Optimum Selective Beam Allocation Scheme for Satellite Network with Multi-spot Beams

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Abstract—**We are living in the world in which resources are limited compared to the traffic demands, which are increasing rapidly. In this environment, it is essential for the resource management techniques to maximize the effectiveness of the resource utilization. In particular, since the satellite resource such as on-board power, bandwidth even beam itself are expensive and limited due to its inherent characteristics, an effort to enhance the efficiency on their utilization is crucial. In this paper, we consider beam resource management in the N multi-beam satellite system. The simulation result demonstrates that the proposed scheme selecting only K(≤N) active beams assigning the beam power can achieve the increase of a total throughput compared to the non-selective beam allocation.**

Keywords-beam selection; resource management; multi-beam satellite; wireless communication

I. INTRODUCTION

A resource management is one of the parts of important techniques in the wireless communications. In this system, it is possible to achieve a improve efficiency in a volatile environment depending on how to manage the resources. Since the satellite resources such as power, bandwidth and the use of a spot beam are expensive and scarce, the effort to enhance their efficiency is crucial. And also, recently, the multi-beam antenna technique plays important role in the satellite communications as it can be flexible network configuration. In previous research [1]-[4], the beam power allocation schemes were proposed using advantages of parallel multi-beams which is monotonically increasing the capacity gain with the number of beams. In particular, Jihwan et al. [1] addressed the issue of long term average gain in terms of Shannon capacity and power efficiency. It emphasized the mathematical formulation and analytic solutions of the optimum resource allocation problem as well as explained the trade off problem between the total system capacity and fairness among all spot beams with traffic demands. It noted that if we want to maximize the total system capacity, we should allocate a fixed amount of power regardless the traffic demand which exceeds the some threshold for each beam and sacrifice the loss of proportional fairness. It is well known that the maximum total capacity can be achieved by water-filling approach [5].

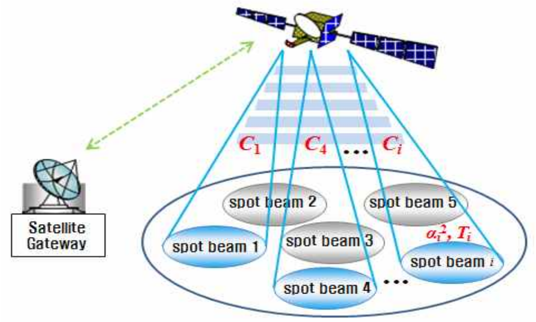

Figure 1. Multi-beam satellite system applying active beam selection scheme

On the other hand, it needs to allocate more power to beam with higher traffic demand and channel condition to achieve the proportional fairness over spot beams, but loses some total capacity. Referring to this, we want to allocate the beam power and small number of K active beams among the $N(>K)$ multiple beams which can be illuminated simultaneously to achieve more total system capacity.

The rest of the paper is organized as follows. Section II describes the background of optimum selective beam allocation scheme, and presents how to give the highest priority to the active beam for multi-beams within a satellite coverage area. Section III presents simulation result to compare the proposed scheme with the case of non-selective beam allocation scheme. Finally, the conclusion is drawn in Section IV.

II. OPTIMUM SELECTIVE BEAM ALLOCATION SCHEME FOR MULTI-BEAM SATELLITE SYSTEM

A. Background of K active beam selection over N multi-beam satellite system

Fig. 1 shows the system configuration of a multi-spot-beam satellite selecting the active beams to allocate the resource. In the network, a multi-spot-beam satellite in geostationary orbit and an ensemble of spot beam cells are deployed in the network. Each spot beam has different traffic demand T_i and signal attenuation α_i^2 by channel conditions. The concept of active beam selection scheme is to allocate the capacity C_i subject to the chosen $K(<N)$ active beams. The purpose of the beam selecting

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algorithm is to maximize the effectiveness of the resources utilization, and then total system capacity can be improved. As parts of this effort, we consider to make the reasonable beam power allocation for each spot beam with different traffic demand and channel condition [1]. Since the real traffic is non-uniform and time is varying, the resource management must reflect the different traffic distribution and channel conditions across all spot beams. Using the time sharing for Gaussian broadcast channels [5], we can obtain the Shannon bounded beam capacity of $C_i = W \log_2(1+\alpha_i^2 P_i/WN_0)$,where N_0 is the noise power density and W is the allocated bandwidth. P_i is the beam power to be allocated and adjusted. In this paper, we mainly consider that downlink channels have the property of rainfall attenuation, which are slow fading events.

B. The review of optimum power allocation(OPA) scheme

As one of the metrics to evaluate the system performance of resource allocation over satellite downlinks, Jihwan et al. [1] addressed some tradeoff between different objects for system optimization. They derived the downlink multi-beam capacity optimization problem and proposed a schematic method. It focused on the best case when available capacity matches demand under the assumption of a simplified model. Minimization of difference between the supported capacity C_i and traffic demand T_i for ith beam can provide a reasonable objective for resource allocation, considering trade-off between the maximization of total capacity and the support of fairness among beams with traffic demand. In view of this, a square deviation cost function between capacities and traffic demands was adopted as given below.

$$\arg\min_{C_i} \sum_{i=1}^{N} (T_i - C_i)^2. \quad (1)$$

where

$$C_i \le T_i \quad \text{for } i=1,2,\ldots, N \quad (2)$$

$$\sum_{i=1}^{N} P_i \le P_{total} \quad (3)$$

First constraint in (2) means that the capacity allocated to each beam cannot exceed the traffic demand generated in each beam to prevent the unnecessary waste of resources. The condition in (3) implies the power for whole spot beams should be allocated within total system power and is called as aggregate power constraint. Applying the Lagrangian function as $L(P_i,\Lambda)=\sum_i(T_i-C_i)^2+\Lambda(\sum_i P_i-P_{total})$, it can obtain the optimum beam power profile P_i, which should satisfy as follow equation (4).

$$T_i - W\log\left(1+\frac{\alpha_i^2 P_i}{WN_0}\right) = \frac{\Lambda N_0 \ln 2}{2}\left(\frac{1}{\alpha_i^2}+\frac{P_i}{WN_0}\right), \quad (4)$$

where Λ is a Lagrange multiplier that is determined by the total power constraint of (3). If Λ is a nonnegative value, it means that the determined bandwidth by (4) satisfies the constraint $C_i \le T_i$ of (2).

As we mentioned, this OPA scheme needs to allocate more power to beam with higher traffic demand and channel condition to achieve the proportional fairness among the spot beams, but loses some total capacity. Therefore, we present a proper beam selection algorithm to achieve more total system capacity based on OPA scheme.

C. OPA with selective beam allocation scheme

In order to derive the selective beam allocation algorithm, we adopt another constraint as below.

$$P_i \ge 0 \quad (5)$$

The constraint (5) is added to see which users should be served with non-zero power and to consider the beam selecting algorithm [6]. Applying the Lagrangian function as $L(P_i, \Lambda, s_i)=\sum_i(T_i-C_i)^2+ \Lambda(\sum_i P_i-P_{total})+\sum_i s_i(-P_i)$ and differentiating with respect to P_i, we can derive the following (6).

$$\frac{\partial L(P_i,\Lambda,s_i)}{\partial P_i} = \frac{\partial \sum_i (T_i - C_i)^2}{\partial P_i} + \Lambda - s_i \quad (6)$$

where, Lagrangian multipliers $s_i(\ge 0)$ are for $-P_i \le 0$, and Λ for the total power constraint. The Kuhn-Tucker condition [7] can yield $s_i = 0$ if $P_i > 0$, and $s_j \ge 0$ if $P_j = 0$. First, applying this condition to (6), we have the $s_i = 0$ and $\partial L/\partial P_i|_{P_i= P_i*} = 0$ at the optimum beam power $P_i^* > 0$. From (6), we obtain as follow.

$$-\left.\frac{\partial \sum_i (T_i - C_i)^2}{\partial P_i}\right|_{P_i=P_i^*} = \Lambda < -\left.\frac{\partial \sum_i (T_i - C_i)^2}{\partial P_i}\right|_{P_i=0} \quad (7)$$

where the inequality is valid by concavity of capacity C_i. Next, when the optimal power is $0(P_j^* = 0)$ for jth beam, we have the $s_j \ge 0$ and $\partial L/\partial P_j|_{P_j=0} = 0$. Then, (6) can be expressed as in (8).

$$-\left.\frac{\partial \sum_i (T_i - C_i)^2}{\partial P_j}\right|_{P_j^*=0} + s_j = \Lambda \ge -\left.\frac{\partial \sum_j (T_j - C_j)^2}{\partial P_j}\right|_{P_j=0} \quad (8)$$

By comparing the right sides of (7) and (8) with respect to common Λ, we can find the optimum policy to select K active beam with highest value of

$$-\frac{\partial \sum_i (T_i - C_i)^2}{\partial P_i}\bigg|_{P_i=0} = -\frac{\partial \sum_i \left(T_i^2 - 2T_iC_i + C_i^2\right)}{\partial P_i}\bigg|_{P_i=0} \quad (9)$$

Inserting $C_i = W \log_2(1+\alpha_i^2 P_i/WN_0)$ to (9),

$$-\left[-2T_iW\frac{\frac{\alpha_i^2}{WN_0}}{\left(1+\frac{\alpha_i^2 P_i}{WN_0}\right)\ln 2} + W^2\frac{2\left(\frac{\alpha_i^2}{WN_0}\right)\log_2\left(1+\frac{\alpha_i^2 P_i}{WN_0}\right)}{\left(1+\frac{\alpha_i^2 P_i}{WN_0}\right)\ln 2}\right]\Bigg|_{P_i=0}$$

$$= \frac{2T_i\alpha_i^2}{N_0 \ln 2} \quad (10)$$

In other words, in order to select the K active beams among the N spot beams with traffic demand, we only need to investigate the value of (10) across all spot beams. Whereas if we look at it, we can find that the factor affecting to value of (10) is only term of $T_i\alpha_i^2$. It can deem that the higher traffic demand and better channel condition for whole beams give the highest priority to the active beam. It can achieve the improvement of system capacity, but lose the fairness for some of the beams. We can compare the performance when used with beam selection algorithm in the next section.

III. Simulation Results

This section presents the simulation result. For the purpose of performance comparison, we create a simplified simulation model as follows. We evaluate the performance of beam selection scheme in an S-band GEO satellite channel. Also, we assume non-uniform signal attenuation α_i^2 ($\leq$1) across each spot beam, and generate randomly for the simulation. Table 1 represents the system parameters used in our simulation model for fig. 2.

Fig. 2 shows the capacity distributions of spot beams that are allocated by water-filling method and optimum power allocation scheme and OPA with beam selection scheme, respectively. It is well known that the maximum total capacity can be achieved by water-filling approach. As confirmed in Table 2, indeed, a water-filling scheme can achieve greater total system capacity than the conventional OPA scheme. On the other hand, the selective beam allocation scheme results in total throughput gain compared to non-selective allocation scheme. However, in some cases, it cannot be selected as active beam based on worse channel condition despite the beam with high traffic demand by considering the total system capacity (e.g., ith beams for i= 10, 14, 15, 18, 20 in the Fig. 2). From this result, we can infer that we can achieve more total system capacity, but lose the fairness for some of the beams. In other words, we face a trade-off problem between the maximum total capacity and fairness among the spot beams.

TABLE I. System Parameters in the Simulation for Fig. 2

Parameters	*Values*
Number of spot beams, N	20
Number of active beams, K	15
Total system bandwidth	500 MHz
On board EIRP	80.33dBW
Free-space path loss [8], f_s=2.5GHz	191.53 dB

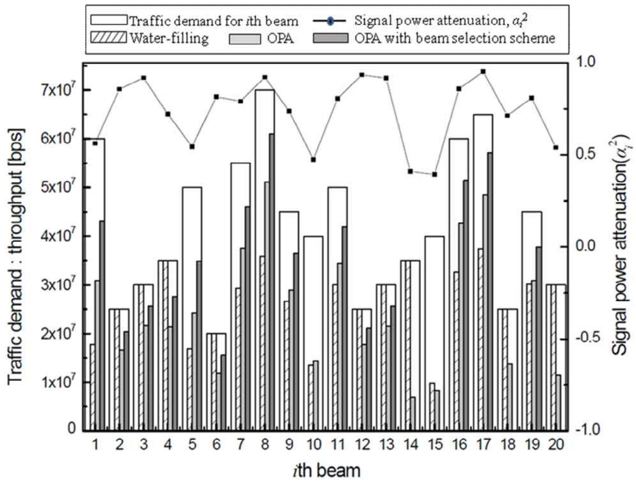

Figure 2. The comparison of throughput of ith beam for water-filling, OPA scheme and OPA scheme with selective beam allocation

In this regard, we focused on the minimization of the gap between supported C_i and T_i, and can confirm that the proposed scheme coincides more closely to the objective of this resource allocation through a comparison of the total sum of the gaps shown in Table 3.

TABLE II. The comparison of total throughputs

Schemes	*Total throughput*
Water-filling in [5]	534.64 Mbps
OPA scheme in [1]	494.75 Mbps
Proposed selective scheme	545.76Mbps

TABLE III. Comparison of the total sum of $\sum_i (T_i\text{-}C_i)^2$

Schemes	$\sum_i (T_i\text{-}C_i)^2$
Water-filling in [5]	7.0797E15
OPA scheme in [1]	5.6435E15
Proposed selective scheme	1.1480E15

IV. Conclusion and Future Work

In this paper, we proposed an optimum selective beam allocation scheme based on the traffic distributions and channel conditions for the parallel multi-beam satellite system. This paper studies how to allocate the active beam

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considering trade-off problem between maximum total capacity and proportional fairness among beams with traffic demand by minimizing difference between beam traffic demands and allocated beam capacities assuming a simplified model and minimization problem. The simulation results demonstrate that the proposed beam selection scheme sacrifices the fairness for some of the beams, but nevertheless, can achieve more proportional fairness compared with water-filling method. In addition, it can achieve the best performance of total system capacity. In order to implement the interaction of the algorithm such as ACM, the practical simulation condition with weather impairments should be considered in future.

REFERENCES

[1] Jihwan P. Choi and Vincent W. S. Chan, "Optimum Power and Beam Allocation based on Traffic Demand and Channel Conditions over Satellite Downlinks," IEEE Trans.on wireless Communications, vol. 4, no. 6, pp. 2983-2993, Nov. 2005.

[2] Michael. J. Neely, Eytan Modiano, and Charles E. Rohrs, "Power Allocation and Routing in Multibeam Satellites with Time-Varying Channels," IEEE/ACM Trans. On Networking, vol. 11, no. 1, pp. 138-152, Feb. 2003.

[3] Kwang Jae Lim, Soo Young Kim and Ho Jin Lee, "Adaptive Radio Resource Allocation for a Mobile Packet Service in Multibeam Satellite Systems," ETRI Journal, vol. 27, no. 1, pp. 43-52, Feb. 2005.

[4] Yang Hong, Anand Srinivasan, Brian Cheng, Leo Hartman and Peter Andreadis, "Optimal Power Allocation for Multiple Spot Beam Satellite Systems", Proceedings of IEEE Radio and Wireless Symposium (RWS 2008), pp. 823-826, Orlando, FL, Jan. 2008.

[5] Thomas M. Cover and Joy A. Thomas, *Elements of Information Theory*. New York: Wiley, 2006.

[6] Jihwan P. Choi and Vincent W.S. Chan, "Resource Management for Advanced Transmission Antenna Satellites," IEEE Trans. on wireless Communications, vol. 8, no. 3, pp. 1308-1321, Mar. 2009.

[7] Dimitri P. Bertsekas, *Nonlinear Programming*. Athena Scientific, 1999.

[8] ITU-R, "*Calculation of Free-Space Attenuation,*" Rec. P. 535-2, International Telecommunication Union, 1994.

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