6G Non-Terrestrial Networks


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5G Non-Terrestrial Network (NTN) technology has successfully triggered the convergence across satellite and mobile cellular ecosystems. Compared with proprietary technologies, the open standard 5G NTN technology can enable satellite communications in more affordable devices and mainstream consumer markets thanks to economics of scale. The recent examples by smart phone direct access to satellite already demonstrates high market interests and potential which will benefit both ecosystems.

However, 5G system was not designed for satellite communication from its first standard release. Until 3GPP Rel-17 standard enables IoT NTN and NR NTN features for handheld devices connected with GEO and LEO satellites. The enhancements were designed to avoid physical layer change and to minimize hardware impact. There is still room to further optimize the efficiency and performance if NTN could be natively designed along with 6G standardization from Day-1. In the meantime, more advanced and powerful satellites will also be developed, which can also outperform the user experience and network performance. It is anticipated that the 6G NTN technology will further escalate satellite communication services to next level.

The objective of this Special Issue (SI) is to publish the latest NTN research findings and technology trends for global researchers to envision the potential framework for 6G NTN system. The objectives also include the publication on the latest 5G NTN standard development status and trends to help global researchers understand the state of art. With many high-quality submission by the experts around the world, the guest editors select the following manuscripts to be published which covers a wide variety of future NTN system design issues from direct-to-cell use case, seamless mobility, NTN/TN spectrum sharing, inter-satellites communication/routing, and HAPS NTN system consideration to 3GPP NTN standardization progress.

In the article, "Ubiquitous 6G Service through Non-Terrestrial Networks," by Jeroen, *et al.* overviews how 3GPP Release 17 integrates NTN as part of 5G Advanced to meet satellite communication market requirements. It also outlines a few of 6G key components identified as vital enhancements to the current NTN baseline provided by 5G Advanced. Examples are the seamless mobility between terrestrial and non-terrestrial networks, GNSS independent operation and efficient spectrum reuse between terrestrial and non-terrestrial networks. Another article, "Toward Integration of 6G-NTN to Terrestrial Mobile Networks: Research and Standardization Aspects," by Mehdi *et al.* further discuss the Release 18 NTN standardization progress and forecast the potential directions for 3GPP Release 19. It also introduces ITU-R and NGMN views on NTN with examples on technology development directions.

Another article, "Distributed Approach to Satellite Direct-to-Cell Connectivity in 6G Non-Terrestrial Networks," by Diego *et al.* introduces an interesting idea on using multiple small satellites with smaller antenna array to jointly form a sparse phased array. This may provide another direction to resolve the difficulty to deploy huge antenna array in the orbit and close the link budget gap in direct-to-cell use case for regular smartphones that can connect directly to a satellite.

Spectrum shortage is another challenge for future NTN market space to scale up. The article, "Feasibility and Opportunities of Terrestrial Network and Non-Terrestrial Network Spectrum Sharing," by Hao-Wei *et al.* investigates the feasibility for terrestrial and non-terrestrial networks to share the same spectrum resources and address the ICT industry's growing needs on new spectrum. Moreover, in order to verify user location for regulation requirements, the article, "NTN-Based 6G Localization: Vision, Role of LEOs, and Open Problems," by Harpreet *et al.* reviewed the positioning solutions in 3GPP and concluded the research landscape with open problems identified.

Different than other articles, "HAPS in the Non-Terrestrial Network Nexus: Prospective Architectures and Performance Insights," by Zhengying *et al.* investigates the role and importance of HAPS platform within entire non-terrestrial network architecture. Coverage and capacity tradeoff for different deployment models are also investigated.

The article, "Computer Vision-Based Joint Space Sensing and Communication Systems: Non-Source Autonomy and Low Latency," by H. Yu, et. al., addresses the challenges in outer space communications. It introduces a pioneering approach using computer vision to enhance satellite communications, focusing on joint space sensing and communication (JSC) systems. The article proposes a novel, open-loop JSC method, emphasizing improved efficiency, reliability, and low-latency communications, a significant stride in the field of inter-satellite communications.

In, "MaCRo: Mega Satellite Constellations Routing Systems with Multi-edge Cross-domain Features," by J. Zhang, et. al., an innovative routing approach MaCRo is presented for mega satellite constellations with multi-edge and cross-domain capabilities. It utilizes an architecture separating control and user planes across layers of GEO, MEO, and LEO satellites as well as a ground control center. Overall, MaCRo offers flexible, low-com-

plexity routing to address the demands of evolving mega-constellations in future 6G NTN networks.

The guest editors would like to express our appreciation to all the authors who submitted their outstanding research results to this SI. All the reviewers who spent their precious time and technical expertise to share constructive comments and help to improve the presentation of this SI are also greatly appreciated. The advice and great support by EiC Prof. Nirwan Ansari are also critical throughout the preparation of this SI.

Biographies

I-Kang Fu (ik.fu@mediatek.com) is currently a Senior Director of Technology at MediaTek Advanced Communication Technology Division. He received his Ph.D degree from National Chiao Tung University, Taiwan, in 2007, then joined MediaTek, in 2008 until present. From 2005, I-Kang has been actively developing and contributing new technologies to mobile cellular standardization projects in IEEE and 3GPP for mobile WiMAX, LTE, NB-IoT, and 5G NR systems. He has been leading MediaTek's NTN R&D initiatives from research, PoC prototype, standardization, and support ecosystem engagement, since 2019. Now he is also contributing to MediaTek's 6G R&D initiative. I-Kang has been serving multiple roles in different international and regional standard organizations. He also received MediaTek Special Contribution Award and Innovation Award in 2010 and 2023, respectively. Now he is serving Taiwan standard organization (TAICS) as TC1 Chair since 2018.

Olof Liberg (olof.liberg@ericsson.com) is a Line and Program Manager at Ericsson's department for Standards & Technologies. He is responsible for near-radio concepts and spectrum standardization at Ericsson Networks and is also leading Ericsson's 3GPP radio access network standardization program. Olof holds a bachelor's degree in business and economics and a master's degree in engineering physics, both from Uppsala University, Sweden. Over the years, he has actively participated to the work in several standardization bodies, such as 3GPP, ITU-R, ETSI, and the MulteFire Alliance. He was the chairman of 3GPP TSG GERAN and its Working Group 1, during the 3GPP study on new radio access technologies for Internet of Things leading up to the specification of NBIoT. Olof is the leading author of the first and second edition of the book Cellular Internet of Things (Elsevier) and has co-authored several academic publications and patents.

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Tony Q. S. Quek [S'98, M'08, SM'12, F'18] (tonyquek@sutd.edu.sg) received his B.E. and M.E. degrees in electrical and electronics engineering from the Tokyo Institute of Technology, in 1998 and 2000, respectively, and his Ph.D. degree in electrical engineering and computer science from the Massachusetts Institute of Technology, in 2008. Currently, he is the Cheng Tsang Man Chair Professor, ST Engineering Distinguished Professor, and Head of ISTD Pillar with Singapore University of Technology and Design as well as the Director of Future Communications R&D Programme. He was honored with the 2008 Philip Yeo Prize for Outstanding Achievement in Research, the 2012 IEEE William R. Bennett Prize, the 2017 CTTC Early Achievement Award, the 2017 IEEE ComSoc AP Outstanding Paper Award, the 2020 IEEE Communications Society Young Author Best Paper Award, the 2020 IEEE Stephen O. Rice Prize, the 2020 Nokia Visiting Professor, and the 2022 IEEE Signal Processing Society Best Paper Award. He is a Fellow of the Academy of Engineering Singapore.

Pei Xiao (p.xiao@surrey.ac.uk) is a Professor in Wireless Communications in the Institute for Communication Systems (ICS) at University of Surrey. He is currently the technical manager of 5GIC/6GIC, leading the research team in the new physical layer work area, and coordinating/supervising research activities across all the work areas (https://www.surrey.ac.uk/institute-communication-systems/5g-6g-innovation-centre). Prior to this, he worked at Newcastle University and Queen's University Belfast. He also held positions at Nokia Networks in Finland. He has published extensively in the fields of communication theory, RF, and antenna design, signal processing for wireless communications, and is an inventor on over 15 recent patents addressing bottleneck problems in 5G/6G systems.