A Hybrid Beam Hopping Design for Non-uniform Traffic in HTS Networks

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***Abstract*—In this paper, we discuss and propose a novel & hybrid approach for future High Throughput Satellite (HTS) networks using beam hopping and comparing the overall performance and capabilities of the proposed solution. This work focuses on a time switched payload configuration by monitoring the system resources and traffic demands based on geographical distribution. The proposed work, develops a standard protocol between satellite operators' Network Management System (NMS) and their telemetry, tracking and control (TT&C) division to enhance overall efficiency of HTS networks which results in reducing the operational cost and boosting users' overall experience.**

Keywords:
- High Throughput Satellite (HTS), Beam Hopping, Multi-beam, Clustering.

I. Introduction

HTS provides an exceptional opportunity to hand over broadband access to numerous users in a cost efficient configuration. A major challenge for satellite operators is that the overall system capacity deliverables should correspond to capacity demands for each region. Higher speeds and advanced data capacities are a common practice for every day communications. The first generation of HTS systems was proposed on a model that with a uniformly distributed capacity there would be fixed spot beams covering a desired geographical regions. This design limited the operational flexibility as power distribution was uniformly distributed regardless of the traffic demand.

The next generation of HTS adopts advanced modulation and coding schemes and a wider range of frequency bands. DVB-S2X deploys LDPC codes which can better approximate the Shannon limit compared with existing forward error correction designs. Implementing multi-beam operations and lower order frequency and polarization (color) reuse will lead to increased interference modules, resulting in the satellite communications channel interference limited as compared to noise limited.

Recently, beam hopping has been discussed to offer numerous advantages in the HTS systems. Taking into consideration the capacity demands on different geographical locations, it is observed that not all spots (areas) have the same demand for capacity at a certain time of the day. Studies have shown that some beams are more active than other beams given population density for that region [5]-[6].

II. System Architecture

In order to achieve improved traffic demands for future HTS systems for non-uniform usage areas, we propose a hybrid and dynamic design. In order to optimize the overall efficiency, an intelligent gateway diversity management solution is proposed. A number of gateways will be in operational mode and there would be some limited number of idle (standby) gateways supplemented. These additional gateways assure link availability for on-demand unprecedented traffic. The gateways are connected to the user beams in a multi star topology with each gateway assigned a predefined set of beams which can dynamically be re-assigned based on live traffic demands [1].

Figure 1 illustrates a high-level framework for the ground segment resulting flexibility in the feeder links and user beams. As shown, during peak hours on the East Coast, users on the West Coast are in less demand and the same applies for the other regions at a later time of the day. It is worth adding that this structure assumes a single user beam is provisioned by a limited number of gateways simultaneously at a given time. There would be a fixed number of active time-multiplexing hybrid gateways which continuously monitors the traffic and channel conditions. Once a deep fade is recognized, the system is qualified to deliver service with downsized capacity.

In the proposed beam hopping HTS system, the algorithm assigns a time slot to every beam according to the system illumination plan. In that given time, the entire downlink bandwidth is assigned to that beam. We assume a trade off can be made between the number of feeds acquired as a cluster simultaneously, the system resilience, and the number of configured Traveling-Wave Tubes (TWT).

The architecture described here, considers user beam clusters as shown in figure 2, to enable beam hopping arrangement. The beam hopping satellite changes it's illumination plan, providing longer beam time to the higher

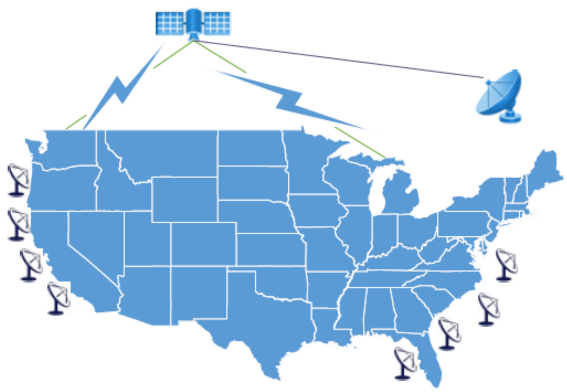

Fig. 1. A typical satellite communications network architecture with taking into account different capacity demands in each region

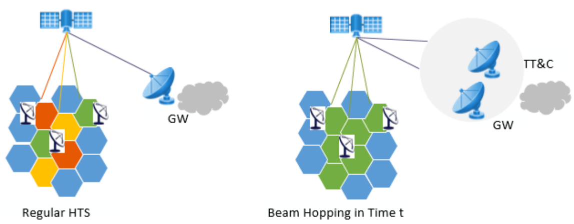

Fig. 2. beam hopping with clustering vs. non-beam hopping

in demand region. This will increase the overall capacity. Using a switching matrix to logically route the feeder to user beams requires a physical terrestrial mapping to where user beams point of presence (POP) are terminated [4]. This is an optimization approach where the goal is to minimize the connections while connecting all the gateways.

An initial approach is to select the beam hopping sequence, by selecting which beam is illuminated in every assigned timeslot [2]-[3]. If the *i-th* beam will be illuminated at *j-th* timeslot, it equals to

$$C_{ij} = 1,$$

resulting that the following constraint needs to be met:

$$\sum_{i=1}^{b} C_{ij} = K, \forall j$$

where b is the number of beams and K is the maximum number of beams that can be illuminated in a specific timeslot. Finally, we need to discuss the selection of the proper gateway to every illuminated beam at a given timeslot, trying to optimize the resources. In this scenario, the design selects which user beam is being served by which pool of gateways to guarantee link availability. In order to ensure link l is connected to beam j (of the pool of illuminated beams) at a given timeslot t, we have

$$C_{ljt} = 1,$$

the following optimization equation is considered. If P is considered as the overall satisfaction metric or the overall backhaul cost of the network, the goal is to optimize P subject to:

$$\sum_{i=1}^{b} C_{ljt} \leq K, \forall j, t$$

The proposed solution for HTS beam hopping would be the minimization of intra interference and better C/I overall performance compared to the non-hopped HTS systems. It has been shown that there is 30% throughput increase for a beam hopping network compared to a non-beam hopping network with uniform bandwidth and power allocations to each spot beam. Table 1 shows each region before and after applying the beam hopping technique.

TABLE I
BEAM HOPPING BETWEEN GATEWAYS AND USER BEAMS

Beam Hopping	Region 1 users	Region 2 users	Region 3 users
No	8	4	3
Yes	9	6	5

III. CONCLUSION

We have discussed the benefits of beam hopping when traffic demands in HTS spot beams is uneven in dissimilar geographical locations and times of the day or population density varies. To overcome sub-optimal constant transmission power allocation in traditional HTS systems, a novel & hybrid beam hopping feeder link architecture which adopts time switching payload transmission has been proposed. This solution functions on the fact that illumination of a cluster of beams at a specific time and spatial transmission will result in a repetition rate. We have studied both non-beam hopped and hybrid beam-hopped HTS systems using system optimization techniques to show the performance of the overall system based on capacity demands and power limitations. In comparison to static illumination systems, given the nature of beam hopping, congested spots are alleviated and overall power efficiency is improved.

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