Beam-Hopping and Resource Allocation for NOMA Based LEO Satellite Network: Genetic Algorithm

Shruti Sharma, Mesut Toka, and Wonjae Shin
Department of Electrical and Computer Engineering, Ajou University.
shruti.ashu22@gmail.com, *tokamesut*@ajou.ac.kr, *wjshin*@ajou.ac.kr,

Abstract

In this paper, we investigate a multi-beam low earth orbit (LEO) satellite network to offer a solution for services in a wide-coverage area. Owing to the advantages of beam hopping (BH) and non-orthogonal multiple access (NOMA), we apply Genetic Algorithm to optimize the performance of multi-beam LEO satellite network using improved BH pattern and reduced power consumption via the NOMA scheme. With this method, we propose to reduce the gap between offered capacity and demand, which yields a better performance compared to conventional orthogonal multiple access.

I. INTRODUCTION

Beam hopping (BH) in LEO satellites, which provides flexible radio resource management, has introduced a spark in wireless communications [1]. In BH, only a subset of multi-beam spots is illuminated at each time slot [2]. Beam illumination pattern or beam time-slot assignment alleviates the cost constraints on satellite launch operations, and consequently, enhances resource utilization and achievable system capacity.

Despite the advantages mentioned above, spectral efficiency (SE) of conventional BH is limited by the existence of inactive beams [1], which further motivates us to improve the SE by using sufficient means. Another scheme that is beneficial to the BH system is non-orthogonal multiple access (NOMA) which provides an extra degree of freedom in the power domain compared to orthogonal multiple access (OMA) [3]. NOMA allows multiple users to share the same resource simultaneously, that yields significant improvement in the SE and sum rate. To extract the desired data, users apply successive interference cancellation (SIC) technique to the receivers. Motivated by these, we propose to design an efficient joint time-space beam illumination pattern for BH and power allocation as a multi-objective problem. The focus of this work is to design a robust BH-NOMA scheme in the presence of imperfect channel state information (CSI) which is still a new yet challenging topic in LEO satellite communication networks.

II SYSTEM MODEL

In this section, we will optimize the power and beams hopping pattern simultaneously by formulating a joint optimization problem. The schematic diagram is shown in Fig. 1, which we consider a multi-beam LEO satellite network. As, in this scenario, there is a large propagation delay and synchronization among satellites is perplexing. Therefore, we consider the practical case that the beam is pre-scheduled. While the set of the satellite is denoted by S, N_s represents the set of the candidate beam patterns. K_s is the set of the terminals served to the satellite s. According to the NOMA scheme, one beam of signal terminal is superimposed at the transmitter side. g_{sk} is the channel gain of terminal k associated to satellite s. p_{sk} is the maximum power. σ^2 is noise power. I_{sk}^{Intra} and I_{sk}^{inter} are intra, and inter-beam interference of terminal k associated to satellite s. Thus, the signal-to-interference-plus-noise ratio (SINR) of terminal k associated to satellite s is given by:

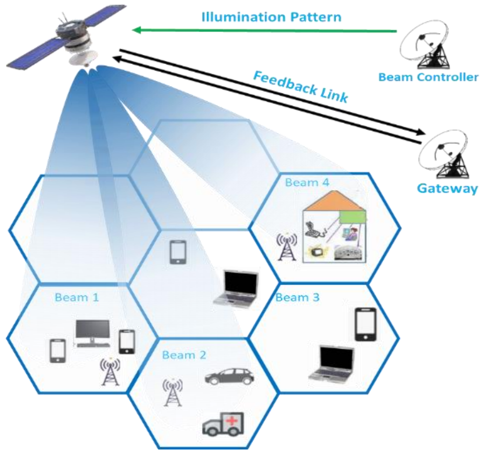

Fig. 1: System model of BH-NOMA in LEO satellite network.

$$\gamma_{sk} = \frac{|g_{sk}|^2 p_{sk}}{I_{sk}^{Intra} + I_{sk}^{inter} + \sigma^2}. \quad (1)$$

The offered capacity of terminal k assisted by satellite s is given by:

$$C_{sk} = B \log_2(1 + \gamma_{sk}), \quad (2)$$

where B is bandwidth.

III. PROBLEM FORMULATION

Now we jointly optimize power allocation and beam pattern selection to minimize offered capacity and requested demand $(C_{sk} - R_{sk})^2$. Here C_{sk} and R_{sk} are offered capacity and requested demand, respectively.

The problem is then formulated as:

$$\min_{p,x} \sum_{s \in S, k \in K} (C_{sk} - R_{sk})^2 \quad (3)$$

$$\text{s.t. } \textstyle\sum_{k \epsilon K} p_{sk} \leq \hat{p}_s, \forall s \in S \quad (3a)$$

$$\textstyle\sum_{n \epsilon N} x_{sn} = 1, \forall s \in S \quad (3b)$$

$$C_{sk} \geq C_{sk}^{min}, \forall k \in K, \forall s \in S \quad (3c)$$

where $x_{sn} \in \{0,1\}$ denotes beam pattern selection. The satellite s selects the n th pattern if $x_{sn} = 1$ and not otherwise. Due to the non-convexity and existence of binary variables, our problem is mixed-integer nonconvex programming (MINCP) which is hard to solve. Thus, to solve the optimization problem given by (3), this paper proposes to exploit genetic algorithm (GA) [4].

IV PROPOSED WORK

Developing a novel BH-NOMA synergy for LEO satellite systems for power allocation scheme benefiting from the intrinsic features of both technologies. In the proposed work, multi-parameters and variables need to be concurrently optimized such as power and beams illumination pattern. Thus, the optimization approach becomes MINCP which is solved by GA.

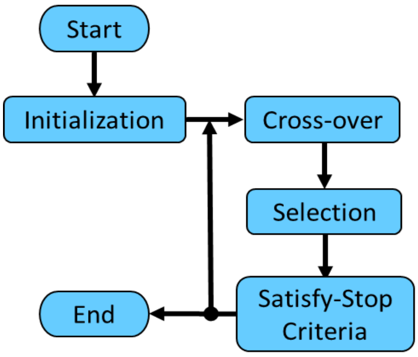

Fig. 2. Flow chart of genetic algorithm

The flow chart of the proposed GA is shown in Fig 2. The objective is to find the BH resource allocation which optimizes the geometric mean of offered capacity and demand. GA is a population based meta-heuristic algorithm for exploring a large space in complex optimization problems. In GA, the solution is selected on their fitness will be mutated and altered. At cross-over, offspring will be used to form a new population which perform better than the old one. The process continues until the stopping criteria is satisfied. Compared with the conventional optimization methods like heuristic algorithm, GA has a decent performance of convergence. Our result compares the beam indexed versus requested demand (*R*) and the offered capacity (*C*) that is achieved by the NOMA and proposed GA algorithms

V. CONCLUSION

In this paper, we have studied the beam illumination pattern for BH-NOMA and power allocation as a multi-objective problem. The performance of the proposed BH-NOMA concept for LEO satellites will show improved by optimizing power allocation. With our proposed method, we are expected to ease the capacity-demand gap and achieve improved performance over conventional method.

ACKNOWLEDGMENT

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REFERENCES

[1] Kodheli et al., “Satellite communications in the new space era: A survey and future challenges,” IEEE Communications Surveys & Tutorials, vol. 23, no. 1, pp. 70–109, 2021.

[2] Wang et al, “Joint beam-hopping scheduling and power allocation in NOMA-assisted satellite systems,” in Proc. IEEE Wireless Communications and Networking Conference (WCNC), Nanjing, China, 2021, pp. 1–6.

[3] Angeletti et al., “Beam hopping in multi-beam broadband satellite systems: System performance and payload architecture analysis,” in Proc. 24th AIAA International Communications Satellite Systems Conference, San Diego, California, USA, 2006, p. 5376.

[4] Gen, M. and Cheng, R., “Genetic Algorithms and Engineering Design”. Wiley, New York, 1997