Dynamic Power Allocation for Broadband Multi-Beam Satellites

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***Abstract*—Broadband multi-beam satellite networks play a substantial role in worldwide telecommunication and providing direct satellite services to users. Geostationary satellite has always been serving as the backbone of the commercial satellite communication networks. In broadband satellite communication, the high frequency bands are generally used. At these frequencies, there are various impairment factors that degrade the quality of signals. Among these factors, rain attenuation is the dominant factor at frequencies of 10 GHz and above. Using different models for rain attenuation prediction and power allocation algorithm, it has been shown that the number of served users is increased. In this paper, a new dynamic power allocation algorithm is proposed, which provides better results in terms of time elapsed and number of users served. The advantage of algorithm is the simplicity with which it allows the simulation. This is important for complex models of adaptive networks where finite response time is of great importance.**

Keywords - Satellite communication; rain attenuation; optimal power allocation; finite response time.

I. INTRODUCTION

Broadband multi-beam satellites are used for communication networks. A satellite communication system uses satellites to relay the radio signals between earth terminals. The satellite is used as a repeater; it amplifies the signals received and then retransmits them back to the earth. This increases the strength of signal at the receiving terminal. A typical operational link involves an active satellite and two or more earth terminals.

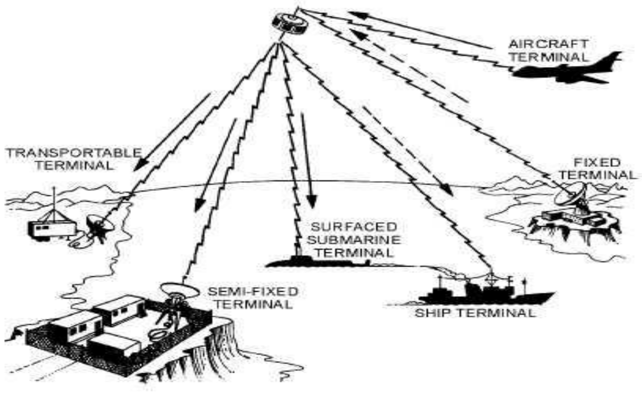

Fig.1 Satellite communications system

There are various attenuation factors present in the atmosphere that impair the RF signals used for satellite communication such as cloud attenuation, atmospheric absorption, ionospheric scintillation, rain attenuation etc. Among these, rain attenuation is the dominant factor that heavily degrades the signals at frequencies of 10 GHz and above. It is highly space and time varying parameter. Thus, it has given rise to the need for designing the algorithms for allocating power among the beams of a multi-beam satellite according to the atmospheric conditions.

In [3], a power allocation algorithm is proposed, which uses a controller and packets transmitted from users to maximize the throughput of the system. The controller aims to stabilize the system and achieve maximum throughput. Later in [4], the problem of optimal power allocation based on the traffic distribution on Earth is discussed. It maximizes system performance and achieves reasonable fairness among the users. In [5], the quality of service and requirement of service level agreement is discussed. An innovative power allocation algorithm is proposed in order to meet the total power constraint and individual Service Level Agreement constraint. Subsequently in [1], an algorithm is proposed to serve the problem of maximizing the number of users served using a stochastic model for rain attenuation prediction. Based on that, a simple dynamic power allocation algorithm is proposed. This serves the more number of users than the static model. Recently in [2], an improved dynamic and flexible algorithm is addressed to serve the maximum number of users. In this algorithm, the users having the similar power requirement is grouped together, instead of individuals. Thus, it gives the optimum solution and serves the more number of users than the existing techniques. But the complexity involved is more and hence the response time is more. In this paper, a dynamic power allocation algorithm is proposed, which gives the comparatively similar results for optimum number of users served. The complexity of the algorithm is less and hence the response time is less. This is an important advantage for the systems where finite response time is of great importance.

II. SYSTEM AND CHANNEL MODEL

We consider a communication satellite that has M beams and provides its broadcast services to N geographically separated users, where N >> M. Every user requires a minimum power for being served called threshold power. Assume it to be the same for all the users and denote it as P_{thr}. Let the received power of user i is $P_{r,i}$ and the input power at beam j is $P_{s,j}$. The relation between them can be expressed as

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$$P_{r,i} = h_{i,j} P_{s,j}\ ,\ \ (i = 1......N, j = 1......M) \qquad (1)$$

where $h_{i,j}$, denotes the power gain of the channel from beam j to user i. There can be two types of channel: a clear sky channel and a rain attenuated channel. For clear sky channel, the clear sky gain is given by [1]

$$h_{i,j,cs} = \frac{Gs\ Gr}{(4\pi d)2}\, 10^{\frac{-Ac}{10}} \qquad (2)$$

where, d is the length of the satellite link, G_s is the gain of the satellite transmitter antenna, G_r is the gain of user receiver antenna, A_c is the clear sky attenuation. A_c is the attenuation due to clouds, fog, gases, melting layer absorption etc, which shows very little variation with time and hence assumed to be constant [1]. Now for any user i served by beam j, the condition $h_{ij}\, P_{s,j} \geq P_{thr}$ must be valid for reliable operation. Hence, it can be deduced that the minimum power requirement of beam j in order to serve user i is $P_{thr}/h_{i,j}$.

For rainy users, the time dependent channel gain $h_{ij}(t)$ can be given using the time varying attenuation $A_r(t)$ as

$$h_{ij}(t) = h_{ij,cs}\, 10^{\frac{-A\mathrm{r}(t)}{10}} \qquad (3)$$

where $A_{r,}(t)$, is the attenuation due to rain and can be found using the following stochastic model for rain attenuation [6]

$$\frac{dAr\,(t)}{dt} = A_r(t) dA[S\alpha^2 - (\ln(A_r(t)) - \ln(A_m))] + S\alpha A_r(t)\sqrt{2dA}\; n(t) \qquad (4)$$

where A_m, S_α are statistical parameters of the long-term log-normal distribution of the rain attenuation in the decibel scale, dA is statistical parameter describing the dynamic properties of rain attenuation along the propagation path [6] and $n(t)$ is white noise process. The initial value for $A_r(t)$ can be evaluated as described in [7]

$$A_r(t = 0) = A_0(t = 0).L_{eff} \qquad (5)$$

where $A_0 = a\, R^b$

and $$L_{eff} = \frac{Lreal}{a1 + Lreal\,.\frac{(a2.Rij\ + a3.Lreal\ + a4)}{a5}} \qquad (6)$$

where, R_{ij} is point rainfall rate in mm/h, L_{eff} is effective path length which accounts for inhomogeneity of rain medium, L_{real} is equivalent path length. The parameters a and b depend on frequency, polarization and elevation angle. The parameters a_1, a_2, a_3, a_4, a_5 (the constants of Garcia-Lopez Model) and $Lreal$ [8] can be found using the methodology described in [7].

For a rainy user i to receive adequate power from beam j so that it is said to be served, it is required to satisfy the condition $P_{s,j} \geq P_{thr}/h_{i,j}(t)$. This means that, if power is allocated to any beam j such that user i with channel gain $h_{i,j}(t)$ is served, then any other user covered by this beam having its channel gain greater than $h_{i,j}(t)$ is automatically served. Again, $A_r(t)$ is a positive quantity and hence from (3), it is concluded that $h_{i,j}(t)$ is always less than $h_{i,j,cs}$ and thus serving any user under rainy condition will ensure that all the clear sky users corresponding to that beam are automatically served. Different algorithms can be used to allocate available power of the satellite among the different beams j. The aim of this power allocation is to serve maximum number of users in specific time.

III. STATIC AND DYNAMIC APPROACH

There are various approaches one can adopt to serve the number of users available in each beam. But the ultimate requirement is that, the power allocated to the beams is such that the number of users served is as high as possible and the computational complexity involved in assigning the power to the beams should be as low as possible. If any approach to allocate the power to different beams of multi-beam satellite satisfies this condition, then that approach is considered to be most desirable. The simplest way to allocate the available power of satellite to its various beams is to allocate equal power to each beam. This approach is called as the static approach. In all conditions, power allocated to the beams is same and hence it does not provide satisfactory results. It is not the efficient use of the available resources.

The other approach is the dynamic and greedy approach [1]. This algorithm of power allocation forms a set of users by sorting them in increasing order of their power requirement. In this process, it does not consider from which beam they are served. Then, the users at the beginning of the set which has the minimum power requirements are removed one by one and their power requirement is fulfilled by allocating the required power to the corresponding beams. The algorithm terminates when the available power with satellite is less than the required power by the next user. That is the available power is less than the threshold power required by the user for being served. This is the essential condition for serving the user, which gets violated. Hence, the results obtained are not as good. This can be illustrated by a simple example. Let there be only two beams available which serves the users with power requirements {20, 30, 40, 50} and {35, 45, 55, 65}. Let the total available power is 50 units. Then, the sorted set according to the power requirement of users is formed as {20, 30, 35, 40, 45, 50, 55, 65}. Now this algorithm will serve only the first two users in the set, both of which correspond to beam 1 and 20 units of power will remain unallocated. This is not the efficient utilization of available resources, which are very precious. In this example, the user with power requirement of 40 units of beam 1 after having served the one with power requirement of 30 units from the same beam requires only 10 units of extra power, whereas serving the user with power requirement of 35 units from beam 2 requires 35 units of extra power. Thus, this algorithm does not consider this fact. As a result, this approach will not serve users with power requirement 40 & 50 units of beam 1, while they can be actually served since the total available power is 50 units. In this example, if static approach is used, then it will allocate 25 units of power to each beam. Then, only one user from beam 1 will be served and the remaining power of beam 2 will be unutilized.

Another algorithm in [2] provides better results in terms of number of users served. In this algorithm, power

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is allocated dynamically. The users with similar power requirement are treated as a group, instead of individuals. Then, the available power is allocated to the groups, so that optimum solution is obtained. Thus, it is able to serve more number of users than the other existing techniques. As the number of groups formed within a beam with same power requirement of users is increased, the result gets improved. This approach provides a very good result, which is near about similar to the optimum solution. But, the complexity involved in computation is more and hence the response time of this approach is more.

IV. PROPOSED ALGORITHM

By keeping in mind that the cost incurred to set a satellite in the orbit is very high, the satellite communication system should generate the revenue as much as possible. Hence, it is required to utilize the available resources effectively and to serve the maximum number of users possible. So, each beam should get the sufficient power so that each user of that beam is served. We call this power requirement as minimum power requirement of beam. But, this requirement of all beams cannot be satisfied, because the available power is very limited. Hence, there should be an efficient way by which maximum users can be served with the same available power. But, this power allocation should also take place in some definite time. We call it as finite response time. So, the requirement of a good algorithm is that it should serve maximum users in finite response time.

To fulfill this requirement, we will first decide the sequence of the rainy beams which should get served first depending on their power requirement and number of users available in that beam. Then, according to this priority, the beams will be fulfilled with their power requirement one by one.

Algorithm **:**

Step 1: Determine the minimum over all clear sky channel gain $h_{min,i,j}$ among all the clear sky beams.

Step 2: Evaluate power for it, $P_{s,j,cs} = P_{thr}/h_{min,i,j}$ and allocate this power to all clear sky beams.

Step 3: For rainy beams, compute all the channel gains h_{ij} and evaluate $P_{j,max}$ for each beam.

Step 4: Find the difference between $P_{j,max}$ and number of users available in each beam j.

Step 5: If $P_{j,max}$ of each beam is greater than number of users in respective beam, then arrange the difference of step 4 in ascending order; otherwise arrange in descending order.

Step 6: For each beam, calculate the product of $P_{j,max}$ and available users in that beam and arrange this product in descending order.

Step 7: Allocate the available power among the beams according to the order of Step 5 & Step 6 separately.

Step 8: Select the powers allocated to the beams according to Step 7, which optimizes the solution.

V. SIMULATION RESULTS

In this Section, simulation results of the proposed dynamic power allocation algorithm are presented using MATLAB. Here, we are considering a hypothetical satellite network of Hellas Sat 2 (39°E) operating at 12 GHz. Consider that the multi-beam antenna has 16 beams. Out of these 16 beams, six are assumed to be rainy and the remaining ten are assumed to be clear sky beams. The coverage area of each beam is assumed to be equal and serving a span of 6°N in latitude and 6°E in longitude. The users are assumed to be uniformly distributed with distances of 0.5° from each other both in latitude and longitude. The total users come out as 2304. The number of users per beam turned out to be 144. Thus, there were a total of 864 rainy users and 1440 clear sky users. For rain attenuation stochastic model described in (4), the parameter values are taken to be same as [6]. For the simulation purposes, the point rainfall rate data is obtained from ITU-R rain-maps [10]. The values of parameters *a* and *b* are obtained by the method described in [9].The value of other parameters a_1, a_2, a_3, a_4, & a_5 are obtained by method described in [7].

In this simulation, we are considering only users under the rainy condition. We are assuming that all clear sky users are satisfied by their power requirement and hence said to be served. The corresponding threshold power for every satellite terminal is assumed to be -100dBm. Assume the total available power of satellite is 3300 units. We know that the rain attenuation is highly space & time varying and thus power requirement of the users keep on changing continuously. The time interval between two consecutive reconfigurations of the multi-beam antenna is set at 30 min. The satellite network has been simulated for the duration between two reconfiguration time instants, so only one configuration has been implemented. The beam powers are configured at the starting time that is at t=0 and then kept constant until the next configuration i.e. for the entire 30 minute interval.

Fig. 2 shows the number of rainy users served for different values of available power by different approaches. The algorithm in [2] provides better result, which is nearly equal to optimum solution. Hence, it is used to calculate the optimum value. In each case, the number of rainy users served by proposed algorithm is more than that in algorithm [1] and static approach and almost equal to the optimum solution.

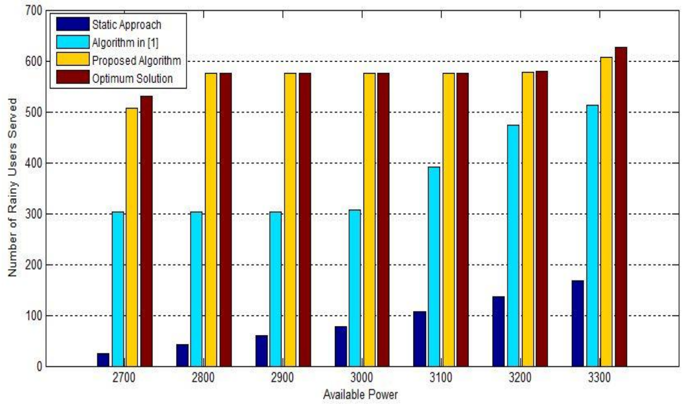

Fig.2 Number of rainy users served for different values of available power

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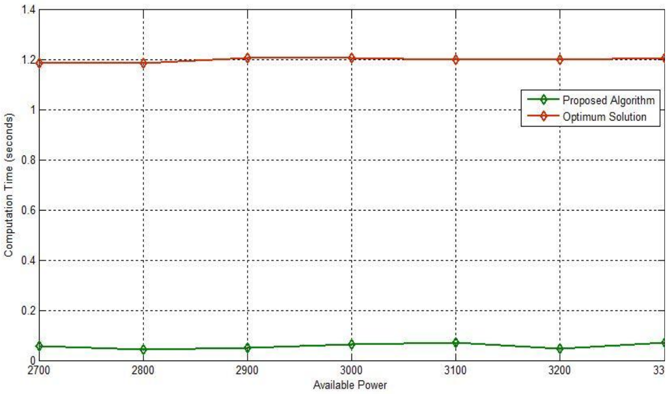

Fig.3 Computation time required for different values of available power

Fig. 3 shows the computation time required in seconds by proposed algorithm and algorithm [2], from which optimum solution is obtained for different values of available powers. From figure, it is seen that there is a huge difference between computation times required by both approaches. Hence, it is an advantage of proposed algorithm to have very less computation time to serve the almost equal number of users served by optimum solution.

VI. CONCLUSION

In this paper, a new dynamic power allocation algorithm is proposed with less complexity. It allocates the available power of satellite to different beams so that the number of users served is greater than the number of users served by other algorithms proposed recently. The advantage of the proposed algorithm is that the computation time required by it is very less. This is important for complex models of adaptive networks, where finite response time is of great importance.

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