Dynamic Optimization Framework for Multi-Hop Code Offloading in LEO Satellite Edge Computing

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***Abstract*—In our swiftly digitizing world, the importance of low-earth-orbit satellite (LEO SAT) communication is escalating. Advancements in 5G, IoT, and AI underscore the need for a robust communication network. Research reveals that nearly 40% of the global population faces Internet service challenges due to limited high-performance access by 2022. This technology not only addresses coverage limitations but also mitigates latency issues. Multinational corporations like SpaceX and Amazon are already exploring its potential. As we approach the 6G era, users' computational demands surge, prompting satellite edge computing with onboard processing. Our paper proposes a multi-hop code offloading model using LEO SAT, reducing energy consumption, and introduces a dynamic optimization algorithm for LEO SAT - mobile edge computing. The research aims to enhance satellite-based communication networks, with a focus on optimizing satellite edge computing efficiency.**

***Index Terms*—multi-hop code offloading, LEO satellites, edge computing, dynamic optimization**

I. Introduction

The growing significance of the LEO SAT communication sector is becoming increasingly evident in a swiftly digitizing world. The ongoing advancements in technologies such as 5G, IoT, and AI necessitate a robust communication network to support their functionalities. Failure to establish such a network would lead to a rapid deterioration in the quality of available Internet services. Moreover, based on the available investigations, it has been determined that by 2022, almost 40% of the global population encounters challenges in using the Internet service smoothly due to limitations in accessing high-performance Internet [1]. Consequently, the role of LEO SAT communication in rectifying this imbalance while offering Internet connectivity with dependable transmission speeds and bandwidth gains an unparalleled importance. This technology emerges as a solution that not only addresses the coverage limitations of terrestrial communication but also mitigates the latency issue, a significant drawback of conventional approaches. Several prominent multinational corporations (e.g., SpaceX, Amazon, OneWeb) have already initiated endeavors to harness the potential of LEO SAT communication, and their projects are currently in progress [2].

Traditionally, LEO SATs primarily functioned as intermediaries for relaying communication services to ground-based servers. However, as we transition into a 6G communication era, users' computational demands have surged considerably, and satellite communication is also confronted with a similar predicament. As a result, recent researchers have spearheaded the realm of satellite edge computing, enabling on-board processing by strategically placing edge servers directly onto LEO SATs. This emerging field is currently being investigated [3]. Nevertheless, existing studies on satellite edge computing inadequately account for the real-time positional changes induced by the high velocity of LEO SATs, leading to a lack of realism in their findings. To address this concern, this paper proposes a multi-hop code offloading framework employing LEO SATs, thereby resolving this limitation and concurrently minimizing energy consumption. Moreover, we introduce a dynamic optimization algorithm flowchart grounded in Lyapunov optimization principles, designed for system models necessitating brief time slots due to the mobile nature of LEO SATs [4].By making these contributions, this research endeavors to bolster the effectiveness and sustainability of satellite-based communication networks, particularly within the framework of dynamic orbital parameters and the demanding limitations of available resources. This includes the integration of enhancements aimed at increasing the efficiency of satellite edge computing .

II. System Model

Fig. 1 illustrates a multi-hop code offloading model in LEO SAT edge computing, designed to meet user's computational needs within the target area. On the ground, K users, labeled as $\mathcal{K} = \{1, \cdots, K\}$, are randomly spread across the region, generating computation-intensive tasks. In space, several LEO SATs on the same orbit cover the target area with overlaps. For streamlined control, it's assumed that a ground-based gateway (GW) can create links with multiple visible satellites during specific times [5]. As satellites move across the sky, their links with the GW change, established only when the elevation angle is high enough [6]. The main goal is long-term system performance optimization, which is challenging in a continuous time model. We adopt a slot-based time approach as seen in prior studies [7]. Each time slot, denoted by $t \in \mathcal{T} = \{0, 1, \cdots\}$, has a short duration τ, assuming the satellite-user relationship remains stable and the communication channel is fixed.

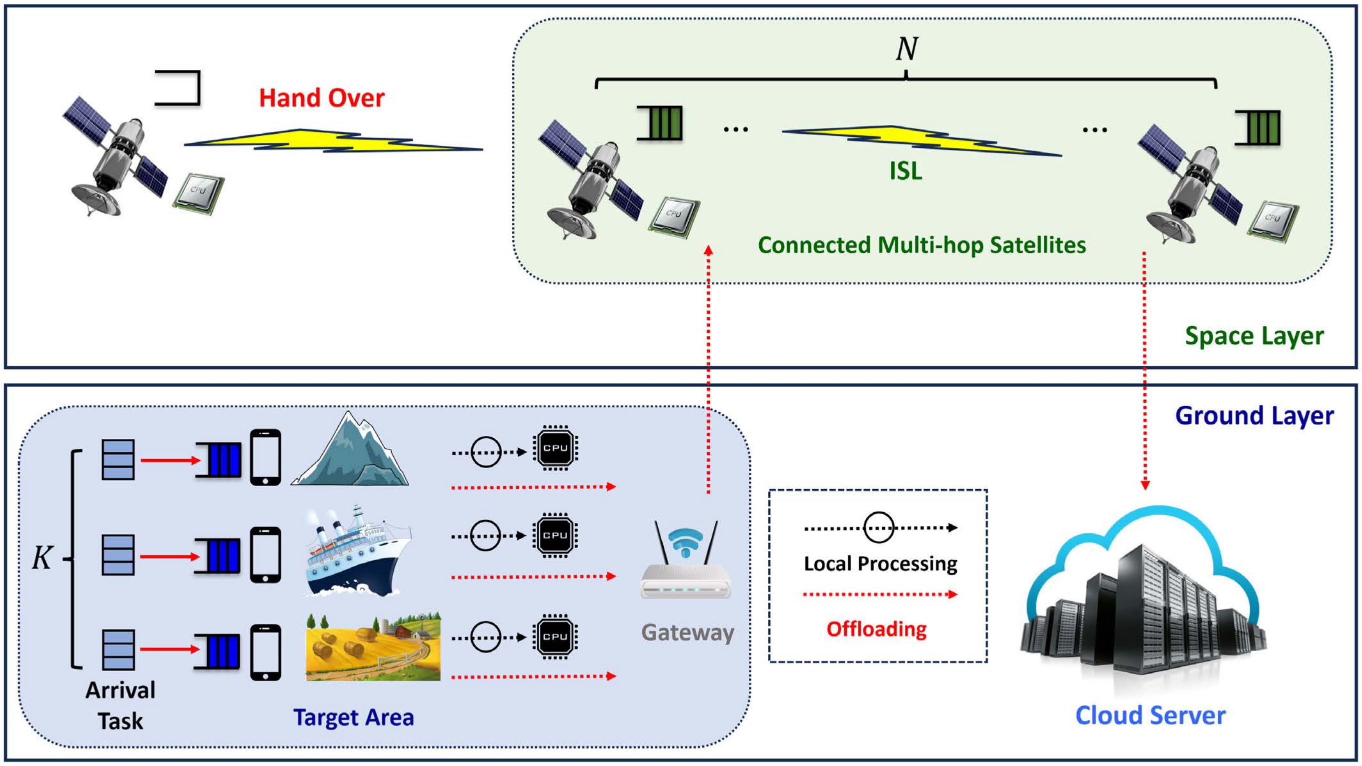

Fig. 1. Multi-Hop code offloading model in LEO satellite edge computing

To handle task changes across slots, we use queuing theory. The framework, along with research objectives, covers power use, task processing, and delivery. Relevant information, including channel data, is integrated into the proposed algorithm per slot. Three offloading choices determine where tasks process in slot 't'. Fig. 2 illustrates the straightforward operational mechanism of the algorithm introduced in this study. The aim is to improve satellite data processing, using a practical LEO SAT edge computing model and an appropriate algorithm.

III. Contribution of This Paper

The main contributions of this study are as follows:

- This paper contributes by presenting a multi-hop code offloading model in LEO SAT communication, reducing power consumption and latency.
- It introduces a dynamic optimization algorithm for LEO SAT edge computing, with a focus on enhancing efficiency in satellite-based communication networks.

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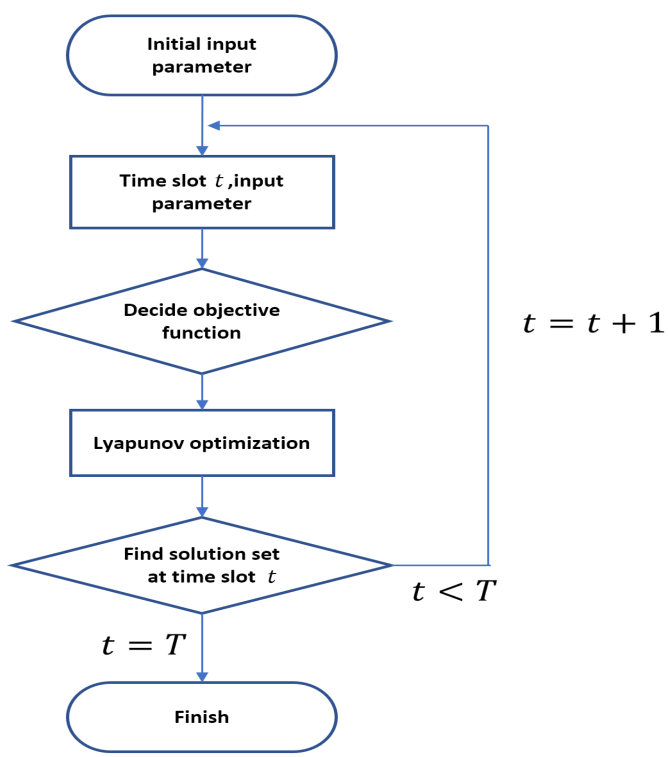

Fig. 2. Dynamic algorithm for proposed system model

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