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Assessment of the Challenges of Non-Terrestrial Network (NTN) Communication

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Abstract: The aim of this research work was to investigate some challenges related to the communication in non-terrestrial network (NTN). The research was carried out using the explanatory and review research methods. A non-terrestrial network communication is a communication network that provide communication services over a wide area including hard-to reach or difficult terrain areas, using non-terrestrial platforms such as satellite, unmanned aerial vehicle or High-Altitude platform stations like balloons. Some of the unique features of NTN are wide coverage area, long-distance communication, flexibility. It was observed from the result that some of the challenges faced by non-terrestrial network communication are latency, interference, security, infrastructure, atmospheric condition. It was concluded that, despite the various unique features or characteristics of NTN, it is faced with a lot of challenges, thus, the adoption of NTN for a task needs careful planning. It was recommended that some possible solutions to these challenges facing non-terrestrial network (NTN) communication be looked into in future work.

Keywords: Atmosphere, Drone, Latency, Non-terrestrial, Satellite.

1.0 Introduction

A non-terrestrial network communication is a communication network that provides communication services over a wide area, including hard-to-reach or difficult terrain areas, using non-terrestrial platforms such as satellites, unmanned aerial vehicles, or high-altitude platform stations like balloons. According to Jamshed *et al. (2024)* & Muhammad *et al.* (2024),

the term NTN is often associated with satellite communications, as the fight for space communications supremacy has captured everyone's attention over the last few years. They went further to state that other platforms that can provide communication services, including unmanned aerial vehicles (UAV) and high-altitude platforms (HAP) (on-demand NTN), come under the broader definition of NTN and that NTNs provide connectivity in areas where terrestrial networks are unavailable or challenging to deploy.

Non-Terrestrial Networks (NTNs) are increasingly gaining popularity as a solution to provide connectivity in remote areas due to the growing integration of satellites and Unmanned Aerial Vehicles (UAVs) with cellular networks (Plastras *et al.*, 2024). According to Manlio et al. (2020), NTN can play an important role in the development and growth of the 5G network by supporting the terrestrial infrastructure and overcoming some of its limitations. In addition, NTNs have the capability to improve communication availability in remote or disaster zones or to preserve the connection in emergency situations when the primary terrestrial path is out of service (Dengke, 2021). Unlike terrestrial scenarios, NTN is faced with challenges like latency and mobility, owing to the operations in spaceborne and airborne platforms (Amjad *et al.*, 2017); thus, these challenges and others will be looked at in this work. The work makes use of the explanatory research method mostly in addition to the review of some relevant literature.

2.0 Features of Non-Terrestrial Network (NTN) Communication

Non-Terrestrial Network (NTN) has its unique features that distinguish it from terrestrial network communication. Below are some of those features of Non-Terrestrial Network (NTN).

2.1. Global Coverage: One of the unique features of NTN is global coverage. NTN communication can provide global coverage, including remote and underserved areas. This is made possible due to the wide footprint of satellites. The possibility for satellite constellation, where two or more satellites work together, made it possible to cover a wider range of locations from a particular location. For example, the constellation of three satellites in the geostationary orbit already covers the entire globe. With this, it is now easy to receive and send information from one part of the world to the other part of the world if one is using the service of this satellite network. In addition, unlike the terrestrial communication networks that make use of terrestrial or communication masts and that cover a certain area in a state based on the size of the cell, NTN is not limited to just a location in town or state or country because even one satellite in space has a wider area of coverage than many masts combined together.

2.2. Satellite-Based or High-Altitude-Based Device Communication: A non-terrestrial network communication is a communication network that provides communication services over a wide area using non-terrestrial platforms such as satellites, unmanned aerial vehicles, or high-altitude platform stations like balloons. NTN communication uses satellites in orbit around the Earth to transmit and receive data. It also uses high-altitude platforms like hot air balloons, especially if a wider view or footprint is needed but not as wide as that which requires the use of satellites. Hot air balloons are also used when the operation is temporal, such as disaster management, flood situation reports, etc., which is for a certain period of time. Another device or platform used by NTN is the unmanned aerial vehicle, or drone. This can be coordinated or controlled to a particular remote location or area not reached by the terrestrial network. A drone or UAV is mostly used for short-duration communication or data/signal transmission from a particular location.

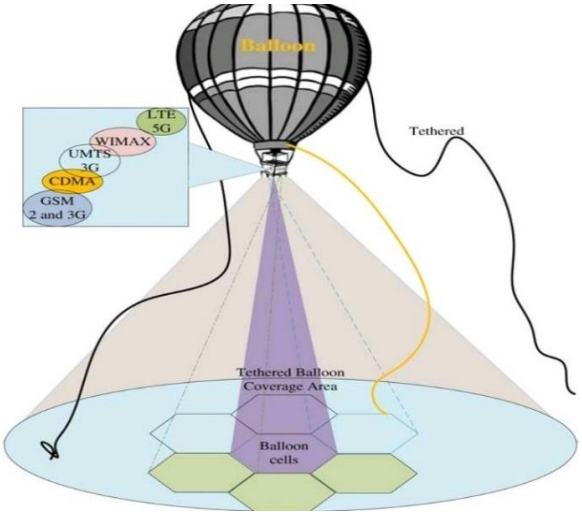

Fig. 1: Tethered hot air balloon for rescue operation (Source: Cambridge university)

2.3. Long-Distance Communication: Non-terrestrial networks (NTNs) enable long-distance communication by utilising satellites or other aerial platforms to transmit signals over vast distances. This enables it to connect remote, underserved, or globally dispersed areas, as well as facilitating communication across oceans, mountains, or other barriers that traditional terrestrial networks may struggle to reach.

2.4. High Latency: Non-terrestrial networks (NTNs) often experience high latency due to the long-distance signals travel between the Earth and satellites or other aerial platforms, resulting in noticeable delays in signal transmission. Although this can impact real-time applications such as video conferencing, online gaming, and voice communications, even as the extent of latency varies depending on the satellite's orbit, signal path, and network configuration, it is a feature of NTN and is mostly due to the long distance between the earth and the satellite in space or the high-altitude platform. The distance covered by the signal to reach the satellite from the sender and then to be retransmitted from the satellite to the receiver is long, which will cause a delay. Signal would not be received at the appropriate time, especially in real-time online communication data exchange.

2.5. Line-of-Sight Requirements: Non-terrestrial networks (NTNs) often require a clear line of sight (LOS) between the user terminal or Earth station and the satellite or aerial platform. This is the reason why television dishes at homes and offices are always positioned in a location free of obstacles to the “sky” view. In other words, in NTN communication, obstacles such as trees, tall buildings, or mountains can block or weaken the signal reception in a location. This will, in a great way, affect the availability and reliability of the network. The setting up of the NTN network must be carried out in a place with a clear line of sight from the ground station or device on the earth to the space or atmosphere, and that condition must be maintained throughout the period of the operation.

2.6. Specialised Equipment: Non-terrestrial networks (NTNs) require specialised equipment, such as transceivers, which have the ability to transmit signals as well as receive signals; high-gain antennas for signal reception and transmission to and from the transceivers; and signal processing systems, which are designed and set up on the earth or ground to communicate with satellites in the orbits or other aerial platforms. In addition to the equipment, the setting up of this equipment is also a complex task that requires the services of expert technical personnel in the field.

3.0 Challenges facing non-terrestrial network communication

Non-terrestrial network communication has some unique features as well as some benefits, such as global coverage, disaster resistance or resilience, and others. Some of the challenges of non-terrestrial network communication are as follows.

3.1. Atmospheric Conditions Effect: Atmospheric conditions create a serious challenge to non-terrestrial network (NTN) communication, particularly for satellite-based systems. The atmosphere can affect signal transmission, propagation, and reception. This can be in the form of signal attenuation, which is caused by atmospheric gases, such as oxygen and water vapour, that absorb or scatter electromagnetic signals, reducing their strength and quality. It can also result in refraction, which is the change in the direction of signal paths as it travels through the atmosphere from and/or to the satellite, thus causing signal delay and affecting signal timing as well as synchronization. Atmospheric conditions also affect the NTN negatively in the form of scintillation, which is a rapid fluctuation or variation in signal amplitude and phase caused by atmospheric turbulence. This can result in the fading and distortion of the signal transmitted or received at the destination or by the satellite or high-altitude platform receivers.

3.2. Latency: Latency is defined as the delay between the transmission and reception of a signal in a non-terrestrial network (NTN) communication system. In NTNs, latency is a significant challenge due to the long distances involved in signal transmission. In addition to distance, processing time of the signal is another cause of latency in NTN. When the signal is to be routed through different nodes or points, like transmitting through crosslink, in which the signal is sent from the ground to one satellite, which then re-transmits the signal to another satellite, which will then transmit the signal to the destination. This is used when the first satellite is not the one having coverage in the affected area and hence needs another satellite to link with the location. The challenges caused by latency can affect real-time applications, especially when NTN is to be used for disaster management, rescue operations, and other emergency tasks, as it can affect voice and video communication reception time, which can make them unreliable and even unusable. Also, latency affects the speed of both the download and upload as well as the ping. This implies that high latency will result in poor efficiency of the network.

3.3. Interference: Interference is defined as the disruption or degradation of a signal caused by unwanted electromagnetic radiation or signals from other satellite systems using the same or close frequency, terrestrial systems, or natural sources. Interference is also defined as the phenomenon that modifies a signal in a disruptive manner as it travels from the source to the destination along the communication channel. Although interference may not be destructive all the time, it is not needed in communication because even constructive interference results in the increase of communication signal beyond its amplitude. In non-terrestrial network (NTN) communication, interference can be in the form of co-channel interference, which is the interference from other signals using the same frequency band; adjacent channel interference, which is the interference from signals using adjacent frequency bands; or intermodulation interference, which is the interference caused by non-linear interactions between multiple signals. Interference in NTN results in reduced data rates, increased error rates, and reduced link reliability and system availability. As confirmed by Shang et al. (2025), terrestrial and satellite systems may operate within overlapping frequency bands, which will lead to mutual interference if not properly coordinated. In addition, within satellite constellations, especially in Low Earth Orbit (LEO), closely spaced satellites can cause interference with each other if their beam patterns and frequencies are not precisely isolated (Chen *et al.,* 2021).

3.4. Satellite Deployment: Satellite deployment deals with the process of placing a satellite into the intended orbit in space. Satellites are launched into space for various purposes but with the aim of acquiring information from the surface of the earth or a given target and then

transmitting it to the destination or the ground station. The platform or equipment onboard a satellite is determined by its function. In other words, the equipment or devices carried by an earth observation satellite on board are different from those on board a communication satellite. But in any case, the stages or processes for launching them are almost the same even though they are to operate at different altitudes or orbits. This is very expensive. It begins with the building of the satellite, which involves adequate expertise and technicalities. It is also very expensive, as, in addition to the materials or components needed to build the satellite, the laboratory for building it is also very expensive to build and/or maintain. After the satellite is successfully built, launching it into space is also another great task, as only a few nations have the technological capability to launch satellites even in this 21st century. This is a great challenge, as its use for wireless communication (NTN) involves a higher financial implication.

3.5. Infrastructure Challenge: Non-terrestrial network technology does not only work with satellites in space or drones or high-altitude platforms like hot air balloons; it also works with some devices on the earth or ground. In addition to the infrastructure that will make the NTN operate efficiently, there are other technologies existing on the terrestrial basis that work with the NTN. For instance, there is a need for a ground station infrastructure. A ground station infrastructure serves as the interface between the satellite or aerial network and the terrestrial network. A ground station or earth station is a facility built on the ground with various devices or equipment used for receiving data from the satellite as well as sending data to the satellite from the ground. The ground station receives the signal from the satellite or aerial network, converts the data to the frequency receivable by the terrestrial network terminals, and then sends it to the terrestrial network to be received by communication devices. The ground station is also responsible for the amplification of the signal received from the satellite to make the signal quality as it is supposed. In addition to how a ground station enables connectivity between NTN and terrestrial networks, it also helps to troubleshoot problems and sends feedback to the required receiver for corrections or rectifications. The building of a ground station, as well as its maintenance, requires significant investment and technical expertise. Furthermore, in some cases, only one satellite will not be able to cover the needed locations or affected areas; hence, a constellation or networking arrangement between two or more satellites is needed. This is also a challenge, as it requires a complex infrastructural network. In addition, the space segment must be able to operate with the ground or terrestrial devices. That is, one must ensure the interoperability between different NTN systems, ground stations, and user equipment for seamless communication.

3.6. Security Challenge: Security is a critical concern in non-terrestrial network (NTN) communication, as these systems can be affected by different types of cyber threats and attacks. Security challenges in NTN can be in the form of data interception, in which the NTN communication signals are intercepted by unauthorized parties, compromising data confidentiality; signal jamming, in which NTN signals are disrupted or jammed, thus resulting in communication unreliability; and cyberattacks, in which NTN systems are attacked through cyber means such as phishing, hacking, malware, and ransomware attacks. When NTN is attacked, it can result in downtime of critical applications and infrastructure or sectors that depend on it. It can also result in significant national security implications, particularly for military and government communications, which can cause compromise of sensitive or classified information. According to Caus et al. (2021), security in NTN communication involves ensuring confidentiality, integrity, and availability of data transmitted through space-borne and airborne platforms. Unlike terrestrial networks, NTN components often operate in untrusted environments, with long-range wireless links that are inherently more vulnerable to interception and jamming.

3.7. Throughput Challenge: Throughput is defined as the amount of data that can be transmitted over a non-terrestrial network (NTN) communication system within a given time

frame. In other words, throughput is the measure of how much data or information is transferred from the source to its destination at a given time. Achieving a high throughput in NTN communication is sometimes challenging due to various factors. Some of these factors are bandwidth limitation, noise, latency, and data packets. Bandwidth is the maximum amount of data that can be transmitted over a communication channel or network channel within a given period of time. This implies that higher bandwidth favours higher throughput and vice versa. In some cases, due to the expensive nature of the satellite service, it is sometimes difficult to acquire larger bandwidth, and this will affect the volume of information transmitted at a given time frame. Another challenge is noise. Noise in communication is the unwanted signals that add to the signal or data being transmitted. If the noise and the original signal are being transmitted together, even though it will be filtered at the receiving end, already it has affected the amount of data that can be transmitted at a given time, which is the throughput. Latency, which is the delay in signal reception, also affects data packets, which are the small units of data that are transmitted over a network. When the data packet is increased, it will lead to an increase in throughput and vice versa.

3.8 Regulatory Compliance: Regulatory compliance is defined as the adherence to laws, regulations, and standards governing non-terrestrial network (NTN) communication in a given location or country. Some of these could be in terms of spectrum allocation, licensing, or data protection. One cannot just start the establishment of an NTN facility in a county without passing through the necessary procedures. NTN is not very common; hence, the issuing of a license to start may not be easy or fast like in other communication types. The allocation of spectrum or frequency band will also be a challenge, as it will require a lot of experiments and tests in order to avoid any negative consequences on the people using it as well as the people offering the services, and various measures are to be put in place to ensure the information or data of the users are protected. As a result of the global operation of NTN systems, complying with the multiple regulatory requirements of various countries concerned is a great task or challenge.

4.0 Conclusion

The research on the assessment of the challenges of non-terrestrial network (NTN) communication was carried out using the explanatory and review research methods. In addition to the challenges, the research also looks at some of the unique features of NTN, such as wide coverage area, long-distance communication, and flexibility. It was observed from the result that some of the challenges faced by non-terrestrial network communication are latency, interference, security, infrastructure, and atmospheric conditions. It can be concluded that, despite the various unique features or characteristics of NTN, it is faced with a lot of challenges; thus, the adoption of NTN for a task needs careful planning.

5.0 Recommendation

It is recommended that future work explore potential solutions to the challenges faced by non-terrestrial network (NTN) communication.

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