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Implementing 6G via Non-Terrestrial Networks (NTN): Considerations for High Altitude Platform Stations (HAPS)

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ABSTRACT

Non-terrestrial networks (NTN) covering space-based and airborne network assets will be crucial for 6G delivery. Satellite constellations constitute a significant part of the NTN infrastructure but have certain limitations like long latency and Doppler shifts. High Altitude Platform Stations (HAPS) will complement the role of satellite systems and add signicant value to the 6G NTN offering. This article draws the attention of the 6G development ecosystem to the need to prioritise HAPS studies and specications. HAPS NTN will address three main factors relevant to 6G NTN deployments: Technology limitations of satellites, complexities of operations, automation and maintenance (OAM) and futureproong 6G NTN. Wireless technologies change in 10- year cycles on average. However, intra-cycle changes (evolutions) also occur, further shortening the actual spans of the technology cycles. HAPS NTN can future-proof 6G NTN since it is retrievable for upgrades, retooling or redesign. Satellite systems will be highly exposed if these intra-cycle evolutions need hardware upgrades. Softwarisation and virtualisation would be helpful but do not eliminate the risk. This paper addresses the need to elevate the consideration for HAPS in 6G studies as it may serve as the ultimate technology guarantee for the success of 6G NTN.
Keyword: 6G, NTN, HAPS, NETWORKS

ABSTRAK

Jaringan non-terestrial (NTN) yang mencakup aset jaringan berbasis ruang dan udara akan sangat penting untuk pengiriman 6G. Konstelasi satelit merupakan bagian penting dari infrastruktur NTN tetapi memiliki keterbatasan tertentu seperti latensi panjang dan pergeseran Doppler. High Altitude Platform Stations (HAPS) akan melengkapi peran sistem satelit dan menambahkan nilai signifikan ke tawaran 6G NTN. Artikel ini menarik perhatian ekosistem pengembangan 6G pada kebutuhan untuk memprioritaskan studi dan spesifikasi HAPS. HAPS NTN akan menangani tiga faktor utama yang relevan dengan penyebaran 6G NTN: keterbatasan teknologi satelit, kompleksitas operasi, otomatisasi dan pemeliharaan (OAM) dan masa depan 6G NTN. Teknologi nirkabel berubah rata-rata dalam siklus 10 tahun. Namun, perubahan dalam siklus (evolusi) juga terjadi, lebih memperpendek jangkauan sebenarnya dari siklus teknologi. HAPS NTN dapat proof-future 6G NTN karena dapat diunduh untuk upgrade, retoling atau re-design. Sistem satelit akan sangat terpapar jika evolusi dalam siklus ini membutuhkan peningkatan perangkat keras. Software dan virtualisasi akan membantu tetapi tidak menghilangkan risiko. Dokumen ini membahas kebutuhan untuk meningkatkan pertimbangan untuk HAPS dalam studi 6G karena dapat berfungsi sebagai jaminan teknologi terakhir untuk kesuksesan 6G NTN.
Keyword: 6G, NTN, HAPS dan Jaringan

1. Introduction

The 6G wireless technology specification work has begun with stakeholders addressing various technical issues and consider- ations. Implementing Non-terrestrial networks (NTN) for 6G networks is no longer a theoretical or conceptual idea. 6G networks will rely on NTN infrastructure to achieve its uni- versal and ubiquitous network goal. Previous generations of mobile technologies (2G, 3G 4G) were designed to be imple-mented via terrestrial networks (TN) infrastructure and mainly for mobile users. 3rd Generation Partnership Project (3GPP) specifications previously focused on TN-supported infrastruc- ture and use cases. However, with release 17 of the 5G wireless technology, 3GPP included a new family of space-borne and airborne network infrastructure [1, 2]. These included satel- lites, high-altitude platform stations (HAPS) and Unmanned Aerial Vehicles (UAVs) (see figure 1).

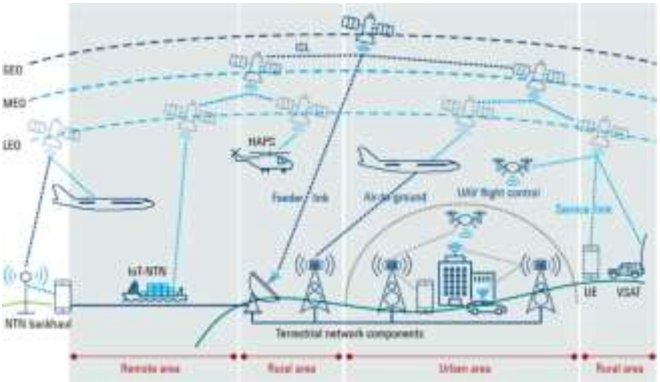

Fig. 1. Overview of TN & NTN infrastructure [2]

The main feature of these aerial platforms was that they oper- ate from an entirely non-terrestrial domain. It is important to note that non-terrestrial networks, specifically satellites, have been used for wireless communications for over five decades. However, these satellites used strictly proprietary technologies, interfaces and end-user devices for connectivity. With such pro- prietary regimes, Satellite operators and the supporting device and technology ecosystems were limiting and detrimental to expanding the market. In contrast, 3GPP established a com- mon wireless specification across markets and stakeholders, extending its reach and dominating the technology. It created viable technology and vendor ecosystems that ensured com-mercial and market success. It is essential to highlight that the adoption or integration of NTN by 3GPP has both technologi- cal and commercial dimensions. However, this paper will focus on technical considerations which could impact the successful implementation of NTN for 6G.

2. HAPS as NTN Infrastructure

HAPS is a stratospheric platform operating between 17 - 25 km and fits well within the definition of NTN by 3GPP. The tech- nical document of 3GPP release 17 specifically mentioned and identified HAPS as an NTN infrastructure. However, HAPS, though a fairly new technology to many, has been in exis- tence since the 80s. Despite its history, HAPS has not been fully deployed on a commercial basis, though that may change soon. HAPS is uniquely positioned among NTN platforms like satellites and low-altitude drones. It can support rural con- nectivity gaps, backhauling solutions, and traffic offloading, among others [3]. The current consideration for HAPS as NTN infrastructure describes HAPS as a monolithic system. This is partially correct but does not reflect the technical and com- mercial hurdles involved. As the development of 6G takes off, 6G NTN will inherit some of the current 5G NTN paradigms, which serve as foundational concepts. However, decoupling the HAPS system into two distinct layers or segments will be help- ful for its standardisation and implementation in 6G. These layers are (see figure 2);

- HAPS Platform Layer/Segment:
- HAPS Payload Layer/Segment.

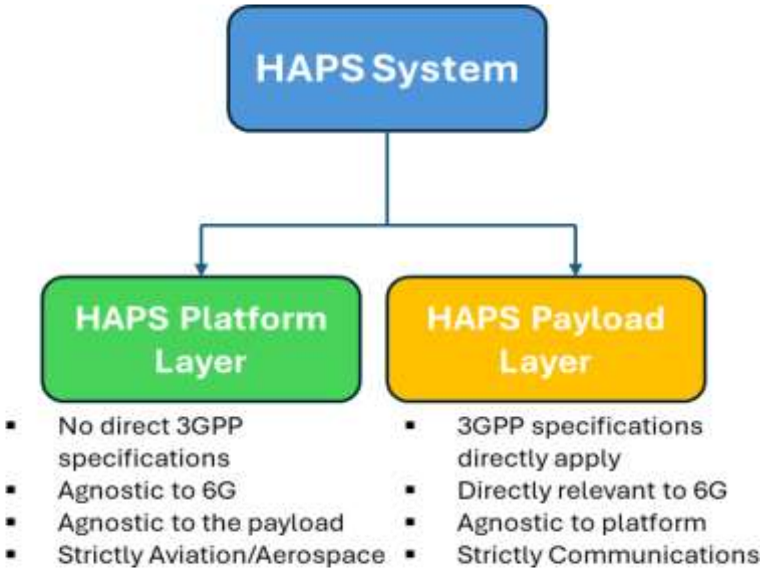

Fig. 2. HAPS System Overview

The HAPS platform layer applies to all considerations, ensuring HAPS airworthiness and fitness as an aerial platform. It covers all regulatory, technical and business considerations that must be fulfilled regardless of what mobile technology is in play, 5G or 6G. The 3GPP specifications that introduced 5G NTN have no direct influence or contribution to this layer of the HAPS system. HAPS comes in 3 main variants: fixed-wing, balloons and airships (see figures 3, 4 and 5).

The HAPS payload layer is the aspect of the HAPS system that directly relates to what 3GPP release 17 and beyond spec- ifies. NTN-based systems will be implemented mainly through two broad architectural paradigms: regenerative (advanced payload on-board) and non-regenerative (basic repeater pay- load) [5]. The 3GPP technical specification does not provide any solution to how the HAPS platform layer should meet the requirements to keep the HAPS airborne and available for ser- vice. 6G will be access network agnostic like 5G [6] so that it can provide 6G services through 3GPP and non-3GPP radio access technologies (RAT).
The HAPS Alliance is an international organisation champi- oning the interest of HAPS and working hard to address the specification for the platform layer and some aspects of the hardware for the payload layer. The HAPS Alliance may likely succeed in unifying these layers at the specification level.

Fig. 3. Aalto's Fixed wing HAPS (Zephyr) [4]

It is not a satellite as it never makes orbit but operates in a considerably challenging location. HAPS have to be built to be light enough to optimise power yet structurally resilient to withstand the harsh ascent to the stratosphere. It also presents a significantly different technical framework compared to satel- lites. Satellite systems have far better technical studies and research underpinning their operations. HAPS, on the other hand, has far fewer and many aspects to its operations that need more studies. For instance, the channel models between HAPS and satellite systems require more studies [7] to ensure seamless integration in a 6G connectivity scenario. This, how- ever, is fast changing with the work being done by the HAPS Alliance to accelerate the adoption of HAPS. The alignment of several technology and industry stakeholders is impacting the trajectory of HAPS.

Fig. 4. Project Loon Balloon HAPS

2.1 Research Data and Methodology

The implementation of 6G networks necessitates the explo- ration of innovative technologies and platforms to address the growing demand for connectivity. HAPS represent a promis- ing solution for non-terrestrial networks (NTN), offering the potential to enhance coverage, capacity, and resilience of com- munication networks. The research data and methodology used to compile this position paper relied on mostly secondary data sources and the author's observation of past and current trends. Academic journals and conference papers from sources like IEEE Xplore, which holds some collections of research papers on 6G technologies, NTNs, and HAPS, were explored. Industry and regulatory sources like GSMA Intelligence, Erics- son Mobility Reports and the International Telecommunication Union (ITU) were also consulted. A significant source of data and information for this position paper is 3GPP, which oversees the 6G technical specification [1].

The research methodology and data sourcing strategies employed in this position paper provide a comprehensive foun- dation for understanding the role of HAPS in implementing 6G networks. The paper aims to present balanced, established, and some aspirational perspectives on the opportunities and chal- lenges associated with deploying non-terrestrial networks via high-altitude platform stations for 6G implementation.

Fig. 5. Sceye's Airship HAPS

3. Considerations for HAPS in 6G Implementation

Satellite systems are the leading NTN infrastructure candidate, but due to their distance from the terrestrial user equipment (UE), long latency is an issue [2]. This long latency makes using satellites for low-latency communications, especially in NR-NTN, a major challenge. There are a few other lim- itations with satellite NTN that will be highlighted in this section, which will be challenging for 6G networks. How- ever, due to its unique technical capabilities, HAPS can be deployed in such scenarios to address the limitations. These areas will be highlighted for due consideration as 6G speci- fications are developed for the NTN segment.

However, 6G NTN specifications development should consider 3 broad areas of HAPS: Technology Limitations, Operations & Maintenance and Future-Proofing.

3.1 Technology Limitations of NTN Systems

HAPS has specific strengths that would address the limitations of other NTN platforms, especially satellite systems. Some of these limitations are highlighted below;

- HAPS NTN suited for Low Latency Communications in 6G: HAPS will play a key role in 6G NTN networks to achieve low latency communications with minimal oper- ational or design costs. HAPS operating at about 20 km have similar latency profiles as terrestrial networks. In con- trast, LEO satellites have round-trip time (RTT) of about 60-80ms, while GEO constellations have as much as 544ms one-way. These figures will be prohibitive for latency- sensitive applications like self-driving cars, remote surgery and so on.
- Doppler shift concerns with LEO systems can be addressed by HAPS NTN: 6G networks will rely on LEO and VLEO- based NTN to support 6G TN to service various use cases. However, the impact of the Doppler shift can be significant for LEO constellations due to the velocity of the satel- lites relative to the UEs and the frequency of transmission. The consideration is that several technical approaches could minimise the impact of Doppler shifts in satellite NTN implementations. However, HAPS could be implemented in 6G networks with negligible Doppler impact as the relative speed between the HAPS and the UEs is relatively minimal.

3.2 Operations, automation and maintenance (OAM) of NTN assets

6G networks will potentially have the highest levels of avail- ability and redundancy due to the integration of NTN assets. Previous generations of mobile technologies (2G, 3G, 4G) have mainly relied on satellite systems for backhauling support. The future 6G networks will rely on NTN infrastructure to achieve service continuity and universal or ubiquitous coverage. How- ever, this cannot only be achievable if the NTN platforms are available and supported by an advanced operations, automa- tion and maintenance framework. Satellite systems are robust in this sense but have apparent limitations as the satellite pay- load cannot be retrieved for maintenance or upgrades. HAPS systems will provide the highest levels of assurance. The abil- ity to retrieve and upgrade payloads easily will be critical for advanced 6G networks and verticals. The business case for many verticals will be based on the assurance of service conti- nuity and reliability. 3GPP Release 17 captured some of these challenges linked to satellite mobility (high Doppler offsets in LEO) and altitude (high path loss & RTT in GEO) [8]. 6G is expected to be deployed with these issues primarily addressed.

3.3 Future-Proofing 6G NTN with HAPS

5G networks support this position. While it is generally agreed that 3GPP wireless technologies change every ten years, the reality is quite different. There are always significant changes or upgrades of the technology within the ten years. For instance, LTE to LTE-Adavnaced and 5G to 5G advanced hap- pened within the 10-year cycle. NTN assets like satellites are space-based and not easily retrievable for upgrades. While efforts have been made to virtualise and softwarise wireless technologies, it is inevitable that some hardware upgrades may be needed during intra-cycle evolutions. HAPS can be the ulti- mate future-proofing for 6G NTN, as it can be easily retooled, upgraded or redesigned at minimal relative costs to other sys- tems. It is expected that 6G may require significant intra-cycle upgrades. Therefore, system designers and operators of 6G NTN must consider this risk.

4. Conclusions and Future Work

HAPS will play a significant role in strengthening the 6G NTN infrastructure. Satellite systems will remain the central infrastructure for NTN services for the anticipated 6G roll-out in 2030. However, HAPS will play an essential role in sup- porting 6G NTN by future-proofing it from the impact of the expected intra-cycle evolutions of 6G. It will also plug gaps in areas where Satellite deployments may be cost-prohibitive. This paper highlights considerations that should be central to HAPS NTN studies for 6G networks. Satellite studies and technical papers are significantly more but it is essential to encourage more considerations and funding for HAPS studies, as the success of 6G NTN depends on HAPS complement- ing Satellites to deliver meaningful and universal connectivity experience. Future work will highlight specific considerations relevant to the ongoing development of the 6G standard and specifications.

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