A Region Based Channel Allocation Scheme for LEO Satellite Communication

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Abstract — **In wireless communication, low earth orbit (LEO) satellite has become a popular name, due to their low propagation delay and low power requirements. Throughout the last few years a plenty of researches had been done to improve the LEO satellite communication by implementing several channel allocation techniques. In this paper we are going to propose a new adaptive channel allocation scheme for efficient utilization of resources (channels) for originating and handover call in LEO Satellite communication by region based analysis. We have divided the total footprint region in different sections, according to the traffic load of different spot-beams and for each section we have assigned different channel allocation techniques according to their traffic loads. This approach reduces the unnecessary complexity and unnecessary reservation of resources (channels) which in turn reduces the complexity of the communication network.**

Keywords — Footprint, Low Earth Orbit (LEO), channel allocation, spot-beam, Next Generation Wireless System (NGWS), Mobile Station (MS), Base Station (BS).

I. Introduction

Satellite communication has become an essential criterion in mobile communication due to their coverage superiority. As the 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 mobile user (MS) must be correctly received by a satellite and forwarded to one of the Base Station (BS) from the satellite. The BSs keep track of all MSs located in the area, controls the allocation and de-allocation of radio channels and perform most of the intelligence and decision making process to reduce the computational effort and the weight of the satellites.

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 [13] .

For an incoming call from the PSTN, the gateway helps to reach the closest BS which, in turn, indicates the satellites 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).

Foot print: Footprint is the area within which a mobile user can communicate with satellites.

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.

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.

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.

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.

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.

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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.

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 [1].

In section II we take you through the various works that have already been done to achieve this and in section III we explain our proposed method. This is followed by performance evaluation of our proposed technique using simulations in section IV after which in section V we propose a few areas in which further improvement can be made. Finally, we provide an extensive list of references that has helped us tremendously in our work.

II. 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.

A dynamic channel; allocation scheme is proposed in [1]. In [2], a novel scheme of location update and paging is proposed. 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 [3].In research paper [4], a Guaranteed Handover (GH) scheme have been proposed where a Doppler based LEO satellite 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 [4]. According to the proposed method in [5], the time of channel blocking is decided based on the forced termination requirements, by using a complex Markovian model. Another a connection admission control (CAC) based vertical handover management scheme for LEO satellite is proposed in [6] where no channel reservation technique is used. The Time-based Channel Allocation Algorithm (TCRA) algorithm, presented in [7], improves on GH by taking advantage of the user positions to delay channel blocking. On the contrary, in [8] a bandwidth sharing channel allocation is proposed. A mobile IP based handover algorithm is proposed in [9] and [11]. The method for satellite handoffs proposed in [12], reserve resources in the next cell/satellite when the handoff occurs for both classes of users. However, this technique has the problem of determining threshold point and does not take the QoS issues into account. With the above techniques, various solutions have been proposed to minimize the blocking probabilities in wireless networks [10]. Most of these studies focus on the channel allocation algorithms where they try to maximize the channel utilization efficiency.

III. Proposed Work

In this section we are going to explain our proposed scheme. 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 total number of channels, average call duration, the areas to be covered etc. Thus the resources necessary during a particular interval can be preplanned. Here we consider the spot-beams as hexagonal cells due to their overlapping coverage region.

A LEO satellite covers a large footprint area and after different case studies we came to know that the call arrival rates are not same at everywhere in a footprint region. In some areas, handoff call arriving rate is much higher than the new call arriving rate whereas, in some areas new call arriving rate is much higher than that of the handoff calls. Here we assume the arrival rates: a) λ_{n-c} : arrival rate of new-calls b) λ_{h-o}: arrival rate of hand-off calls.

TABLE 1

Area ID	Color	Relation
1	Red	$\lambda_{n-c} << \lambda_{h-o}$
2	Green	$\lambda_{n-c} < \lambda_{h-o}$
3	Blue	$\lambda_{n-c} > \lambda_{h-o}$

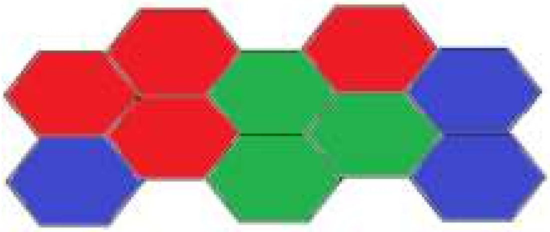

Figure 1

So, we decide to subdivide the whole satellite communication region (i.e. the footprint region) in three areas according to their call arrival rate:

Section 1 areas ($\lambda_{n-c} << \lambda_{h-o}$)

Section 2 areas ($\lambda_{n-c} < \lambda_{h-o}$)

Section 3 areas. ($\lambda_{n-c} > \lambda_{h-o}$)

Now, we will follow three different channel allocation techniques for these three regions as shown in table 2.

TABLE 2

Region Type	Specification for Channel Allocation
Section 1 ($\lambda_{n-c} << \lambda_{h-o}$)	➕ Reserve some channels specifically for handover. ➕ Employ separate queuing for both handover requests calls.
Section 2 ($\lambda_{n-c} < \lambda_{h-o}$)	➕ Reserve some channels specifically for handover ➕ Do not employ queuing
Section 3 ($\lambda_{n-c} > \lambda_{h-o}$)	➕ All available channels may be used for handover requests or new calls.

We are considering following parameters for the rest of our discussion,

P(i): the probability of i channels to be busy

α_O : the probability of an originating call in the cell

α_H : the probability of the handoff call from neighboring cells.
B_O: the blocking probability of the handoff calls
S: the total number of channels allocated in a cell
μ: the call service rate
μ_C: the average call duration
These different channel reservation schemes provide both the resource efficiency and the lower call dropping probability.

A. Channel Allocation for Section 1 Area

We are following guard channel allocation technique as well as channel queuing technique for the section 1 areas where we are reserving number of channels for specially handoff purpose and rest of the resources can be used for both the handoff and new calls, as shown in figure 2. This will ensure that the blocking probability is as minimum as possible. We can assign some discrete weights to represent this fraction [14].
The total number of channels may be determined by the following expression.
Let,
C_T=total number of channels;
$C_{H\text{-}N}$= number of channels reserved for both hand-off and new calls generated within the cells;
C_H= number of channels reserved only for hand-off.
$W_{H\text{-}N}$=weightage on $C_{H\text{-}N}$
W_H=weightage on C_H
Here we assume $W_{H\text{-}N}+W_H=1$.
Determination of the values of $W_{H\text{-}N}$, W_H.
$W_{H\text{-}N}=\lambda_{n\text{-}c}/(\lambda_{n\text{-}c}+\lambda_{h\text{-}o})$ …………………… (1)
$W_H=\lambda_{h\text{-}o}/(\lambda_{n\text{-}c}+\lambda_{h\text{-}o})$ …………………………(2)
Equation (2) is not so significant in this case because suppose for the case $\lambda_{n\text{-}c}=0$, it doesn't really make any effect if we take $W_{H\text{-}N}=W_H$……………………………………(3)
as hand-off calls will be processed in any case.
Thereby
$C_{H\text{-}N}=W_{H\text{-}N}*C_T=\lambda_{n\text{-}c}/(\lambda_{n\text{-}c}+\lambda_{h\text{-}o})*C_T$ ………(4)
$C_H=W_H*C_T=\lambda_{h\text{-}o}/(\lambda_{n\text{-}c}+\lambda_{h\text{-}o})*C_T$ …………….(5)
Which reaffirms our assumption that:
$C_T=C_{H\text{-}N}+C_H$…………….(6)

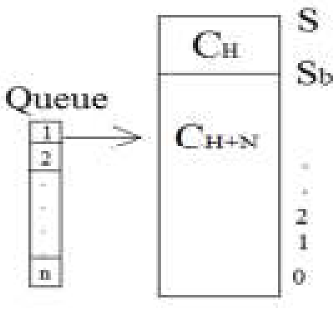

Figure 2

In section 1area, except the guard channel allocation technique we are following channel queuing technique also, as stated in table 2. For channel queuing technique we will follow the algorithm stated in [3]. This scheme utilizes the overlapped area between two spot-beams where the handoff takes place. When a user terminal is in the overlapped area, the handoff process is initiated and if a channel is available in the new spot beam, it is allocated to the user terminal; otherwise, the handoff request is queued. When a channel becomes available, one of the calls from the queue is served. Though we are following the same HQ technique of [3], but in this case, the call dropping probability will be much less than that in [3] because in section 1 areas the overlapping area is sufficient and we have allocated sufficient resources for only handoff purpose.
The state balance equations can be obtained as,
$i\,\mu P(i) = (\alpha_H)\,P(i-1)$ for $0 \le i \le S_b$,
$i\,\mu P(i) = \alpha_H\,P(i-1)$ for $S_b \le i \le S$
$S\mu + (i - S)(\mu C + \mu')]\,P(i) = \alpha_H P(i-1)$ $S < i \le \infty$
Where μ' is the time duration of the MS remain in handoff region. As the new call arrival rate is very small, we can neglect the parameterα_o (the probability of an originating call in the cell).
The blocking probability for originating call (Bo) is,
$BO = \sum_{i=sb}^{S} P(i)$
Handoff failure probability B_H, due to force termination is,
$BH = \sum_{k=0}^{\infty} P(S+n)\,Pf$
Where Pf is the probability of the handoff request fails after joining the queue in position $n+1$.

B. Channel Allocation for Section 2 Area

We are following guard channel *allocation* technique for the section 2 areas where we are reserving number of channels for specially handoff purpose and rest of the resources can be used for both the handoff and new calls. This will ensure that the blocking probability is as minimum as possible. The total number of channels may be determined by the previous expression (equation 6). It can be notified that channel reservation technique is used for both the cases of section 1 and section 2 but the number of guard channels will be different for them. When $\lambda_{n\text{-}c} << \lambda_{h\text{-}o}$ (i.e. section 1 areas), it is evident that the channels allocated for handoff call and new call must be much smaller than that for only Handoff calls, whereas when $\lambda_{n\text{-}c} < \lambda_{h\text{-}o}$ (i.e. section 2 areas), the number of guard channels will be almost equal to the unreserved channels, allocated for both handoff and new calls. In section 2 areas all available free channels (except reserved channels) are usable for both handoff and new calls. In this case arriving calls follow the first come first serve rule. The channel allocations of section 2 areas are shown in figure [3].

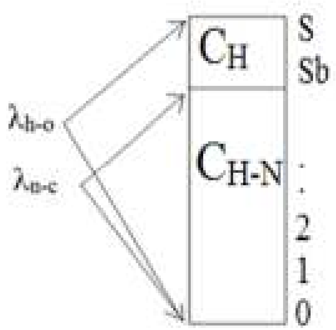

Figure 3

S_h channels are reserved exclusively for handoff calls and rest (S_b=S - S_h) are for both handoff and new calls.
The state balance equations can be obtained as,
$i\,\mu P(i) = (\alpha_O + \alpha_H)\,P(i-1)$ for $0 \le i \le S_b$,
$i\,\mu P(i) = \alpha_H\,P(i-1)$ for $S_b \le i \le S$,
Thus we can obtain the handoff failure probability as,

$B_H = (\alpha_O + \alpha_H)^{(S - sh)} . \alpha_H^{sh} P(0) / S! \mu^S$ ………. (7)

The blocking probability for originating call (Bo) is,

$BO = \sum_{i=sb}^{S} P(i)$.................................. (8)

C.Channel Allocation for Section 3 area:

For section 3 areas, both the new call and handoff call follow the first come first serve technique. In that case we will calculate the call blocking probability as follows.As the Handoff call arrival rate is very small, we can neglect the parameterα_H (the probability of the handoff call from neighboring cells).

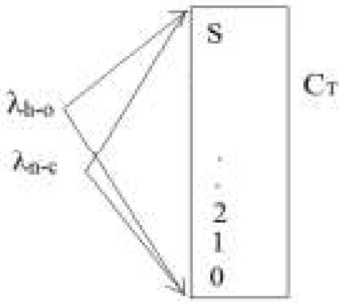

Figure 4

For state i the equilibrium equation can be given as,

For $0 \leq i \leq S$,

$P(i) = P(i-1)/i \mu$

Now, the sum of all states must be equal to one i.e.

$\sum_{i=0}^{S} P(i) = 1$;

The steady state probability can easily found as,

$P(i) = (\alpha_O)^i . P(0) / i! \mu^i$

Where

$P(0)=1/\sum_{i=0}^{S} \frac{(\alpha O)^i}{i!\,(\mu)^i}$

The blocking probability for originating call (Bo) is,

$BO = \frac{(\alpha O)^S}{S!\,(\mu)^S} / \sum_{i=0}^{S} \frac{(\alpha O)^i}{i!\,(\mu)^i}$.................................. (9)

So, the blocking probability of a handoff call is given as,

B_H=Bo…………… (10)

D.Comparison with Previous Works

It may be noted here that, to reduce call dropping probability different kinds of channel allocation technique have already been proposed in different research papers as stated in related works. But most of them have immense drawbacks. In our research work we have tried to effectively overcome those drawbacks by applying them in an efficient way. In case of channel queuing technique call dropping probability becomes very high for small overlapping area and high new call arriving rate. But here the overlapping area is sufficient and the new call arriving rate at section 1 area is very small than the handoff call arriving rate, which causes a low call dropping probability. In guard channel allocation technique the new call blocking probability is very high. But here we apply this technique in an efficient way by changing the number of guard or reserved channel according to the handoff call arrival rate. This ensures a low call blocking probability for the new calls. For section 3 area and section 2 area, we utilize the first come first serve technique in an efficient way, as we have already shown in the above mathematical approach. The call dropping probability or the handoff blocking probability increases with increase in call arrival rate. But both the new call and handoff call arrival rate at the section 3 and section 2 areas are very small compare to section 1 areas. Later, we will see in simulation section that by applying this new channel allocation technique we can effectively reduces the average handoff failure probability for section 3, section 1 and section 2 areas.

IV. Simulation Result

In this section we will see how our proposed method actually works in real atmosphere. Here we will found the call blocking probability and call dropping probability at each of three areas i.e. section 1, section 2 and section 3by using Global Mobile Information System Simulator (GloMoSim). Here we consider DCA algorithm in [11] and guard channel algorithm in [12] to compare our proposed work with existing schemes.

First we will find the handoff failure probability and new call blocking probability at section 1 areas. According to our proposed scheme the handover call arrival rate of section 1 region is high. So, here we consider the new call arrival rate is 20 per second and the handoff call arrival rate is 80 per second. The mean call duration is assumed to be 100 seconds. We have considered the total number of channels in our network is 70 and the number of guard channel is 45. Figure [5] shows the handoff call blocking probabilities for these channel assignment schemes. Here we can see that for our approach and the guard channel scheme, the handoff failure probability is initially zero and then it increases rapidly towards 1 whereas, for DCA scheme it is initially a nonzero finite value and then it increases to 1. But in our approach the increment in handoff failure probability is less rapid than that of [12] and [11] due to the channel queuing technique. Figure [6] shows the new call blocking probabilities for these channel assignment schemes. In our scheme the new call blocking probability increases less rapidly than that of [12] and [11] due to the use of dynamic channel reservation technique.

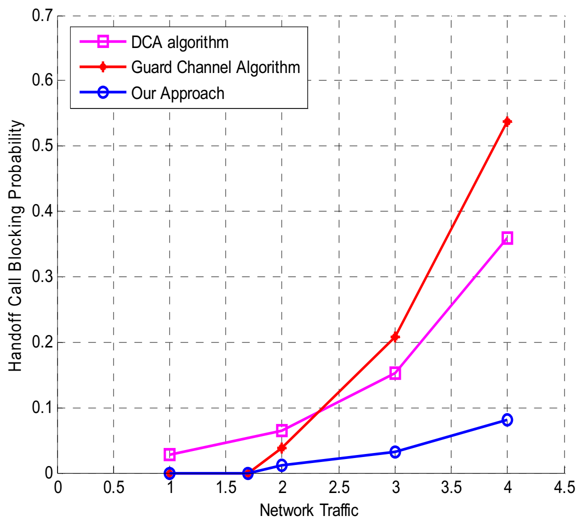

Figure 5

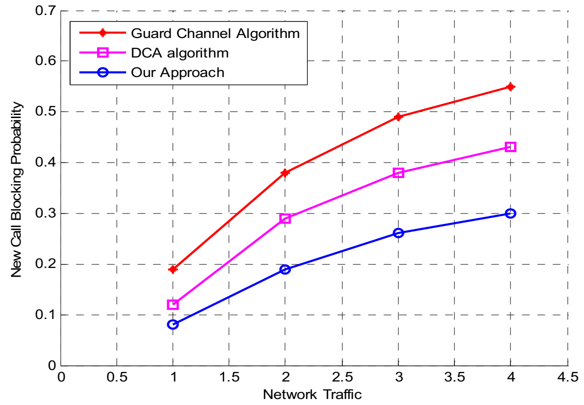

Figure 6

Next, we will find the handoff failure probability and new call blocking probability at section 2 areas. According to our proposed scheme the call arrival rate of section 2 region is moderate. So, here we consider the new call arrival rate is 40 per second and the handoff call arrival rate is 60 per second. The mean call duration is assumed to be 90 seconds. We have considered the total number of channels in our network is 70 and the number of guard channel is 25. Figure [7] shows the handoff call blocking probabilities for these channel assignment schemes.

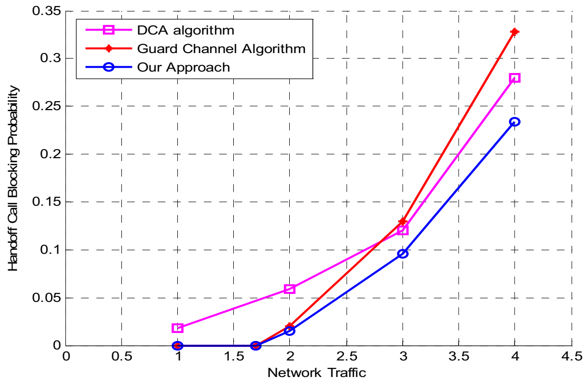

Figure 7

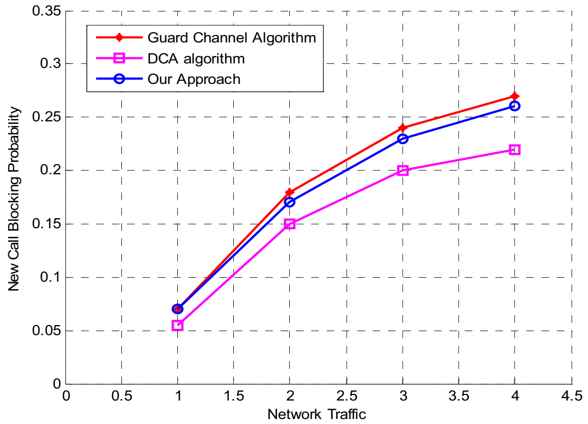

Figure 8

Here we can restrict the handoff failure probability to 25% of the total call arrival rate. As the handover call arrival rate is low, only guard channel allocation scheme efficiently reduces the handover call dropping probability. Figure [8] shows the new call blocking probabilities for these channel assignment schemes. In our scheme we can restrict the new call blocking probability to 27% of the total call arrival rate. Here we can see the DCA algorithm performs better (new call blocking probability= 22%) by using channel queuing technique for the new calls. But it will unnecessarily increase the complexity of the scheme.

At last, we will find the handoff failure probability and new call blocking probability at section 3areas. According to our proposed scheme the new call arrival rate of section 3region is high. So, here we consider the new call arrival rate is 80 per second and the handoff call arrival rate is 20 per second. The mean call duration is assumed to be 80 seconds. We have considered the total number of channels in our network is 70. Figure [9] shows the handoff call blocking probabilities for these channel assignment schemes. Here we can restrict the handoff failure probability to 15% of the total call arrival rate as the handover call arrival rate is low. Figure [10] shows the new call blocking probabilities for these channel assignment schemes. As in our scheme, all the channels are available for new calls; we can restrict the new call blocking probability to 29% of the total call arrival rate.

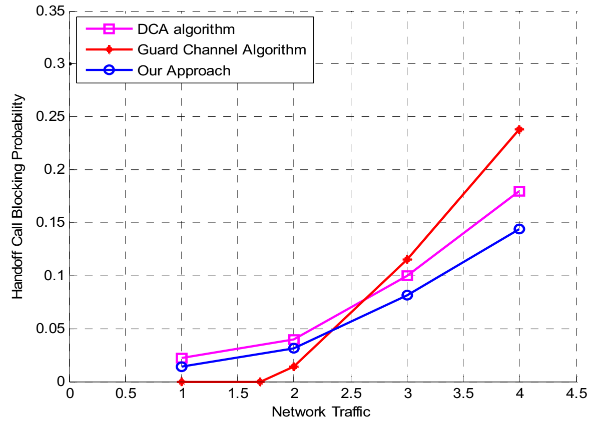

Figure 9

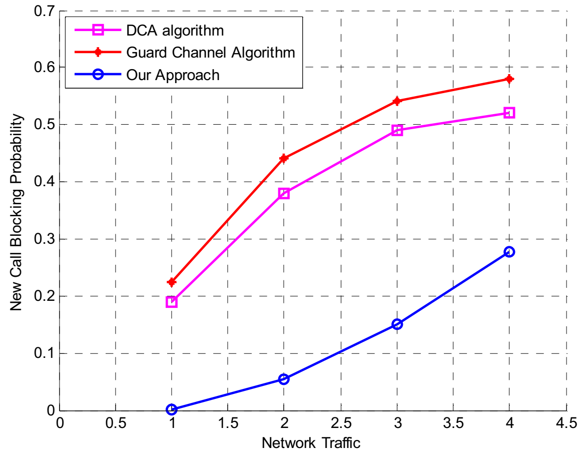

Figure 10

To further explain the practicability of our scheme we calculate the completed call ratio which is defined as the following and is closely related with the throughput of the system.

Completed Call Ratio

$$= 1 - \frac{\text{number of blocked or dropped calls}}{\text{total number of arrived calls}}$$

Our region based channel allocation scheme is compared to the DCA strategy and Guard channel strategy with respect to the completed call ratio as shown in Fig. 11. The simulation result shows the significant improvement of our approach.

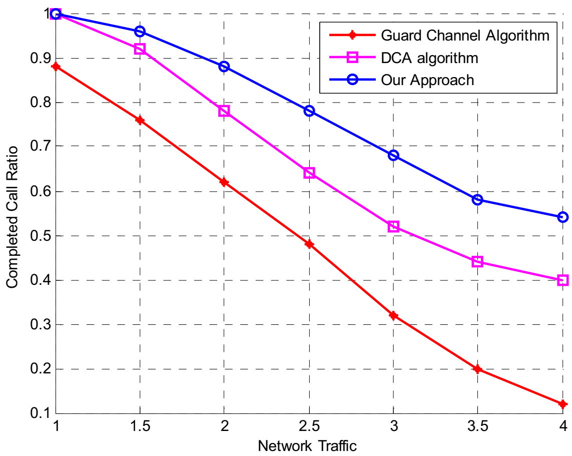

Figure 11

V. 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.

However the area division is not pre-deterministic. The area division process is performed by the satellite, according to the call arriving rates. Though it reduces the handoff failure probability effectively and ensures the flawless calculations, but it causes the significant increment in handoff latency. The computation effort of the satellite also increases significantly to perform this decision making step.

As we are using different channel allocation techniques for different areas, the complexity increases.

We intend to take up these matters in future studies. The real challenge as of now is to interpret the call arrival rates and incorporate that knowledge locally to optimize handoff performances.

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