User-Selection for Mobile-LEO Satellite Networks Over Rapidly Varying Channels

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Abstract

This paper presents a user-selection strategy to improve system throughput as well as minimizing latency in mobile-LEO satellite (Sat) networks operating under rapidly varying channel conditions. Herein are discussions on possible Sat benefits and challenges of integrating terrestrial (Ter) and Sat networks. We also propose a distributed user-selection mechanism to select users for attachment to different Sats to not only enhance throughput but also minimize latency, by formulating a stable match with low complexity. Based on simulations, we conduct evaluations by comparing the performance of the proposed scheme with other conventional schemes. The obtained results render the proposed scheme potential in improving system throughput and minimizing latency.

Ⅰ. Introduction

The challenge towards meeting 6G requirements such as more spectrum resources remains big for the naked eye to see. Moreover, in Ter networks, the existing spectrum resources have been overly stressed to support the exponentially increasing traffic. For that reason, extending Ter communications to Sats [1] has been considered as potential to overcome the spectrum constraint, hence, embracing the integrated Ter-Sat networks (ITSN). Just like Ter networks, Sats have shown promising capability to support various applications ranging from data, voice, video, to mention but a few. Furthermore, Sats can provide wide coverage especially in out-of-reach areas, which are not adequately served by Ter networks. Fortunately, ITSN could be beneficial for seamless service delivery in the next generation of networks such as 6G.

However, Sats have limitations, which may include, high-power amplifier (HPA) nonlinearity, Doppler shift, propagation delay and others [2]. Due to long-distance transmission, the need to maximize power efficiency necessitates operation of HPAs close to the saturation point. Consequently, undesirable HPA nonlinearities are introduced into the transmitted signal. Furthermore, since ISTN considers low earth orbit (LEO) Sats, which are operated at very high speeds, it is even more challenging to support highly mobile Ter terminals due to variations in carrier frequency and longer propagation delays.

In this paper, we discuss the channel characteristics of the channel existing between the highly mobile Sats and Ter terminals. Motivated by the high transmission delays resulting from the channel conditions, we propose the deferred acceptance mechanism to select users for a high data rate and low-latency link establishment.

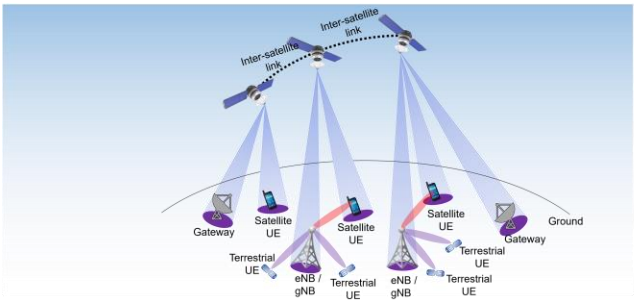

Fig. 1. Example of the ITSN architecture

Ⅱ. Main part

Unlike LEO, the traditional geostationary orbit (GEO) Sats mainly convey data to the Ter terminal via a ground station. Moreover, the GEO Sats have better coverage, and a few are required, albeit at the cost of the long propagation delays due to their distance from the earth. One way to improve service delivery can be through adopting LEO Sats. However, more LEO Sats and an equivalent establishment of a direct link between Sats and the Ter terminals will be required. Additionally, the direct link is constrained by various environmental factors such as rain attenuation and atmospheric absorption. This results in severe shadowing and multipath fading effects. Furthermore, since lower orbits exhibit large gravitational forces, LEO Sats accelerate faster to maintain their respective orbits. Consequently, with the high velocities portrayed by both the LEO Sat and the Ter terminal, Doppler shift effects become inevitable due to increased relative motion. This makes it more challenging to perform synchronization resulting in a deteriorated system performance. Therefore, it would be beneficial to derive approaches towards this cause, such as channel modeling, error-correction, synchronization, and so forth. The channel model used in the simulations presented in this article is adopted from [2].

In this article, we present deferred acceptance-user-selection (DA-US), a technique based on matching theory to improve system throughput and minimize delays over rapidly varying channel conditions. The proposed scheme is based on a two-sided matching technique [3] in which a suitable pair (stable match) between elements in two disjoint sets is formed after satisfying each element's preferences. In this case, the disjoint sets include M Sats and K UEs. Our problem seeks to maximize sum rate $R^u_{m,k}$ as shown in the expression below.

$$\max_{\mathbf{x}} \sum_{m\in M}\sum_{k\in K} x_{m,k} R^u_{m,k}$$
$$\text{s.t. } \sum_{k\in K} x_{m,k} \le L_{\text{M}},\ x_{m,k} \in \{0,1\};\ \forall m\in M, \forall k \in K$$

$x_{m,k}$ and $L_{m,k}$ represent the user-selection factor and the maximum number of UEs that can be associated with a particular Sat. The proposed scheme begins by formulating preference relations of the Sats and the UEs based on maximum channel gain as the utility function. It is worth noting that we consider the same utility function for both Sats and UEs. Both the Sat and UE broadcast their preference lists, which are arranged in the order of priority. The rest of the algorithm for the proposed user-selection has been summarized in Table 1.

Table 1. Algorithm for the proposed user-selection.

a) : Each UE and Sat builds its preference list. b) : Each UE applies to its most preferred Sat. c) : Each Sat ranks its applicants and creates a waiting list based on the order of priority and its quota while rejecting the rest. **Repeat** d) : The rejected UEs remove the previous Sat from their preference lists and apply to their next best Sat options. e) : Each Sat creates a new waiting list based on the order of priority according to its previous list and the new group of applicants, and its quota while rejecting the rest. **Until** No UE is willing to make applications.

The proposed scheme is compared with two baseline schemes including maximum-signal-to-interference user-selection (max-SINR-US) scheme, through which UEs are selected based on highest max-SINR ranking criteria, and the random-user selection (RA-US) where UEs are arbitrary selected regardless of aspects such as channel conditions and max-SINR. The performance metrics in this paper include the transmission delay, data size, and sum-rate. It should be noted that due to space limitations, results indicating throughput have not been shown in this paper. We compute the delay $\tau_{m,k}$ using the expression $\tau_{m,k} = d_{m,k} / R^u_{m,k}$, where $d_{m,k}$ represents the data size. We consider an uplink transmission scenario consisting of 4 LEO Sats distinguished by altitudes in the range of 400~1600km, each limited to supporting 100 high-speed moving UEs at a time. Fig. 2 shows that the average delay increases with the increase in the data size for each scheme. It also shows that the proposed scheme outperforms the baseline schemes by exhibiting the lowest delay. Unlike RA-US and max-SINR-US which are affected by unequal distribution of traffic loads and increased interference resulting in increased delays, DA-US balances traffic load associated with each Sat, hence giving a better performance.

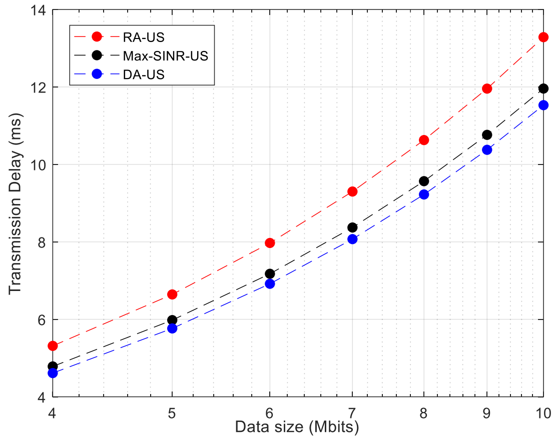

Fig. 2. Transmission delay versus data size

Ⅲ. Conclusion

In this paper, the need for adoption of Sats for 6G communications has been presented alongside the benefits and the associated challenges. The rapidly varying channel characteristics have been discussed including the high mobility, shadowing, and multipath. The discussions show that prior to adopting Sats as complementary links to the existing Ter links, there is need to exploit various ISTN properties including but not limited to channel characteristics. Furthermore, a low complexity and stable matching-based user-selection scheme has been proposed to improve throughput and minimize transmission delays. By attaining low latency, support for high data rates and capacity is made possible. In the future, we would like to achieve a higher performance through employing a combination of the proposed user-selection scheme with other techniques such as enhanced synchronization, beamforming, spatial diversity, etc.

ACKNOWLEDGMENT

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