Orbital Maritime Edge Computing: A Strategy for Task Offloading and Allocation

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Abstract

As maritime applications continue to expand, the need for developing marine networks for task offloading is becoming increasingly crucial. However, the scarcity of resources in maritime networks makes it challenging to fulfill real-time needs. Furthermore, the effective management of numerous compute-intensive tasks poses an additional problem. This paper first propose collaborative task offloading scheme utilizing both LEO and UAVs within maritime communication networks. Based on the above motivations, this paper also introduces an OEC Task Allocation (OEC-TA) algorithm based on the greedy strategy in LEO satellite networks for the Walker Delta satellite constellation, which fully utilizes satellite computing resources to provide services to maritime users.

Ⅰ. INTRODUCTION

With the increasing demands from marine Internet of Things(MIoTs), the limited marine network resources cannot satisfy multiple tasks [1]. Quick deployment and agile maneuverability of unmanned aerial vehicles (UAVs) enable their use in supporting marine Internet of Things(MIoTs) for multiple operations . However, UAVs and unmanned surface vehicles(USVs) produce numerous AI tasks that require significant computational effort, such as autonomous navigation and video processing, during surveillance and rescue missions. So, their limited computational capabilities make it challenging for them to handle these demanding tasks on their own.

Research indicates that satellites are highly effective in delivering services in regions lacking maritime network coverage. They can serve as a supplementary network for maritime systems when these are incapable of managing intensive computing tasks. The integration of Low Earth Orbit (LEO) Satellite Networks with maritime networks is emerging as a trend to offer widespread and efficient real-time services. Borrowing the idea from Multi-access Edge Computing (MEC), the Orbital Edge Computing (OEC) technology introduces MEC into satellite and each LEO satellite is equipped with MEC computing platform [2]. In this paper, we introduce a LEO with MEC-UAV-USV architecture to efficiently handle various tasks in the maritime environment and propose a collaborative task allocation scheme.

Ⅱ. SYSTEM ARCHITECTURE

The focus of this paper is primarily on situations where tasks from Unmanned Surface Vehicles(USVs) are transmitted to satellites for processing as shown Fig 1. The UAV serves as an intermediary link between LEO satellites and USVs, monitoring resource information from the satellites and task data from the USVs to transfer maritime tasks to the LEO satellites. USVs upload the task to LEO satellites for computation via UAVs. The UAVs gathers tasks from all users within its coverage zone and transmits them to LEO satellite. Furthermore, the UAV chooses service satellites according to satellite resources and computational tasks, relays the tasks for processing by the LEO satellites, and delivers computational services to USVs.

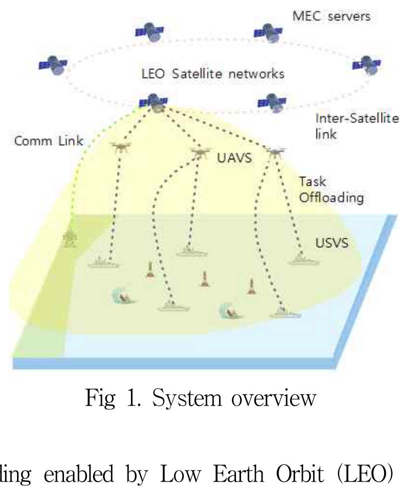

Fig 1. System overview

Task offloading enabled by Low Earth Orbit (LEO) satellite edge computing presents a promising approach to efficiently managing energy and computational resource limitations in maritime services [3]. While the computational capabilities of LEO satellites equipped with MEC servers have significantly advanced, they remain constrained by the satellite's finite energy storage. Assigning tasks to other satellites in the constellation with available computing resources can lead to more efficient use of these limited resources. This strategy not only reduces the computational load on the access satellite but also meets the requirements for low-latency in user tasks and the critical needs for user security and privacy protection.

The framework primarily follows the Walker constellation model [4]. The Walker satellite constellation is made up of a large number of satellites that are evenly distributed over several orbital planes. This setup guarantees reliable and continuous coverage of the global network, providing satellite services to users anywhere and at any time. It is presumed that every satellite in this constellation comes equipped with a Mobile Edge Computing (MEC) server. The connection between users and the constellation is established via User Data Links (UDL), which link the ground stations to the satellites, thus granting access to the satellites computing capabilities. Furthermore, the satellites are linked to one another using Inter-Satellite Links (ISLs), and the internal data transfer within the constellation is carried out using laser communication systems.

Ⅲ. OEC TASK ALLOCATION

The existing strategies for offloading in Orbital Edge Computing (OEC) are efficient in minimizing processing delays and energy usage in tasks, but they overlook the distinct nature of specific computing tasks. This paper introduces a novel offloading approach designed specifically for Delay-Sensitive Tasks (DSTs) and Delay-Tolerant Tasks (DTTs), called Greedy-Based Orbital Edge Computing Task Allocation (OEC-TA). Our strategy takes into account various optimization objectives, leading to a more cost-effective computation process. Additionally, this method enhances user satisfaction by tailoring to the unique requirements of different task types.

Fig 2 describes the operational flow within the OEC architecture. USVs send their tasks to a satellite via UAVs for execution. To reduce both time delay and energy use, the designated access satellite efficiently distributes these tasks across the computing capabilities of other satellites in the network. This access satellite selects specific optimization goals based on the nature of the tasks at hand. Through this algorithmic approach, tasks are delegated to various satellites for processing. Upon completion of these tasks, the satellites relay the results back to the USVs, thus finalizing the entire operation.

Ⅳ. CONCLUSION

In this paper, we present an architecture that utilizes LEO satellites equipped with MEC servers to process tasks collected by USVs. Also, Our approach involves designing a Greedy-Based Orbital Edge Computing Task Allocation (OEC-TA) method for LEO-UAVs-USVs Networks of different types of tasks, aiming to minimize both the delay and the energy consumption during task execution. For DSTs, the primary objective is to reduce the overall computation time of tasks. For DTTs, the focus is on minimizing total energy usage while ensuring that the complete duration of task execution does not exceed a predefined maximum allowable time. Simultaneously, we will enhance the algorithm by optimizing for reduced time delays and lower energy usage. Our method effectively leverages the computational capabilities of satellites to offer improved services to USVs. As unmanned surface vessels are introduced into naval forces in the future, this approach is expected to contribute to improved operational efficiency. Due to the limited specifications of the unmanned aerial vehicles, it is expected that the collected tasks can be processed using LEO to enable rapid command decisions and operations.

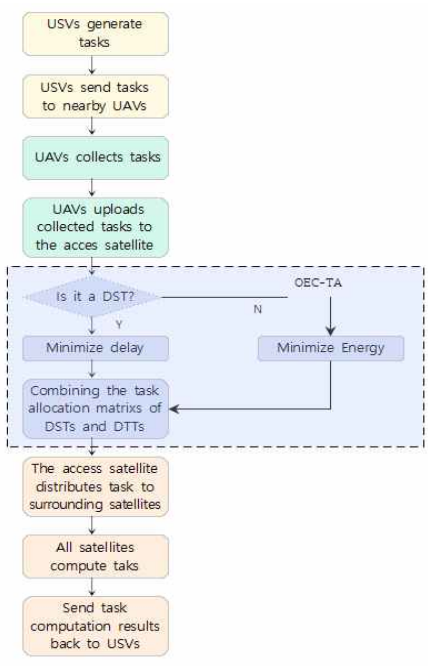

Fig 2. Task processing flow

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