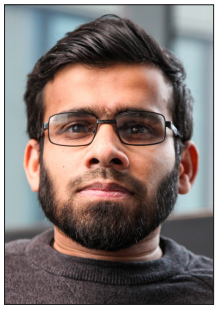
Technical Advancements in NTN-Assisted Internet-of-Things: Global Connectivity from the Sky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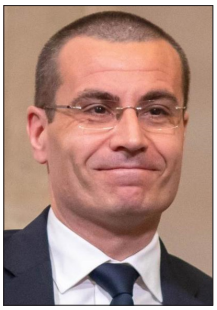
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The rise in popularity and the increasing number of Internet of Things (IoT) devices have raised significant challenges, such as heterogeneity, application needs, limited resources, and connectivity. Among these challenges, ensuring optimal connectivity for IoT devices stands out as a critical aspect. Integrating satellite-based networks into traditional terrestrial networks could be considered a possible and effective alternative to provide improved and low-cost connectivity for IoT devices. In Release 17, the 3GPP proposed standardizing non-terrestrial networks (NTN) to enable 5G-based terrestrial networks to support NTN. This standardization aims to facilitate direct communication between IoT devices and NTN in future IoT systems, which are anticipated to feature a larger number of devices and multi-access environments. These environments will require efficient utilization of different types of wireless spectrum, including Sub6 GHz, Millimeter-wave, and Terahertz. Typically, these IoT devices will require more resources to establish a reliable link with NTN, thereby increasing the challenges associated with maintaining a net-zero carbon emission rate.

This Special Issue (SI) aims at addressing the technical challenges for enabling IoT devices to directly communicate with NTN in order to improve their connectivity without relying on additional infrastructure cost. This SI covers articles showcasing the potential of using artificial intelligence (AI) and reflecting intelligent surfaces (RIS), in enabling NTN-assisted IoT networks and various challenges linked to NTN-assisted IoT networks.

In "Optimization Design in RIS-assisted Integrated Satellite-UAV-Served 6G IoT: A Deep Reinforcement Learning Approach" Wu *et al.* consider the application of RIS-assisted NTN to reshape wireless channels by controlling the phase shift of the scattering elements. The dynamic configuration of the RIS reflection unit poses a high-dimensional problem, making beamforming optimization challenging. They focus on discussing the optimization method of integrating deep reinforcement learning (DRL) in RIS-assisted NTN, which offers flexibility in scenarios where precise channel state information (CSI) is unknown.

In "Non-Terrestrial Networks: An Overview of 3GPP Release 17 & 18" Saad *et al.* provides insights and implications of incorporating satellite access networks as a new 3GPP RAN and as a backhaul solution. They explore the impact of this integration on network architecture and performance, considering factors such as coverage, capacity, and latency. They also highlight the key issues in 3GPP Release 18 and outlines the prospective potential solutions in the context of NTN to support 5G and beyond integrated architecture.

In "Artificial Intelligence and Machine Learning (AI/ML) Technologies for Integration of Terrestrial in Non-Terrestrial Networks (ITNTN)" Khalid *et al.* explores different possibilities of AI/ML-based solutions that can make it easier for terrestrial networks to be integrated into NTN. The roles of adaptive resource allocation, intelligent routing and handover, autonomous network operation, and effective spectrum management are highlighted in the research. These AI/ML-driven functions act as powerful catalysts, improving NTN performance, maximizing resource use, and improving the seamlessness of connections.

In "Reconfigurable Intelligent Surfaces for 6G Non-Terrestrial Networks: Assisting Connectivity from the Sky" Khan *et al.* studies the potential of RIS-integrated NTN to revolutionize next-generation connectivity. First, it discusses the fundamentals of RIS technology. Secondly, it delves into reporting the recent advances in RIS integrated NTN. Subsequently, it presents a novel framework based on the current state-of-the-art for IRS-integrated NTN with classical single connected diagonal RIS and fully connected beyond diagonal RIS architectures.

In "Key Issues in Wireless Transmission for NTN-Assisted Internet of Things" Qi *et al.* investigate three key issues in NTN-assisted wireless networks. The first issue is to enable the massive connection by designing random access to establish the wireless link and multiple access to transmit data streams. The second issue is to accurately acquire CSI in various channel conditions by channel estimation and beam training, where orthogonal time frequency space modulation and dynamic codebooks are on focus. The third issue is to efficiently allocate the wireless resources, including power allocation, spectrum sharing, beam hopping, and beamforming.

In "Multiple Access Schemes for 6G Enabled NTN Assisted IoT Technologies: Recent Developments, Prospects and Challenges" Shah *et al.* investigates the implication of several multiple access techniques for 6G enabled NTN-assisted IoT technologies. Various types of multiple access schemes are discussed and compared in the context of NTN-assisted IoT systems. Simulation results are presented and important performance parameters such as energy efficiency and spectrum efficiency are examined for the discussed multiple access schemes.

In summary, the compilation of articles in this specialized edition presents diverse technical strategies aimed at tackling the challenges linked to NTN-assisted IoT. Despite notable advancements, there remains significant ground to cover in meeting the rigorous demands for NTN-assisted IoT services. We anticipate that this pertinent SI will stimulate further research in this emerging field, potentially paving the way for numerous innovative developments.

Biographies

Muhammad Ali Jamshed [SM] is with University of Glasgow, since 2021. He is endorsed by Royal Academy of Engineering under exceptional talent category and was nominated for Departmental Prize for Excellence in Research in 2019 at the University of Surrey. He is a Fellow of Royal Society of Arts and an Associate Editor of IEEE Sensor Journal. He is a founding member of IEEE Workshop on Sustainable and Intelligent Green Internet of Things.

Aryan Kaushik is with the University of Sussex, UK, since 2021. Previously he has been associated with University College London, University of Edinburgh, Hong Kong University of Science and Technology, and held visiting professor/researcher appointments at Imperial College London, University of Luxembourg, Athena RC, and Beihang University. He has been Editor of two books, several IEEE journals and IEEE CTN podcasts, and in Organizing and Technical Program Committees of several flagship IEEE conferences.

Ana García Armada is a professor at Universidad Carlos III de Madrid. She has been a visiting scholar at Stanford University, Bell Labs, and the University of Southampton. She has published more than 200 papers in conferences and journals, and she holds five patents. She has been a member of the organizing committees of several conferences. She has received several awards from UC3M. Her research mainly focuses on signal processing applied to wireless communications.

Marco Di Renzo [F] is a CNRS Research Director (Professor) with the Laboratory of Signals and Systems (L2S) of ParisSaclay University – CNRS and CentraleSupelec, Paris, France. He serves as the Editor-in-Chief of IEEE Communications Letters. He is a founding member of the Industry Specification Group (ISG) on Reconfigurable Intelligent Surfaces (RIS). His recent research awards include the 2021 EURASIP Best Paper Award, 2022 IEEE COMSOC Outstanding Paper Award, and the 2022 Michel Monpetit Prize.

Doohwan Lee is a Senior Distinguished Researcher at NTT Corporation where he joined in 2009. He received his Ph.D. in Engineering and Information Systems from the University of Tokyo in 2009. From 2012 to 2014, he was a full-time lecturer at the Research Centre for Advanced Science and Technology, the University of Tokyo. He received many academic awards and served as general co-chair at IEEE ICC, GLOBECOM, VTC, PIMRC and WCNC.

Rajitha Senanayake received her Ph.D. from the University of Melbourne, Australia, in 2015. From 2015 to 2016 she was with Monash University, Australia. Currently, she is serving as a senior lecturer at the Department of Electrical and Electronics Engineering at the University of Melbourne, Australia. She is a recipient of the Australian Research Council Discovery Early Career Researcher Award. Her research interests are in cooperative communications, distributed antenna systems and joint radar and communications.

Octavia A Dobre [F] is a Professor and Tier-1 Canada Research Chair at Memorial University, Canada. She published over 450 papers. She was the inaugural Editor-in-Chief (EiC) of the IEEE Open Journal of the Communications Society and the EiC of the IEEE Communications Letters. She is a member of the European Academy of Sciences and Arts, Fellow of the Engineering Institute of Canada, and Fellow of the Canadian Academy of Engineering.