Transonic Speed Mobility Support Techniques for 6G-Non Terrestrial Networks

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***Abstract*—Non-Terrestrial Network (NTN) connectivity is expected to be used in sixth Generation (6G) telecommunication systems to support transonic speed mobility applications. NTN systems can provide wide-area coverage for applications that require high mobility. Third Generation Partnership Project (3GPP) is investigating a study on New Radio (NR) and solutions for NR to support NTN in Release-15 and Release-16 respectively. In this paper, we provide an overview of use cases, requirements and architecture of a non-terrestrial network and explain high mobility such as transonic speed mobility challenges and potential solutions to be resolved in 6G-NTN. In addition, we also describe the existing open research opportunities for non-terrestrial network implementation based on 5G-NR in order to encourage extensive research in 6G technology.**

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

I. INTRODUCTION

The Third Generation Partnership Project (3GPP) has already begun comprehensive research of NR-NTN based on a review of 5G technology, including visions and requirements, technical trends and challenges, to resolve the challenges of coverage, capability, user data rate, and mobile communication system movement speed [1]. The 3GPP has completed studies on satellite network use cases, architectural aspects, radio channel models, and strategies for incorporating NR with NTN support (NR-NTN) [2]. These tests were carried out in 5G, with an emphasis on the 5G core network and 5G-NR. Since so much of the work is standardized, it forms a strong basis for NTN's UAV enhancement (UAVs) research [3]. The overarching goal of the analysis is to provide truly universal aerial connectivity, with a focus on areas where terrestrial network reach is minimal. 5G-NR for NTN should therefore be seen as a support for established terrestrial deployments rather than as a challenge. In 3GPP Release 17 [3], the feasibility of adopting NB-IoT and LTE-M to support NTN will be investigated. The main contribution of this paper is to review 6G-NTN fundamentals and explain the transonic speed challenges by an expansion of 5G-NR. The rest of the paper is organized as section II explains the rationale of the study with the help of a literature survey, section III gives the overview of 6G-NTN based on, use cases, requirements, and architecture. In section IV we review and explain the high mobility challenges and potential solutions for transonic speed mobility of 6G-NTN. The future research work for 6G-NTN and conclusions are given in section V and VI respectively.

II. LITERATURE SURVEY

The 3GPP Working Group 1 (SA1) on Operation and System Aspects (SA) explored various use cases for satellite connectivity in NR, as well as potential service criteria for the system. More details on the use cases and service specifications can be found in the related technical report (TR) [3]. In a report "NR Study to support the Non-Terrestrial networks," 3GPP Radio Access Network (RAN) Working Group 1 (RAN1) established core aspects to be considered for NR-NTN connectivity [1], [2], [4]. Most of the main areas identified were issues with the physical layer such as Doppler and the impact of propagation delays [1] as 3GPP RAN1 analyzed physical layer problems. The resulting TR includes channel model design for non-terrestrial networks (NTN), which are important for performing comparable NTN evaluations [2], [4], [5]. The current research item is a continuation of the previous study item's (SI) work, to identify solutions to solve RAN1's primary identified areas [1], [2]. The comparative analysis of 5G and 6G characteristics are shown in following Table I.

TABLE I. COMPARATIVE ANALYSIS OF 5G AND 6G CHARACTERISTICS.

Parameters	5G	6G
Peak data rate	10 Gb/s	> 100 Gb/s
User experience data rate	1 Gb/s	> 10 Gb/s
Mobility	350 km/h	> 1000 km/h
Delay	ms level	< 1 ms
Spectrum efficiency	3~5x relative to 4G	> 3x relative to 5G

III. 6G-NTN OVERVIEW

A network, or segments of a network, with a transmission equipment relay node or base station onboard an airborne or space-borne vehicle as a payload, is referred to as NTN. Satellites can be classified as space-borne vehicles based on their orbit altitudes [6] which range from 400 km to 2,000 km for Low Earth Orbit (LEO), 2,000 km to 35,786 km for Medium Earth Orbit (MEO), and 35,786 km for Geostationary Earth Orbit (GEO). If the geosynchronous orbit has a zero angular inclination to the equator, it is called a Geostationary Earth Orbit [6].

A. NTN Use Cases

Non-terrestrial systems have been proposed for several years to enable programs such as home distribution, meteorology, video monitoring, TV transmission, remote sensing, and navigation. However, recent technological developments in the aerial/space industry have opened the way for more advanced use cases such as distributed computation and content broadcasting, service boosting for users in congested areas, eMBB in unserved and areas, and multi-connectivity for service continuity using cellular networks [9].

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B. *NTN Requirements*

In NR, the NTN channel model is primarily used. It's close to a terrestrial network's channel model. To offer 5G services using space-mounted platforms such as GEO and LEO satellites, as well as Unmanned Aerial Systems (UAS) air platforms such as HAPs, NTN extracts specifications such as scenarios, long transmission delays, large Doppler impacts, and mobile cells [3], [8], [9]. The assumptions and models used in the 5G NR specification are included in these specifications. Synchronization, retransmission process, control protocol, mobility improvement, operation reliability, and other technical issues are all affected. Quality research and solutions on various technological issues focused on the NTN channel model are currently being discussed at the 3GPP standard conference, at the SI level, with the active involvement of mobile communication and satellite communication companies.

C. *NTN Architecture*

By using the New Radio (NR) air interface, the user control connection directly connects the satellite(s) and the on-ground handheld User Equipment (UEs) [7]. The effect of typical satellite channel impairments, such as large delays and Doppler changes, on both the Physical Layer (PHY), such as subcarrier positioning in the NR waveform and PHY/MAC procedures, such as random access or timing advance is a review in this paper. The basic scenario for link connection of transonic class flight node by the terrestrial network is shown in Fig.1. This illustration shows wide-area wireless connectivity for an aerial node with terrestrial cellular networks [8].

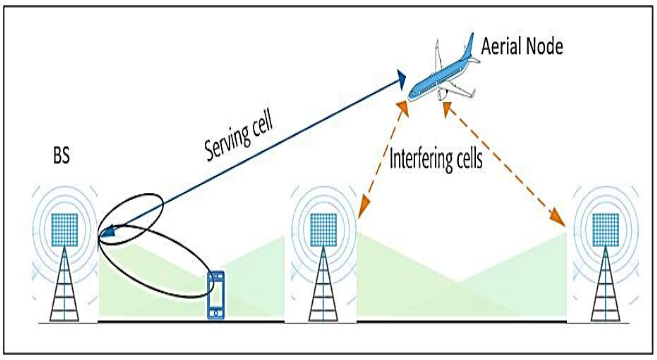

Fig. 1. Scenario for link connection of transonic class flight node by the terrestrial network.

IV. Challenges and Issues

A. *Mobility Challenges for NTN*

In NTN networks, the propagation delay for GEO satellites can be hundreds of milliseconds due to the incredibly long gap between the gNB and the UE, particularly in bent pipe scenarios. Due to the rapid relative movement between spaceborne vehicles, such as LEO satellites, and the UE Doppler effect, NTN faces significant technological difficulties in achieving high mobility, such as transonic speed mobility which is ~1000km/h [10]. For a 2GHz carrier frequency, there is a Doppler change of more than 7km per second and more than 20ppm [2], [8], [10]. The existing NR standards are mostly intended for cellular systems and are not intended to accommodate transmission delays or the Doppler Effect.

Directionality is required to achieve a sufficient link budget when operating at mmWaves to maintain high-capacity connections. Fine beam alignment has serious implications for the design of control operations such as user tracking, handover, and radio link failure recovery in this case [6], [8], [10]. These issues are especially pressing in the non-terrestrial domain, where the high speed of aerial/space platforms may cause beam alignment to be lost before a data transfer is completed. The increased Doppler experienced at high speeds may also cause the channel to become non-reciprocal, reducing the feedback over a broadcast channel. As a result, NR-NTN is critical for 3D spatial mobile connectivity analysis [9].

B. *Potential Solutions for Mobility Challenges*

The key technological challenges that must be addressed are the physical layer management process and scheduling issues. As a result, power control, AMC/CSI feedback, beam switching, and uplink transmission timing can all be used to overcome physical layer control procedure issues [9]. Whereas downlink and uplink synchronization, New physical random access channel (PRACH) format for the RACH process, and HARQ can be used to overcome timing issues in 6G-NTN to obtain higher mobility [6], [7]. Fig. 2. shows the potential element technologies of wireless transmission to support transonic speed mobility for 6G-NTN connectivity.

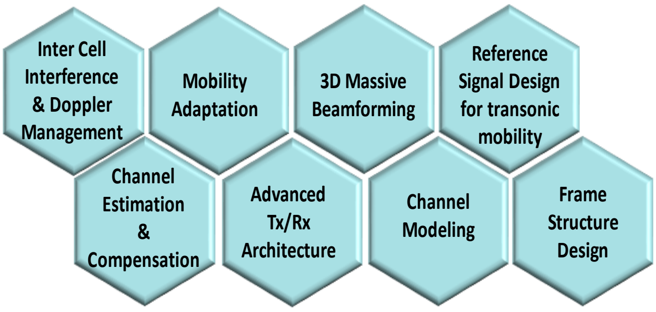

Fig. 2. Wireless transmission element technologies to support transonic speed mobility.

With certain variations, an NR – PRACH preamble consists of cyclic prefix, preamble series, and guard time. For efficient support of varied coverage and mobility needs, as well as carrier frequency, NR embraces various preamble lengths and subcarrier spacing values. Longer preambles with higher energy can be chosen to promote greater cell coverage and to achieve greater mobility. A 6G system, for example, Maglev in a vacuum tube, may involve a train speed of about 1000km/h [8], [10]. As a result, waveform, numerology, and frame structure can be redesigned to deal with extremely high Doppler frequencies.

V. Future Work

The importance of NTN in the beyond-5G ecosystem is expected to grow even more in 6G technology across their two design options (standalone satellite vs. integrated terrestrial and non-terrestrial architecture). By considering these aspects in our future work we will work on the development of 3D spatial mobile communication standard with modem and protocol software design/implementation. We intend to work on transonic speed mobility issues in 6G-NTN technology.

VI. CONCLUSIONS

Non-terrestrial networks are being investigated as a key component of the 6G network to enable ubiquitous, continuous, and unrestricted networking while simultaneously overcoming the range shortcomings and high mobility of envisioned 5G networks. The principles of a 6G non-terrestrial network connectivity are reviewed and explained in this paper. We have addressed the challenges and possible solutions for transonic speed mobility convergence with non-terrestrial networks. We also have reviewed the existing open research opportunities for non-terrestrial network implementation, to encourage further research in 6G technology.

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REFERENCES

[1] RP-170717, “Study on NR to support Non- Terrestrial networks,” 3GPP RAN#75, Mar 2017.

[2] 3GPP TS 38.811 V15.2.0, “Study on New Radio (NR) to support Non-terrestrial Networks,” Oct 2019.

[3] 3GPP TR 22.829 V17.1.0, “Enhancement for Unmanned Aerial Vehicles (Release 17)”, Sept 2019.

[4] 3GPP TR 38.811 V15.4.0 , "Study on New Radio (NR) to Support Non-terrestrial Networks (Release-15)”, Sept 2019.

[5] 3GPP TR 38.821 V16.0.0, “Solutions for NR to support non-terrestrial networks (NTN) (Release 16),” Dec 2019.

[6] Lin, X., Hofström, B., Wang, E., Masini, G., Maattanen, H.L., Rydén, H., Sedin, J., Stattin, M., Liberg, O., Euler, S. and Muruganathan, S., "5G new radio evolution meets satellite communications: Opportunities, challenges, and solutions." arXiv preprint arXiv:1903.11219, 2019.

[7] Kim, J.H., Yoon, M.Y., You, D.H. and Lee, M.S., "5G Wireless Communication Technology for Non-Terrestrial Network." Electronics and Telecommunications Trends 34.6, 2019, pp. 51-60.

[8] Lin, X., Yajnanarayana, V., Muruganathan, S.D., Gao, S., Asplund, H., Maattanen, H.L., Bergstrom, M., Euler, S. and Wang, Y.P.E., "The sky is not the limit: LTE for unmanned aerial vehicles." IEEE Communications Magazine 56.4, 2018, pp. 204-210.

[9] Giordani, M. and Zorzi, M., "Non-terrestrial networks in the 6G era: Challenges and opportunities." IEEE Network, 2020, pp. 244-251.

[10] Chen, S., Liang, Y.C., Sun, S., Kang, S., Cheng, W. and Peng, M., "Vision, requirements, and technology trend of 6G: How to tackle the challenges of system coverage, capacity, user data-rate and movement speed." IEEE Wireless Communications 27.2, 2020, pp. 218-228.