Machine Learning in 6G-NTN: Emerging Technologies and Opportunities

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Abstract—AI based technologies have been integrated into the 6G architecture to enhance coverage efficiency dynamically. By providing wide-area coverage and enabling service availability, continuity, and scalability, Non-Terrestrial Network (NTN) solutions are able to meet the requirements of anywhere and anytime connections. This paper addresses the challenges and potential solutions for 6G-NTN emphasizing on the effective approaches that AI provides in 6G services. Keeping focus on all these challenges and issues, we provide a compressive overview of ML-based solutions for 6G-NTN, which can be utilized in a range of future applications.

Keywords—6G, 5G-NR, Non-terrestrial networks (NTN), Unmanned aerial vehicles (UAVs), Machine Learning.

I. INTRODUCTION

NTN system uses satellite systems, Unmanned Aerial Vehicles (UAVs) and High-Altitude Platform Systems (HAPS) to find the optimum way to connect the unconnected, unserved, and underserved areas on the earth [1], making NTN a very good substitute of terrestrial 5G-NR networks. 5G mobile communication systems offer very low latency communication and greater capacity making Quality of Service (QoS) and Quality of Experience (QoE) better than ever before. Yet Internet access cannot be assured to passengers travelling by aircrafts or high-speed trains, or to people living in remote areas. However, in future, 5G-NR services will be unable to satisfy all the requirements and face new challenges. Therefore, we will have to consider the future 6G systems for NTN which can implement technologies for tactile Internet, mmWave frequency bands, space IoT, ubiquitous use of AI and advanced security schemes [2]. 6G-NTN will also support rising societal needs that cannot be fully satisfied by 5G. The implementation of 6G using satellite technologies may create new issues and their complex solutions will require better optimization. This task calls for the use of Machine learning (ML) and Artificial Intelligence (AI) approaches. ML based fields include interference management, resource allocation, path selection, adaptivity, etc. at different layers of the protocol stack, as depicted in Fig. 1. Techniques such as deep learning can be used to provide better channel estimation, a complex task in satellite systems where the propagation delay causes an inaccurate channel state feedback [2]. Without a good channel estimation, adaptive coding, modulation, and beamforming can be ineffective at the transmitter. This paper is divided into five sections. Besides this introduction, Section II deals with the different issues and challenges of 6G-NTN systems. In Section III, various solutions and emerging technologies are discussed. An overview of ML techniques in 6G-NTN is presented in section IV. Finally, conclusions are drawn in Section V.

II. CHALLENGES AND ISSUES IN 6G-NTN

A. Path-Loss and Propagation Delay

In the communication link of the 6G-NTN platforms, extra delays can be caused due to altitude, especially in the case of GEO satellites reaching round trip latency of 270 ms. This can be an issue for the services and applications which require ultra-low latency.

B. Multi-Layered Network Management

6G-NTN will be a three-dimensional heterogeneous network with different layers containing varying coverage range and link quality, designing the network architecture to make unified management for all layers is a challenge. Especially, UE should have the flexibility to access a preferred layer and communicate with the most suitable layers.

C. Radio Resource Management

Radio resource management should target the efficient support of diverse traffic classes, from multimedia traffic (eMBB), to IoT traffic (mMTC) and reliable low-latency traffic (URLLC). In a UAV/HAPS/LEO multi-layer system, high interference is inevitable [1]. Therefore, interference coordination and mitigation techniques are crucial to utilize the limited frequency and power resources efficiently. Different layers resources need to be allocated in a multilayer system, considering user mobility, traffic density, and traffic congestion conditions.

D. Mobility Management

LEO satellites move at high speeds on their orbits and the satellite speed dominates the relative user mobility. On an average, LEO satellite’s visibility can vary from 2 – 20 minutes [3]. This high speed movement may also cause Doppler effect. Terminal handover is an issue in the case of mobility management which is mainly applies to LEO systems since, UAVs/HAPS provide a focused or more static coverage in the given area.

E. Limited Load Capability

Due to limited load capability, it might impossible to put all network nodes on the satellite. For example, when only distributed unit (DU) of the radio access network (RAN) is set up on the satellite, the transmission delay from user plane can be decreased, but the transmission delay from control plane is similar to that for the bent pipe satellite. Therefore, how to design suitable processing functions for a satellite to get a...
balance between satellite capability and communication link performance is a challenge.

III. SOLUTIONS AND EMERGING TECHNOLOGIES

A. Network Architecture

Like 5G and beyond NTN, 6G-NTN will have a multi-layer architecture including least user ends, satellite stations, terrestrial stations, and core network. The satellite stations will vary in different types, such as GEO, MEO and LEO. With this general architecture, both satellite stations and terrestrial stations can be regarded as accessing nodes to communicate with UEs, under the unified control and management by the core network. Various adaptable architectures given in [2] and [4] are found helpful to enhance the performance of the system.

B. Massive MIMO

In satellite system massive MIMO is generally applied for beamforming and joint transmission [5]. For beamforming, the generation of dynamic and fixed beams are mainly considered. For joint transmission, there is a need for data sharing among multiple satellites. As the LEO satellite moves around the earth, the covered area of a beam also moves with the satellite. When the network detected a UE’s location, a beam is projected in the direction of the UE to have data transmission and move the beam as the UE moves.

C. Multiple Access

In case of sharing time-frequency resources, for IOT and other high-capacity scenarios, non-orthogonal multiple access (NOMA) is used for increasing the number of simultaneously accessed users [5]. To gain the maximum user capacity, NOMA allows to share the time-frequency resources among multiple users. On top of that, to reduce the transmission time, resource allocation is done beforehand, so that users can be sent with grant-free mode without scheduling in advance.

D. Interference Management

Generally, the beam of a satellite has evident direction and is used as a foundation of interference avoidance. In addition, wireless resources between different layers are coordinated reasonably by the network to avoid interference [6]. Factors such as the interference type, interference between satellites, or interference between satellite and terrestrial, interference avoidance methods, and frequency regulation strategies, etc. are considered in the interference management.

IV. OVERVIEW OF ML BASED TECHNIQUES FOR 6G-NTN

Machine learning algorithms are generally categorized by the type of feedback of the learning system. They do not need explicit modeling compared with conventionally engineered algorithms. Fig 2 shows that how different categories of ML algorithms are used in 6G-NTN.

A. Interference Management

To control and reduce inter-beam interference, interference from different ground sources present in satellite systems, pointing and tracking using self-learning and solving POMDP using DRL have been proposed in [7].

B. Managing Transmission Delay

To enhance the performance of the system in high mobility satellite-UE network, occurrence of transmission delay in 6G-NTN should be addressed. The challenge of selecting proper subset of beams and duration to keep each beam active, is addressed in [8] by solving models using DRL.

C. Operation in mmWave

In [9] mmWave beam misalignment is addressed using deep learning approach to predict the angle from the served UE and issue created by beam misalignment from uncertain mobility is investigated.

D. Power Allocation

Satellite-based ground network in downlink is considered to formulate the problem of optimal power allocation strategy for NOMA users [10]. It showed better performance compared to fixed power allocation strategy and TDMA scheme. It uses DRL to efficiently allocate resources for maximum sum effective capacity.

E. Resource Allocation

In [11], spectrum efficiency is improved by applying intelligent resource management which can sense and predict allocation steps based on UE priority. In this work CNN is applied to solve the spectrum detection problem. The use of RL and ANN based algorithm is also available in managing satellite resource management.

F. Hand-Over Management

As the satellites travel in periodic motion, by anticipating the handover factors and applying Reinforced Learning algorithm, handover decisions can be made efficiently. Similar technique has been used in [12] to address the problem of handover and user’s QoS and QoE.

V. CONCLUSIONS

Non-Terrestrial Network incorporated with 6G communication envisions unprecedented capacity and connectivity. Several challenges have been analyzed towards the realization of satellite 5G and 6G services. In this paper, we provide a comprehensive review on the 6G-NTN issues, emerging technologies, and their possible solutions. AI/ML can provide new methods to deal with routing, resource allocation, cross-layer optimization, and handover decision to overcome limitations in 6G-NTN. By considering this aspect, we describe the machine learning based approaches for the evolution of 6G-NTN. As our future work we intend to apply ML based algorithms to improve the link level performance of 5G-NR to support 6G-NTN.
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REFERENCES


