Network Utility Maximization for 6G Maritime Communication in Deep Waters

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Abstract

Worldwide coverage of the communication network is the main goal of next-generation networks. Terrestrial networking is expanding with the desired pace, but still no well-established communication system for maritime data traffic. Some literature work proposes network architecture for maritime but does not provide the overall operation of the system. In our proposal, we provide a heterogeneous network framework of 6G communication systems for maritime users global connectivity. This framework is based on low earth orbit (LEO) satellite and unmanned aerial vehicle (UAV) which makes the network heterogeneous. We proposed UAV as an aerial backhauling and a relay medium between marine users and LEO satellite constellation. The UAV can provide continuous connectivity to marine users while maintaining their backhaul connection with the LEO satellite due to their high altitude. Moreover, our proposed topology provides significant simulation results of network utility maximization.

I. Introduction

To fulfill the user demands cellular system shifted from 1G to 5G. On the other hand, the user's demands are increasing exponentially for high-connectivity and low latency. At the same time, marine users provide a new venture for cellular systems to provide connectivity [1]. Their demands are also time-sensitive in many operations. This topic has got the intention of researchers to investigate another generation of wireless communication frameworks, i.e., Sixth-generation (6G) mobile network, to fulfill the needs of a fully connected and intelligent digital world. To overcome the marine user's demands, we need to integrate new frontiers in existing service provision. In our system design, we provide an analytical framework for the 6G communication system, which can ensure the global connectivity demand of marine end-users.

Satellite communication will incorporate in our next generation terrestrial cellular networks [2]. The evolution of cellular networks, marine users, satellite communication, UAV as an aerial base station and surveillance medium [3], but there is a gap between marine UAV and their integration with satellites. LEO satellites, emerging as good sources of global coverage, but their continuous mobility is still an open issue to be address. Moreover, due to the mobile nature of the LEO satellites, their connectivity with marine users is difficult to maintain. Additionally, a huge gap between marine end-users and LEO satellite pose high latency, which disturbs the freshness of sensitive information.

With the realization of a marine user's connection, which interrupts due to the mobility of LEO satellite constellation. We introduced UAV as an aerial relay between marine end-users and LEO satellite constellation. In this case, the UAV provides aerial backhauling to reduced the latency issue and provide huge connectivity to the marine users. UAV as a high altitude platform than sea surface can maintain their connectivity with any closer satellite in the constellation. Similarly, it can switch to another satellite when the previous one goes beyond their range. Moreover, UAV communication power consumes less energy; therefore, in the case of hovering it can perform relaying communication as well as surveillance [4]. UAVs can also be deployed as central nodes i.e., Cluster head for a wireless sensor network in the internet of things monitoring systems and provide the gateway to IoT sensor networks [5].

Besides the advanced world turns out to be progressively intelligent, computerized and pervasive, the progression of data turns out to be perpetually essential. Maritime mobile wireless networks are the information roadways, which need to be completely associated, intelligent and worldwide connected digitally. Moreover, they should connect everything from individuals, vessels, marine sensors, time-sensitive information, remote cloud resources, and even automated marine robots. The fifth-generation (5G) wireless network that is being early stages of commercialization after the long span of progress, yet might be not able to satisfy the full network needs of rising demand in which maritime communication system is on the top. This paper investigates how 6G frameworks can be created to address the requirements of marine networks in which things to come in the future.

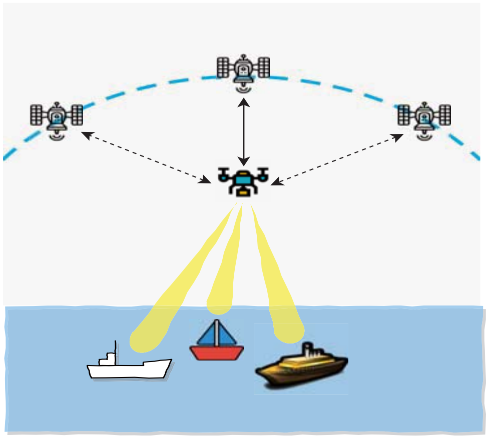

Fig. 1: Illustration of Maritime Communication Network

II. System Model

We consider a network framework with an LEO satellite constellation enabled with Ku-band. This constellation is deployed at h = 1200 km from Earth with a minimum elevation angle of 45 degrees. The proposed heterogeneous network framework introduced aerial relay nodes (ARN) that extend the maritime network coverage with reduced costs. ARNs were introduced and standardized in LTE, and within the 3GPP standardization framework, it is agreed that they will be also implemented in 5G.

Our system consists of a 3D maritime communication network, which is located in the sea region given in Fig. II. The maritime communication network is composed of the low earth orbiting (LEO) satellites, unmanned aerial vehicle (UAV) and marine users, which can be transportation vessels, tourist boats, etc. as shown in Fig. 1. We introduced an LEO satellite in a maritime communication network for the global connectivity of marine users with the rest of the world. In our proposed framework, we provide network resources to the UAV, which in turn share those network resources to the marine users as shown in fig. 1.

The UAV is deployed as an aerial backhauling medium between marine users and the LEO satellite to make sure the latency and throughput requirements of marine users set $U = 1, 2, ..., N$. At the same time, marine users cannot get continuous connectivity from the LEO satellite directly because of their constellation mobility. Therefore, the marine user's connectivity interrupts frequently. On the other hand, UAV due to deployed at high altitude platforms can maintain their connectivity with any closer LEO satellite and provide network services to the oceanic users.

Additionally, UAV performs duties of monitoring and surveillance for numerous marine applications. A coordinated scheme has considered here for topology, which can be controlled by a dynamic network controller. Additionally, due to spectrum scarcity, we consider here the beamforming technique of marine users connectivity with a UAV, which reduces the extra spectrum consumption. Beamforming strategy is a newly developed technique of users connectivity with base stations, which is proposed in the 5th generation of cellular systems.

III. Problem Formulation and Solution Approach

We consider the free space Path loss between UAV and Nth marine user, which can be expressed as,

$$PL_{FS} = -27.56 + 20 * log_{10}(f) + 20 * log_{10}(d_U), \quad (1)$$

here PL_{FS} represents the free space path loss, f is the carrier frequency of the channel and d_U is representing the distance between UAV and each marine user. The gain of each sub carrier can be expressed as,

$$g_i = 10^{(\frac{-PL}{10})}, \quad (2)$$

here PL is representing the free space path loss of each marine user. We can formulate our problem for overall network utility maximization as,

$$\underset{P}{\text{Maximize}} \quad log(\sum_{i \in U} g_i P_i), \quad (3a)$$

$$\text{subject to} \quad P_i \leq (\frac{g_i}{\sum_{j \in U} g_j}) P_T, \forall i \in U, \quad (3b)$$

$$\sum_{i \in U} P_i = P_T, \forall i \in U, \quad (3c)$$

$$P_i > 0, \forall i \in U, \quad (3d)$$

here the objective of the problem in (3a) is to maximize the network utility of marine users. P is the control parameter of each marine user. Constraint in (3b) presents the proportional distribution of power to each marine users based on their channel condition. Moreover, constraint in (3c) ensures the maximum power limit of UAV and last constraint in (3d) presenting that each marine user must get some proportion of power to make sure their connectivity.

We can find the optimal value of network utility by solving the above optimization problem. This problem is convex in nature which can be solved by using KKT conditions for an optimal solution.

IV. Simulation

To draw the simulation results, we deployed our 3D system model of the UAV and marine users according to network topology given in Fig. 2 built-in python environment. The red triangle represents the hovering UAV above the sea and green dots represent the marine end-users at sea surface. Marine users are distributed randomly in a particular region of the sea where UAV is also deployed for network connectivity and backhauling of each user in that region.

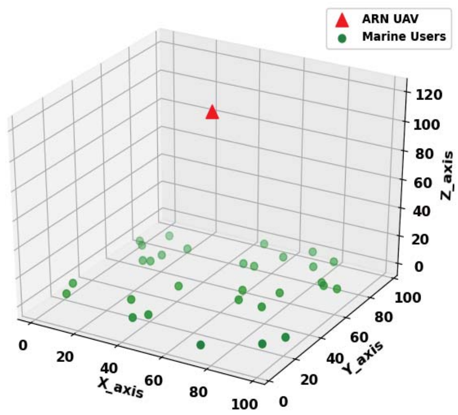

Fig. 2: Illustration of Network Topology in Deep Waters

We consider that UAV has 100 watts of power capacity which can be utilized for their communication purposes. Moreover, UAV operational frequency of communication is considered as 5 GHz according to the European telecommunication standard institute, which is reserved for maritime communication. We are not considering the source of UAV power in this paper, because it is out of the scope. Moreover, we consider the 50 marine users, who are getting their connectivity services through UAV. These users are spread over a $100m^2$ region in the sea. We summarized all simulation parameters in table I.

TABLE I: Simulation Parameters

Parameters	**Values**
UAV Height	$h = 120m$
UAV Communication Power	$P_T = 100W$
Operational Frequency	$f = 5GHz$
No. of Marine Users	$U = 50$
UAV Coverage Region	$100m^2$, $X = 100m$, $y = 100m$

Our simulation result is given in Fig. 3. The given results deduced that when the users initially got connected with UAV, its utility becomes less than the idle mode. However, UAV maintains its network utility as the number of marine users increases, which shows that our approach can handle the maritime network utility with a huge number of marine users.

V. Conclusion

Our framework enables high connectivity of time-critical marine end users applications and improves the network coverage in deep waters. Our proposed framework of the space-air-sea network can be integrated into the next generation of communication networks to fulfill the goal of global network coverage. Existing satellite-based communication architecture has more latency, by introducing this network framework, the latency of the system can be reduced and achieve a good network utility. Moreover, 3GPP in their ongoing research focusing on satellite integration in the 5G cellular system, but there is no release up till now. Therefore, future generations focus on integrated space-air-sea communication networks to get benefit from marine users as well.

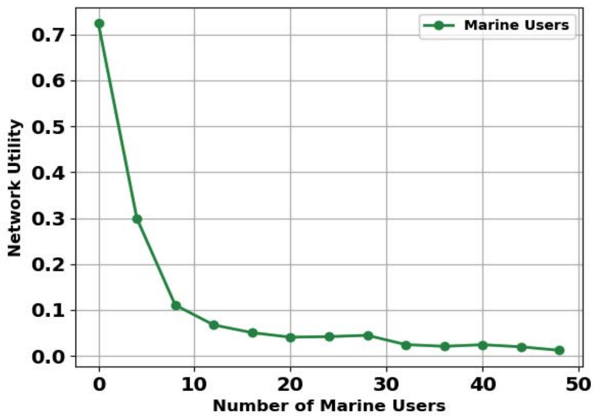

Fig. 3: Network Utility vs Marine Users

Acknowledgment

This work was supported by Institute for Information & communications Technology Promotion(IITP) grant funded by the Korea government(MSIT) (No.2015-0-00557,Resilient/Fault-Tolerant Autonomic Networking Based on Physicality, Relationship and Service Semantic of IoT Devices) and by Institute for Information & communications Technology Promotion (IITP) grant funded by the Korea government (MSIT) (No.2015-0-00567, Development of Access Technology Agnostic Next-Generation Networking Technology for Wired-Wireless Converged Networks) *Dr. CS Hong is the corresponding author.

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