# Special Issue on 6G Technologies and Applications

Arvind Narayanan, *AT&T Labs, Bedminster, NJ, 07921, USA*

Mahesh Marina, *University of Edinburgh, Edinburgh EH8 9AB, Scotland, U.K., and Johns Hopkins University, Baltimore, MD, 21218, USA*

Vijay Gopalakrishnan, *AT&T Labs, Bedminster, NJ, 07921, USA*

*In this issue of Internet Computing, we included articles that tackle the technical challenges around both 6G technologies and applications. The first two articles focus on bringing emerging areas like satellite communications and intelligent surfaces into the 6G context. The third looks at providing a low-latency packet core for cellular networks. Finally, the last article covers the problem of supporting scalable data analysis, automation, and using artificial intelligence/machine learning in the 6G cellular network.*

Cellular networks have become an integral part of our everyday lives and are helping drive the digitization of the world. From bringing the Internet and applications to populations that previously did not have access to them, to enabling automation and robotic operation of industries and equipment, there are a diverse set of capabilities that cellular technology has enabled. Keeping up with the diverse needs has been challenging, and new capabilities and technologies have been integrated with each generation of cellular technology. As operators roll out 5G, it is only appropriate to explore aspects that 6G, the next generation of cellular technology, will bring as enhancements and the applications that it will support.

6G is expected to provide significantly superior communication capacities and capabilities than its predecessor. These range from not only making the underlying technology more efficient, but also support new capabilities, new ways of delivering cellular connectivity, integrate artificial intelligence/machine learning (AI/ML) as a first-class citizen to support real-time decision making, as well as support a plethora of new applications. Emerging technologies such as AI, terahertz (THz) communication, optical wireless communication, intelligent reflective surfaces, integration with nonterrestrial networks (NTN), blockchain, dynamic network slicing, cell-free communication, edge computing, and big-data analytics are among the few that are expected to be the driving forces behind realizing the 6G technology. 6G is expected to fuel innovative applications such as holographic-type communications, tactile Internet, connected autonomous vehicles, unmanned aerial vehicles, autonomous healthcare solutions and manufacturing systems, virtual/augmented/extended reality, and more. This special issue aims to bring together representative contributions from researchers, scientists, engineers, and industry professionals from around the world to capture ideas on the latest advancements and challenges on the path towards 6G technologies and its applications.

1089-7801 
Digital Object Identifier 10.1109/MIC.2024.3377948
Date of current version 16 April 2024.

## IN THIS ISSUE

The four articles in this special issue on 6G Technologies and Applications address many of these technical challenges and new opportunities. The first two articles focus on bringing emerging areas like satellite communications and intelligent surfaces into the 6G context. The third article looks at providing a low-latency packet core for cellular networks. Finally, the last article covers the problem of supporting scalable data analysis, automation, and using AI/ML in the 6G cellular network.

The first article is "Enabling 6G and beyond network functions from space: Challenges and opportunities," by Lixin Liu et al.[A1] The authors focus on the architectural solutions to extend the traditional cellular networks into space, particularly through mega constellations of low Earth orbit satellites, which promise to significantly widen the coverage footprint of terrestrial networks. They observe that recent 3GPP 5G NTN enhancements call for radio access and core functions to be offloaded to satellites while keeping with the traditional hop-by-hop stateful session-based architecture. This NTN approach

## APPENDIX: RELATED ARTICLES


A1. L. Liu, W. Liu, Y. Li, and H. Li, "Enabling 6G and beyond network functions from space: Challenges and opportunities," *IEEE Internet Comput.*, vol. 28, no. 2, pp. 8–17, Mar./Apr. 2024, doi: 10.1109/MIC.2024.3359773.

A2. M. Rossanese, P. Mursia, A. Garcia-Saavedra, V. Sciancalepore, A. Asadi, and X. Costa-Perez, "Open experimental measurements of sub-6GHz reconfigurable intelligent surfaces," *IEEE Internet Comput.*, vol. 28, no. 2, pp. 19–28, Mar./Apr. 2024, doi: 10.1109/MIC.2024.3376772.

A3. S. Qi, K. K. Ramakrishnan, and J.-C. Chen, "L26GC: Evolving the low latency core for future cellular networks," *IEEE Internet Comput.*, vol. 28, no. 2, pp. 29–36, Mar./Apr. 2024, doi: 10.1109/MIC.2024.3376655.

A4. Y. Jeon and S. Pack, "Hierarchical network data analytics framework for 6G network automation: Design and implementation," *IEEE Internet Comput.*, vol. 28, no. 2, pp. 38–46, Mar./Apr. 2024, doi: 10.1109/MIC.2024.3369939.


is argued to have efficiency (e.g., signalling storms), reliability, and security limitations, due to the extreme mobility of satellites and their intermittent connectivity to ground stations. So, to overcome these limitations, the authors propose an alternative user-centric design that refactors cellular functions on board satellites to be stateless and offloads their state to user devices.

The second article is titled "Open experimental measurements of sub-6 GHz reconfigurable intelligent surfaces," by Marco Rossanese et al.[A2] The authors develop a custom reconfigurable intelligent surface (RIS) prototype. They provide useful insights about its design and implementation. They also test and evaluate their RIS prototype and successfully demonstrate its ability to electronically steer the signal reflections from their transmitter towards a specific location. The datasets collected using their prototype have been publicly released to the research community. The authors provide directions on how researchers can make use of their datasets.

While there is a lot of focus on radio technologies and its improvements, the packet core plays a critical part in cellular networks, in particular from a mobility and policy management perspective. In the third article, "L$^2$6GC: Evolving the low latency core for future cellular networks" by Shixiong Qi et al.[A3] draws attention to the need for low latency operation of the cellular core to support emerging application needs and increased disaggregation in the core architecture. Further, they outline the key contributors to latency in the core operations. Then, the authors present their L$^2$6GC cellular core design that reduces latency through a combination of shared memory communication between control network functions, SmartNIC-based data plane packet processing and a hybrid packet classification mechanism for faster rule lookups and updates in the data plane.

As cellular networks evolve to support a diverse set of applications, there is a growing need to learn about the network conditions and change network policies and functioning. Similarly supporting the diverse applications needs sophisticated AI/ML-based approaches to manage, operate, and tune the network. The final article, "Hierarchical network data analytics framework for 6G network automation: Design and implementation" by Sangheon Pack et al.,[A4] presents novel designs and schemes for data collection, model training, and inference from network data analytics function (NWDAF). At a high level, NWDAF was introduced by 3GPP to help network function (NF) modularization as well as help in the automation of network operation and management. The authors propose a hierarchical architecture of NWDAFs where the root NWDAF is responsible to construct the model using the global view of the network, while the leaf NWDAFs can provide results of the analytics to other NFs. The authors implement this system using free5GC and show that their scheme not only provides accurate analytics but also speeds up the analytics provisioning time when compared to conventional NWDAF.

These articles just scratch the surface; there are many other challenges, innovations, and aspects related to 6G technologies and applications. We expect to see related themes covered by *Internet Computing* in the near future.


**ARVIND NARAYANAN** is a lead inventive-scientist at AT&T Labs, Bedminster, NJ, 07921, USA. Contact him at an510a@att.com.

**MAHESH MARINA** is a professor in the School of Informatics, University of Edinburgh, Edinburgh EH8 9AB, Scotland, U.K., and a visiting professor in the Department of Computer Science, Johns Hopkins University, Baltimore, MD, 21218, USA. Contact him at mahesh@ed.ac.uk.

**VIJAY GOPALAKRISHNAN** is a director of inventive science at AT&T Labs, Bedminster, NJ, 07921, USA. Contact him at gvijay@att.com.