Neighbour Location Based Channel Reservation Scheme for LEO Satellite Communication

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Abstract — **In wireless communication, low propagation delay and low power requirements of satellite are key requirements which makes low earth orbit (LEO) satellite preferable over others. Over the years a plenty of researches had been done in this field of satellite handover management, but the problem remains unsolved. One such method is the reservation of a few channels specifically for handover calls. One demerit of this scheme is that not all channels are available for allocation of new calls, leading to an increase in new call blocking probability. Also this scheme may lead to unnecessary reservation of channels for handover even when the number of handovers is very small. During such a period the reserved channels could have been used for allocation of new calls. So, in this paper we are going to propose a new Neighbour Location Based Channel Reservation scheme for efficient utilization of resources (channels) in handover and new channel allocation in LEO Satellite communication. In this scheme, we are reserving few channels in each spot beam especially for handoff based on the number of mobile stations in neighbour locations and the average handover call arrival rate. In the simulation, this approach reduces the unnecessary complexity and unnecessary reservation of resources (channels) which in turn reduces the complexity of the communication network.**

Keywords—Footprint, LEO, channel allocation, spot-beam, Next Generation Wireless System (NGWS)

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.

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.

From each spot-beam, A LEO satellite receives two types of call request: 1) handover call request and 2) new call request. New call requests are originated from the mobile stations which are into the spot-beam region. Handover call requests are originated from the mobile stations which are coming into the spot-beam from neighbor 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.

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 spotbeam handover is the most frequently encountered network function because of the relatively small spotbeam 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. 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. In

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research paper [1], author suggests a quantified method to minimize the fraction of the number of blocked calls out of the number of total calls under non stationary handover traffic. Some new mathematical formulations are also developed of those fraction and optimization models with efficient exact solution algorithms. The exact analysis of dynamic channel allocation (DCA) with first-in/first-out (FIFO) queuing of handover (QH) requests is highly complex, due to the dynamic nature of channel allocation to different cells. In [2], author presents an approximate but accurate analytical method to evaluate the performance of DCA in conjunction with FIFO-QH in low earth orbit mobile satellite systems. Another algorithm proposed in [5] uses the minimum cost as a metric to provide optimum channel solutions for specified interference constraints. Genetic algorithms are robust to dynamic variations in satellite constellation design and provide resource allocation improvements in DCA in MSS networks. In [6], the proposed MAC protocol limited wireless resource is allocated reasonably by multiple users and high capacity was achieved considering three performance parameters: voice packet loss probability, average delay of data packets and throughput of data packets. Authors of [7] propose a new channel assignment strategy to improve QoS performance in low earth orbit satellite systems (LEO-MSSs). Different from previous channel assignment schemes, the proposed strategy is designed to improve the QoS performance of LEO-MSSs by decreasing the average times of handover along the calls duration instead of deducing failure probability of single handover request. Also, recursive formulas are derived to deal with complexity of computing dropping probability of handoff calls and blocking probability of new calls. The Time-based Channel Allocation Algorithm (TCRA) algorithm, presented in [8], improves on Guaranteed Handover (GH) by taking advantage of the user positions to delay channel blocking. On the contrary, both the method for cell handoffs proposed in [9] and the method for satellite handoffs proposed in [10] reserve resources in the next cell/satellite when the handoff occurs for both classes of users. However, this technique has the problem in decision making and does not take the QoS issues into account.

III. Proposed Work

Our proposed scheme is reflected in this section. All the information related to sweeping time over a particular area such as the total number of channels, average call duration, average call arrival rate, the areas to be covered etc. can be determined as satellite's movement can be tracked from earth. Therefore we can preplan the resources necessary during a particular interval.

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 spot-beam

α_H :the probability of the handoff call from neighboring spot-beam.

λ_O : arrival rate of originating-calls

λ_H: arrival rate of hand-off calls.

B_O: the blocking probability of new calls

S: the total number of channels allocated in a cell

μ: the call service rate

μ_C: the average call duration

The spot-beams are considered as hexagonal cells due to their overlapping coverage region. After different case studies it is seen that the MSs of the neighbor locations which are nearer to the spot-beam has higher probability of sending handover call requests than the MSs of distant locations. This observation is very obvious as the MSs nearer to the spot-beam has higher probability to enter into the spot-beam. Based on this observation, here we decide to divide the neighbor locations of a spot-beam in two zones as zone 1 (nearer zone) and zone 2 (distant zone), as shown in figure 1.

For a spot-beam size of a,

Area of Zone 1: $\pi(2r)^2 - \pi(r)^2$

Area of Zone 2: $\pi(3r)^2 - \pi(2r)^2$

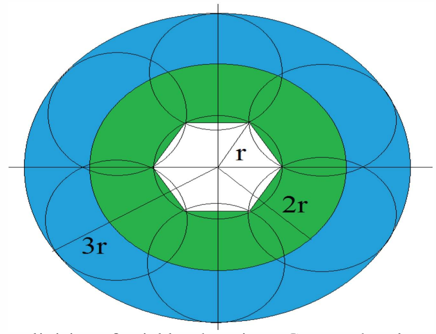

Figure 1: Zone division of neighbor locations. Green colored region is Zone1 and the blue colored region is Zone 2.

Now based on the number of mobile stations in zone 1 and zone 2, a certain number of channels are reserved in the satellite spot-beam exclusively for handover call requests from the neighbor locations. For N_{Zone1} number of mobile stations in zone 1 and N_{Zone2} number of mobiles in zone 2, the number channels is required to reserve for handover call request is,

$$S_r = Integer\ of\ |xN_{zone1} + yN_{zone2}| \ , \quad \text{........ (1)}$$

where, x and y are arbitrary constants.

The values of x and y are chosen stochastically for different spot-beams based on their average handover call arrival rates, as shown in table 1.

Table 1: STOCHASTICALLY CHOSEN VALUES FOR X AND Y

Average handover call arrival rate (λ_H calls/second)	**x**	**y**
λ_H>15	0.5	0.2
15<λ_H<5	0.3	0.1
λ_H<5	0.2	0.04

From the total bandwidth, here we reserve S_r number of channels especially for handoff purpose and rest of the resources can be used for both the handoff and new calls, as shown in figure 2.

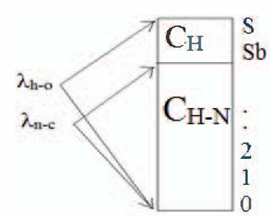

Figure 2: Channel Allocation

The total number of channels may be determined by the following expression.

Let,

C=total number of channels;

C_R= 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_T = weightage on C_R

W_H= weightage on C_H

Here, we assume

$$W_T + W_H = 1 \quad \text{....... (2)}$$

Determination of the values of W_{H-N}, W_H :

$$W_T = \frac{\lambda_o}{\lambda_o + \lambda_H} \quad \text{..... (3)}$$

$$W_H = \frac{\lambda_H}{\lambda_o + \lambda_H} \quad \text{..... (4)}$$

Thereby

$$C_H = W_H * C \quad \text{..... (5)}$$

And we have already obtained,

$$C_H = S_r = Integer\ of\ |xN_{zone1} + yN_{zone2}| \quad ..... (6)$$

Which reaffirms our assumption that:

$$C_{T=} C_R + C_H \quad ..... (7)$$

S_r channels are reserved exclusively for handoff calls and rest of the channels can be used for both new calls and handover calls.
So,

$$S_b = S - S_r \quad ..... (8)$$

The state balance equations can be obtained as,

$$i\mu P(i) = (\alpha_o + \alpha_H) P(i-1) \quad \text{for } 0 \le i \le S_b, \quad .... (9)$$

$$i\mu P(i) = \alpha_H P(i-1) \quad \text{for } S_b \le i \le S, \quad .... (10)$$

Thus we can obtain the handoff failure probability (B_H) as,

$$B_H = \frac{(\alpha_o + \alpha_H)^{(S-S_r)} * \alpha_H^{S_r} P(0)}{S!\,\mu^S} \quad .... (11)$$

The blocking probability for originating call (Bo) is,

$$B_O = \sum_{i=sb}^{S} P(i) \quad ...... (12)$$

These channel reservation schemes provide both the resource efficiency and the lower call dropping probability.

It may be noted here that, to reduce call dropping probability different kinds of channel reservation technique have already been proposed in different research papers as stated in related works. A couple of popular strategies which aim to alleviate the problems in LEO satellite communications are the adaptive channel reservation (ACR) with new call queuing (NCQ) policy [3] and First-input-First-output (FIFO) Queuing with Fixed Channel Reservation policy (FCR) [4].
The first one is an efficient adaptive channel reservation (ACR) scheme, which allows priority to be given to handover requests that are generated by multiparty traffic and a Markovian queuing model is employed to reduce the new call blocking probability. In FCR, a number of channels in each cell are reserved exclusively for handover call. The FIFO queuing employs a similar channel assignment strategy, but allows additional queuing for handover call.
The common demerit of these two schemes is all channels are not available for allocation of new calls, leading to an increase in new call blocking probability. Also these schemes may lead to unnecessary reservation of channels for handover calls even when the number of handovers is very small. During such a period the reserved channels could have been used for allocation of new calls.
In our research work we effectively overcome these drawbacks by applying the Neighbor location based analysis. Here we reserve few channels in each spot-beam exclusively for handover calls based on the number of MSs in the neighbor spot beams and the average handover call arrival rates. Thus for each spot-beam different numbers of channels are reserved specifically for handoff and rest of the channels can be used for both handover and new calls. As we are reserving channels based on not only the number of MSs in neighbor locations but also the average handover call arriving rate, thus, there is a very less chance of unnecessary channel reservation. So, the total bandwidth can be utilized very efficiently. This will ensure the efficient utilization of the allotted bandwidth and minimization of call dropping probability as well as new call blocking probability. Later, we will see in simulation section that by applying this new channel allocation technique we can effectively reduces the average handoff failure probability as well as new call blocking probability.

IV. Simulation Result

In order to analyze the changes made and compare the performance between our Neighbour Location based Channel Reservation scheme (NLCA) with adaptive channel reservation (ACR) scheme and Fixed Channel Reservation scheme (FCR) scheme, we evaluated all three schemes in a simulation environment of 18 spot beams. The number of channels per spotbeam is 15, i.e., 270 channels are available in the common pool for 18 spotbeams. The implementations were performed using the Microsoft Visual C++ and MATLAB version 7.14. The evaluation took place by way of a number of simulation scenarios.
Each simulation scenario was run for a total of 400 seconds in an environment that is conducive to high data loss. The mobile users are assumed to cross the cellular network with a constant relative velocity orthogonal to the side of the spotbeams. The call duration μ_C is assumed to be exponentially distributed with average holding time of 2 minutes. The call arrival process is assumed to be Poisson in all spot-beams. In our experiments, orbital satellite velocity is assumed to be 26,600 km/h and we assume the radius of the circle inscribed in the hexagonal spotbeam to be 200 km. In particular, an edge effect is taken into account, i.e., results have been collected only from the central spotbeams.

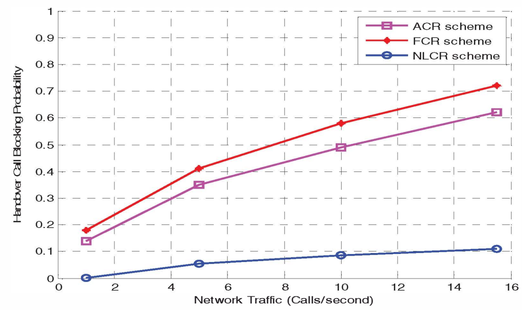

Figure 3: Comparisons of Handover Call Blocking Probability for ACR scheme, FCR scheme, and NLCR scheme.

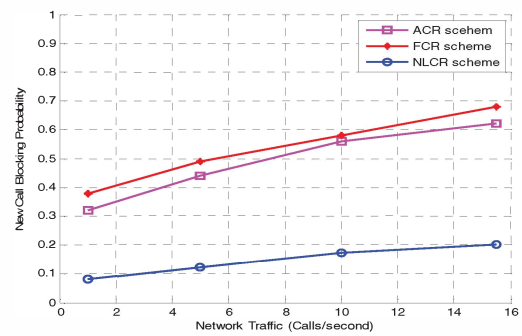

Figure 4: Comparisons of New Call Blocking Probability for ACR scheme, FCR scheme, and NLCR scheme.

Performance evaluation shows that the NLCR significantly lowers handover blocking probabilities compared to other schemes as shown in Fig. 3. In terms of the new call blocking probability, the NLCR technique also out performs ACR and FCA technique as shown in Fig. 4. Handover with ACR and FCR technique does not show good performance compared to the NLCR scheme in terms of new and handover blocking probability because of the over-estimation of guard channels.
In most of previous studies [1], [2], uniform distribution for user location has been assumed. However, in reality, the distribution of user terminals over the Earth surface cannot be uniform, e.g., spotbeams of LEO satellites may cover a number of crowded cities **as** well **as** lightly populated areas such **as** ocean and mountains. The performance of the NLCR algorithm is investigated using both uniform and nonuniform traffic distribution in the coverage area. In case of uniform distribution, every spotbeam generates the call with the same arrival rate. However, in case of the nonuniform distribution, the traffic generation is state-dependent, i.e., a certain spotbeam does not generate any traffic at some time period but it could be overloaded sometime later. In the simulation model, we model the non-uniformity

as only some spotbeams generate traffic, while the others do nothing except accepting handover traffic from adjacent spotbeams.

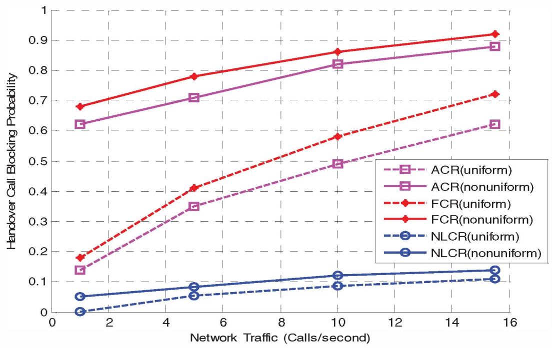

Figure 5: Comparisons of Handover Call Blocking Probability for uniform and nonuniform ACR scheme, FCR scheme, and NLCR scheme.

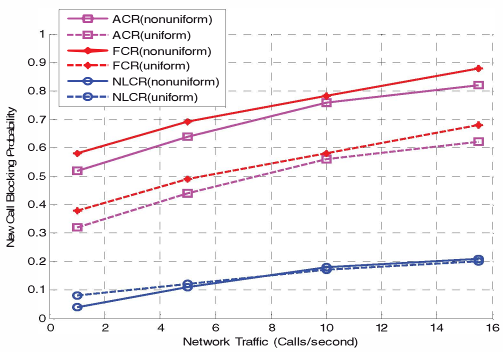

Figure 6: Comparisons of New Call Blocking Probability for uniform and nonuniform ACR scheme, FCR scheme, and NLCR scheme.

As shown in Fig. 5 and Fig. 6**,** simulation results show that the blocking probabilities increase in case of non uniform traffic. We also compared these effects with ACR and FCR technique**.** Performance evaluation shows that the NLCR scheme is less affected by the traffic uniformity than the ACR and FCR technique. In other words, the difference of uniformity and non-uniformity is higher in ACR and FCR technique than the NLCR algorithm. This shows that NLCR technique estimates well the user population distribution.

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.

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

Our NLCR scheme is compared to the ACR strategy and FCR strategy with respect to the completed call ratio as shown in Fig. 7. The simulation result shows the significant improvement of our approach.

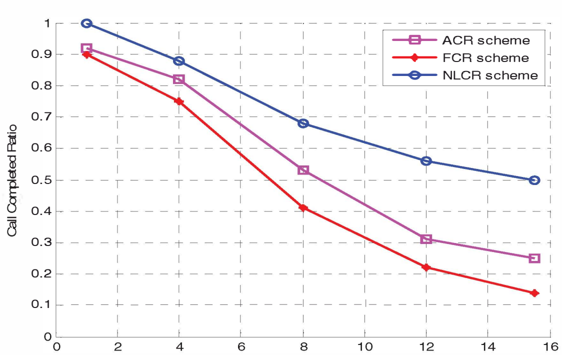

Figure 7: Comparisons of Call Completion Ratio for ACR scheme, FCR scheme, and NLCR scheme.

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 channel allocation is not pre-deterministic. It 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 may cause the significant increment in handoff latency. The computation effort of the satellite also increases significantly to perform this decision making step.

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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