

A Review on AI-Enabled Content Caching Schemes in LEO-Satellite-MEC Networks

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Abstract

In this paper, we study the content caching problem and provide a review on content caching schemes in LEO-Satellite-MEC networks. Inspired by the advantages of applying machine learning (ML) approaches in addressing complex decision-making problems, we review the recent artificial intelligence (AI)-enabled content caching schemes in LEO-Satellite-MEC networks. Finally, we highlight the open research issues to encourage further research investigation in this area.

I . Introduction

With the rapid increase of wireless devices and mobile data, the conventional cellular network is facing severe challenges in terms of backhaul capacity. Low Earth Orbit (LEO) satellite networks acting as complement of terrestrial networks have been explored as powerful solution to meet the requirements of increasing mobile data traffic and ubiquitous connectivity for global users. Introducing the edge caching (EC) technology in LEO-satellite-MEC networks reduces the increasing mobile network traffic pressure while providing ubiquitous coverage to users. Since popular contents can be proactively cached in LEO-satellite-MEC networks, where the LEO-satellite-MEC network infrastructure with large coverage capacity can broadcast the similar popular content to all the requesting users simultaneously.

However, caching the popular contents is crucial due to the limited caching capacity available in LEO-satellite-MEC networks and hence, requires a caching strategy to cache the most popular contents. Recently, ML approaches such as deep learning (DL) and reinforcement learning (RL) have been applied to optimize the caching strategy in content caching problems [1-5]. For instance, [1] introduced a concept-based echo-state network to predict user behavior and deployed cache-equipped UAVs accordingly. [2] proposed DL-based scheme for UAV deployment and content caching, grouping users using the K-means clustering algorithm and employing long short-term memory for caching popular content. A different research investigated in [3] leverages MEC to efficiently manage content distribution at network edges and proposed multi-agent reinforcement learning (MARL) framework utilizing historical demand data to design cooperative strategies to enhance caching effectiveness. Lastly, [4] proposed a deep regression-based method for proactive video caching in multi-access edge computing networks, and [5] proposed a hierarchical FL-based proactive content prediction in HAP-assisted multi-UAV networks to reduce communication delay in content delivery.

However, the afore-mentioned content caching schemes are not suitable to be directly applied to the LEO-satellite networks due to the unique characteristics and constraints of the LEO-satellite-MEC networks such as the dynamic and

time-varying topology of the LEO-satellites, dynamic coverage areas and changing content popularity within different coverage areas, and handover and mobility issues. While some principles of content caching from terrestrial cellular networks may be applicable the unique characteristics and constraints of LEO-satellite communication systems necessitate the development of specialized caching schemes for LEO-satellite-MEC networks. In this paper, we focus on the content caching problem in LEO-satellite-MEC networks and review existing studies on AI-enabled content caching schemes in LEO-satellite-MEC networks. In addition, we highlight the existing challenges. In this regard, the details on the existing AI-enabled content caching schemes are provided in Section II then the open research issues are highlighted in Section III. Finally, Section IV concludes the paper.

II . AI-Enabled Content Caching schemes in LEO-Satellite-MEC Networks

Recently, there have been many research proposals on the problem of content caching in LEO-satellite-MEC networks utilizing the ML technologies. These researches focus on caching decision problem in LEO-satellite-MEC networks with the aim of alleviating traffic pressure in backhaul networks, enabling coverage-aware cooperative content caching, delivery time minimization, and addressing issues on the caching-aware handover problems [6-10]. For instance, [6] presents a coverage-aware cooperative video caching algorithm that optimizes video service delays using a partial observable Markov decision process and multi-agent deep deterministic policy gradient algorithm. [7] addresses the issues on dynamic and time-varying topology along with the real-time changes in content popularity across different LEO coverage areas and propose content popularity model and collaborative caching using POMDP and MADDPG algorithm. [8] adopts multi-spot beam LEO-satellites and optimizes caching strategy by adjusting beam coverage using K-means to reduce content delivery time. To address the problems associated with high mobility of LEO-satellites in LEO-satellite-MEC networks, [9] proposed a multiple attribute decision handover strategy that considers caching capacity, remaining service time, and the remaining idle channels of satellites. Additionally, a caching-aware intelligent handover strategy based on deep reinforcement

learning (DRL) is introduced to maximize long-term system benefits. Then, to alleviate the traffic pressure and provide ubiquitous coverage, [10] studied the caching decision problem in LEO-satellite-MEC networks. They proposed a software-defined networking (SDN)-based management architecture and formulated the caching problem as an MDP. To optimize the caching strategy, they leveraged a graph convolutional neural network (GCN)-based advantage actor-critic (A2C) approach.

III. Open Research Issues

Despite the ongoing research efforts as discussed in section II, it is crucial to design adaptive caching strategies to solve the challenges of the limited caching space, dynamic content popularity, content distribution across inter-satellite links, efficient content delivery, support for seamless mobility and ensuring that the caching schemes can scale with the increasing number of satellites while maintaining service robustness in LEO-satellite-MEC networks.

III. Conclusion

This paper studied the content caching problem and conducted a review of the existing content caching schemes proposed for LEO-satellite-MEC networks. Despite some efforts on coverage capacity, and handover management, challenges such as efficient content distribution and seamless mobility support still remain in designing effective caching strategy. In this paper, we highlighted some open research issues to spur further investigation in this area.

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