Proactive Handover in LEO Satellite Networks

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***Abstract*—Low Earth Orbit (LEO) satellite mobile systems have garnered considerable attention in research due to their potential for high throughput, low-latency communication, and global coverage. These attributes position them as ideal contenders for integration into future 6G networks. This paper outlines the motivation behind incorporating emerging LEO satellite mobile systems into upcoming 6G networks, discusses their main challenges, and proposes a smart, proactive handover approach to address one of the primary hurdles associated with this emerging technology.**

***Index Terms*—LEO, proactive, 6G, handover**

I. INTRODUCTION

To ensure uninterrupted network services with a high level of quality of service (QoS) in a challenging environments such as dense urban canyons, mountains, or marine environments, future 6G networks must integrate with Low Earth Orbit (LEO)-based Non-terrestrial Networks (NTN). One of the main challenges facing this integration is the handover from the serving LEO satellite to the target LEO satellite, must be done quickly. For instance, the handover process in LEO satellite networks, presents notable differences than traditional terrestrial networks. Unlike terrestrial networks, where handover is typically prompted by user mobility, in satellite networks, the movement of the satellite triggers handover. Consequently, in dense urban canyons, the number of obstacles such as high buildings and narrow roads in addition to the large number of users that are situated closely together may trigger handover simultaneously as the serving satellite exits its coverage range. This simultaneous handover scenario can result in a significant processing overhead for the target satellite due to the high speed of the LEO satellites in their orbits.

Fortunately, proactive handover planning, facilitated by deep learning algorithms, is widely regarded as a solution to this requirement [1]. The proactive handover model in LEO satellite networks is forward-thinking, pre-emptively addressing the need for handovers before they become critical. The main objective is to minimize communication disruptions by initiating handovers based on predictive algorithms and network conditions [2].

In the proactive model, the system continuously monitors connection quality, leveraging this data alongside satellite orbit information and network traffic details to forecast when a handover will be necessary. By initiating the handover process in advance, the system ensures seamless transitions and reduces the likelihood of dropped connections [3].

II. SYSTEM MODEL

In this paper, we utilize a traditional geometric 3D Multiple-Input Multiple-Output (MIMO) channel model to establish downlink communication from a satellite to user as depicted in 3GPP [4]. The channel characteristics are described by delineating the geometric interactions between scatterers and the transceiver within the propagation environment. This study focuses on illustrating dense urban canyon areas as the model's context, characterized by dense scatterers such as trees, tall buildings, and narrow roads, as depicted in Figure 1. Consequently, the probability of encountering Non-Line-of-Sight (NLOS) conditions are notably higher around the user terminal and scatterers distributed across the 3D hemisphere surface.

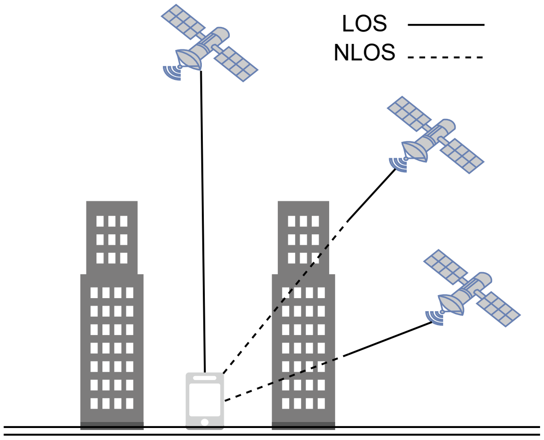

Fig. 1. System Model

A. Channel Model

We adopt the channel model outlined in 3GPP 38.811 [4]. As detailed in the 3GPP technical specification, the signal path between a satellite transmitter and an NTN terminal undergoes various stages of propagation and attenuation. For instance, the path loss (PL) that will be used later on to calculate the available data rate metric between the satellite and the user, consists of four components as in Equation 1:

$$PL = PL_b + PL_g + PL_s + PL_e \tag{1}$$

where the PL represents the total path loss in dB, where PL_b is the basic path loss, PL_g accounts for the atmospheric gases attenuation, PL_s represents the ionospheric scintillation attenuation, and PL_e signifies the building entry loss.

For path loss calculation, the distance between the satellite and the UE (slant range) can be computed based on the satellite altitude h_0 and the elevation angle $\phi_{u,s}$ between the satellite and the UE as in Equation 2.

$$d_{s,u} = \sqrt{R_e^2 sin^2\phi + h_s^2 + 2R_e h_s} - R_e sin\phi_{u,s} \tag{2}$$

where R_e denotes the Earth radius.

III. SATELLITE SELECTION MODEL

In this model, each available satellite for every user at time slot $t = (t_0, t_1)$ over time period Δ is assigned a reference score relative to other available satellites, determined by three metrics: Available Resources (AR), Remaining Time (RT), and available Data Rate (DR). Assigning weights to these metrics is essential, as it allows the selection function to reflect each metric's relative importance or contribution to the overall score. Since each metric plays a different role in determining the overall satellite score, dynamic weighting is necessary to adapt to the changing conditions of the dense urban canyon environment with a highly dynamic network topology [5].

Hence, this model dynamically assigns a weight to each metric based on its entropy values. The general formula for information entropy for user u on metric m is represented by:

$$E_{u,m_j} = -\sum_{i=1}^{n} P_i \log_2 P_i \tag{3}$$

where P_i is the probability of the i^{th} element in the metric m_j for user u.

After assigning a weight to each metric, the model will give a score to each available satellite of each user u, the score will be determined through supervised deep reinforcement learning (DRL) and the user's historical data on that location(e.g., signal strength and network traffic).

Finally, a network state diagram will be constructed for each user to serve as input for the long-term optimization algorithm. For each user, the state S_i^n is defined as the available satellite S_i at time slot t_n. The weight for each edge (u_k, s_i) is defined by the score $Score_{u_k}^{s_i}$, which is the preference score given to each satellite s_i for user u_k based on the local observation data of that satellite at time slot t_n. This score is calculated based on the satellite's remaining visible time RT_m^t, available data rate DR_m^t, and available resources AR_m^t. Figure 2 provides an example of a generated graph.

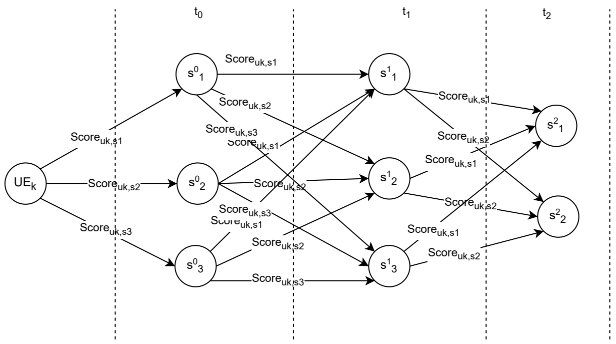

Fig. 2. Network State Diagram

One of the advantages of this proactive handover model is that it's expected to reduce the handover delay, minimize the blocking rate, and increase network throughput. These improvements will result in maintaining a high QoS. These advantages are gained by planning the handover ahead of time, before it is actually triggered. By predicting and planning user handovers, this proactive model ensures that users always maintain a strong connection, regardless of the movement of the satellites.

IV. CONCLUSIONS

In this paper, we propose a proactive handover scheme designed for LEO-based NTN. This scheme is particularly tailored to address dense urban canyon environments. The technique aims to plan handovers over multiple time steps. This approach helps in reducing signaling traffic storms on the target LEO satellite, which are typically caused by user group handovers. Simultaneously, it maximizes the overall QoS for those users.

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