability of getting the call handed of to it and hence scanning period is reduced which effectively reduces the handover delay. In Figure 6 the co-ordinate of the i^{th} satellite surrounding the present satellite's spot beam is denoted as $(x_i, y_i, 0)$. The calculations are performed by converting the 3-dimensional co-ordinate of the satellite to two dimensional for the sake of simplicity with minimum loss of accuracy. The line marked in green shows the minimum distance when MS start handover initiation and the inner-hexagon in which the MS is located presently is the limit beyond which handoff initiation starts(as shown in Figure 6).

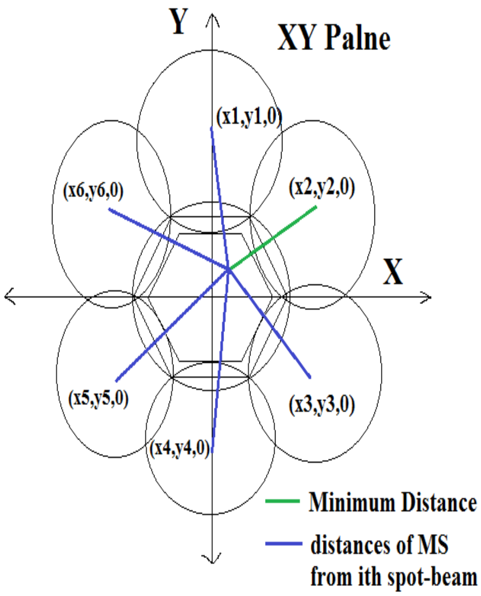

Figure6. The spot beams formed by the neigboring satellite and the threshold distance(region) in distance measurement algorithm

The algorithm executed for the above proposed model is given below.
Input: The co-ordinate of MS and satellite in 3D space, sampling time, threshold distance
Output: Handoff initiation signal, Potential Satellite.

1 Set newconnection ( )// New connection between a satellite and MS//
2 Set sampling time= input sampling time
3 Set 2D co-ordinate of MS= input co-ordinate of MS
4 Set 2D co-ordinate of satellite = input co-ordinate of satellite
5 Set threshold distance = input threshold angle
6 While hanoff_initiation=null //variable that keeps check of handoff initiation//
6.1 After time=sampling time
6.2 Calculate distance between the MS and satellite
6.3 If angle between satellite and MS < threshold distance
6.3.1 Set handoff_initiation = 1 // Escape from the loop and starts handoff initiation//
6.3.2 Measure the distance between the neighboring satellites and the MS
6.3.3 satellite (i)=satellite having the minimum distance with the MS
6.4 End While Loop
7 oldconnection() = newconnection()
8 potential satellite=satellite(i)
9 If a new connection is successful Set newconnection() and continue from line 1

4. SIMULATION RESULTS

The simulation results were run on MATLAB 7.8 in a designed virtual environment with data taken from Table 1 (Papapetrou and Pavlidou, 2002) for Iridium like sateliites. At any given instant of time a call may originate or terminate within a spot beam following Poisson Distribution Function. Performance of the algorithms was checked with performance metrics as Forced Call termination Probability (P_f) and Call Blocking Probability (P_B) compared with the load of the network (in Erlang) with different sampling time. The sampling time t_{samp} was taken to be 10ms, 50 ms and 100 ms for each simulation and the results are depicted in form of graphs. Figure 7(a)-(b) and Figure 8 (a)-(b) shows P_B and P_f with varying Load and different sampling time for angular estimation algorithm and distance evaluation algorithm respectively for iridium like satellites.

Table 1. Specifications for Iridium like Satellites

Call Length (km)	500
t_{cell} (min)	1.26
V_{sat} (km/sec)	6613.75
Channel/cell	10

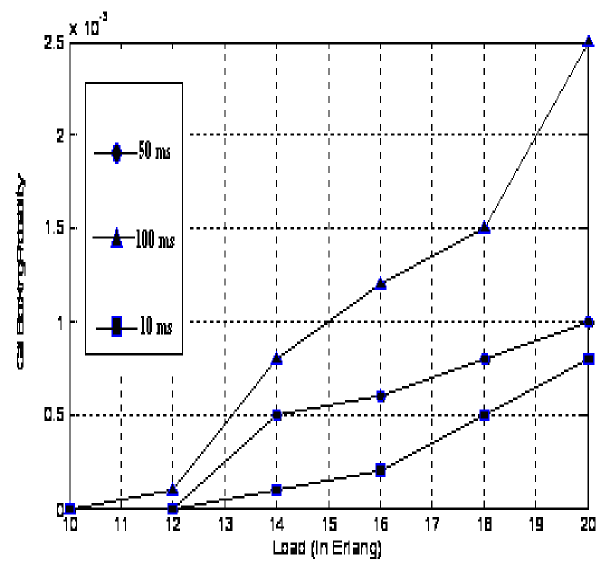

Figure 7(a). Call Blocking Probability with varying load (in Erlang) for Iridium like satellite (Angle estimation algorithm)

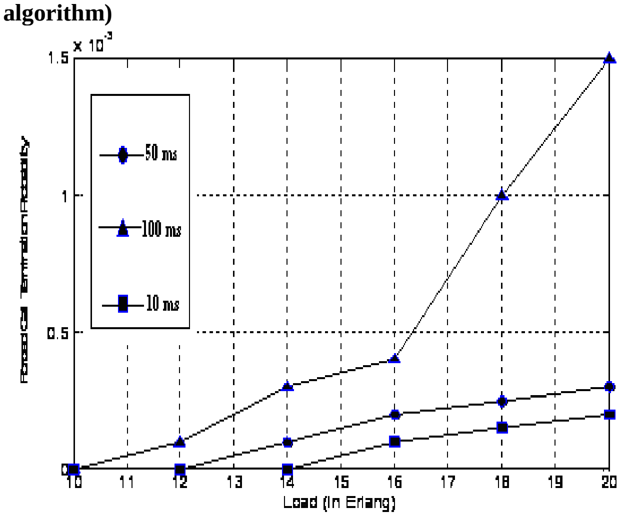

Figure 7(b). Forced Call Termination Probability with varying load (in Erlang) for Iridium like satellite (Angle estimation algorithm)

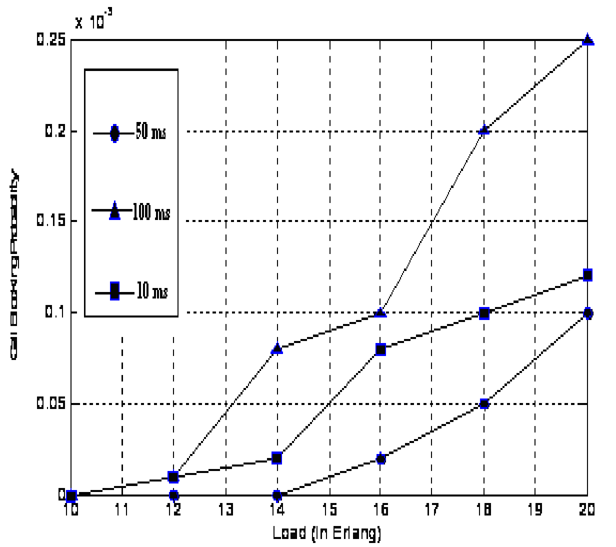

Figure 8(a). Call Blocking Probability with varying load (in Erlang) for Iridium like satellite (Distance evaluation algorithm)

Compared to the result obtained in (Papapetrou and Pavlidou, 2002), which were simulated for Erlang value ranging from 8-16 compared to 10-20 in this case, the forced call termination probability and call blocking probability metric totally outperforms for t_{samp} 10 ms and 50 ms. For optimal conditions t_{samp} of 10 ms is not feasible and 50 ms t_{samp} produces a desired result as shown in the plots. Thus the algorithms perform better than that of proposed in [20] which provide a base in its applicability in real time scenario. Apart form the betterment in respect to the above two metrics, distance evaluation algorithm effectively reduce the handover delay owing to the knowledge of the prioritized satellite to which handover of the MS has the highest probability. The delay in handover is not tabulated as it is not experimentally proved and is hypothetical. Due to lack of experimental setups and data the work on estimating the reduction of the delay metric using this algorithm is a future work prospect relative to this manuscript.

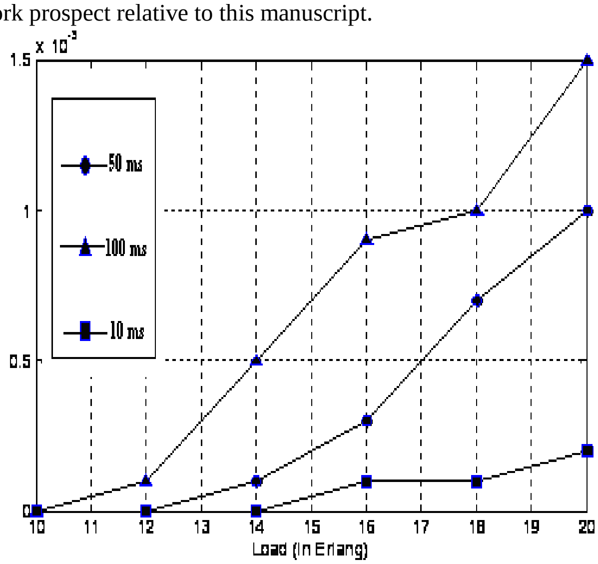

Figure 8(b). Forced Call Termination Probability with varying load (in Erlang) for Iridium like satellite (Distance evaluation algorithm)

4. CONCLUSION

As we have already seen above, model simulations give favorable results for our new approach. Also the simplicity and flexibility of the proposed method point to diverse fields of implementation with the help of appropriate improvements and modifications.

It is worth mentioning here that although the proposed work has been presented considering honeycomb structures yet our algorithm would work in a similar manner for other cell structures and neighbor AP locations. Minor changes would be introduced depending on the network topology.

However, our proposed method leaves some drawbacks which we can leave for the future works.

For example, when a MS moves back and forth between two spot-beams very frequently, a significant the number of false handoffs takes place. Handoff cannot take place in this condition due to this frequent movement of MS. Also, our approach may result in handoff failure in a very small number of cases when the MS moves along the borders of the spot-beams or the footprints. In that case, the satellite cannot decide the nearest spot-beam or the nearest footprint of the MS. The use of GPS is not an economy friendly approach.

We intend to take up these matters in future studies. The real challenge as of now is to interpret the coverage areas of spot-beams geometrically and incorporate that knowledge locally to optimize handoff performances.

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