Low Earth Orbit Satellites to Enable Access Equality


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Humanity shares the need for Internet access. However,the International Telecommunication Union (ITU) estimates that only 63 percent of the world's population is connected in 2021. The emerging low Earth orbit (LEO) mega-constellation networks, planned to be composed of thousands of satellites, have the potential to connect all through their global footprint and bridge this ever-existing digital divide. Supported by more cost-effective launch systems and reconfigurable software architectures, the capabilities of new LEO satellites are significantly higher than traditional satellites. Moreover, these mega-constellations can provide services not only to sparsely populated areas but also to urban centers to enable and maintain their economic sustainability. However, the provision of access equality would still require architectural, management, and operational changes.

This Feature Topic (FT), focusing on *access equality solutions in LEO mega-constellations*, has attracted numerous *geographically diverse* submissions from researchers. All submissions were evaluated with at least three reviews. Overall, seven papers were accepted, all of which went through rigorous review rounds. This current FT contains four of these articles, which focus on the potential of the emerging mega-constellations and the associated challenges. In addition, the modeling approaches and diverse functionalities are noted, opening the door to the evolution of space information networks. Three more articles will be included in an upcoming issue.

The shift in the communication paradigm due to the emerging LEO satellite constellations for global communications introduces the need for new mathematical models and simulation approaches for accurate performance estimation. The article by Al Homssi *et al.*, "Next Generation Mega Satellite Networks for Access Equality: Opportunities, Challenges, and Performance," provides guidelines for the systematic analysis of next-generation LEO mega satellite constellations. The challenges that stem from the deployment of mega-constellations are noted, and the opportunities that position LEO constellations as a promising solution to attaining global coverage are highlighted along with the target performance metrics.

The challenges of dense LEO constellations in terms of cost and frequency coordination are addressed in the article "Ultra-Dense LEO Satellite-Based Communication Systems: A Novel Modeling Technique." The authors highlight the strength of stochastic geometry (SG)-based modeling techniques to determine the system performance in a realistic manner. The major factors affecting latency and coverage probability using SG-based models are discussed, and the impact of the number of satellites and the height of the constellation on performance is shown through numerical analysis. Envisioned future deployment scenarios are also detailed along with their new challenges that need to be addressed by the research community in the near future.

The functionality of the emerging mega-constellations is expected to extend beyond solely communication purposes. The authors of the article "Orbital Edge Offloading on Mega-LEO Constellations for Equal Access to Computing" investigate the possibility of integration of the in-network computing paradigm and feature the benefits of the presence of an orbital edge (OE) platform to exploit the fast and distributed computational capability of LEO constellations. The presented preliminary analysis demonstrates the importance of task offloading strategies on overall performance. The potential of artificial intelligence is emphasized, and the emerging challenges for future research directions are noted toward the evolution of space information networks.

Another contribution deals with the concept of ring road networks (RRNs), which builds on the use of small affordable LEO satellites as store-and-forward nodes to asynchronously receive, carry, and deliver data from and to places that lack Internet connectivity. In the article "Ring Road Networks: Access for Anyone," the authors show how the main advantage of such a concept is that it can be implemented with delay-tolerant network (DTN) protocols so that even a single nano-satellite can provide (extremely high-latency) connectivity services worldwide. Clearly, target beneficiaries are unconnected or isolated populations where the deployment of synchronous connectivity may be hardly justified. The contribution illustrates the great potential of DTNs over RRNs with field tests and proof of concept by using modular open source lightweight DTN protocols.

As the Guest Editors, we believe that the FT not only provides valuable insights into the current state of the art on the topic, but also contains the future research directions to shape the evolution of satellite networks. We deeply appreciate the reviewers for their high-quality, insightful, and constructive reviews. Finally, we would like to thank the former Editor-in-Chief Tarek S. El-Bawab, the current Editor-in-Chief Antonio Sanchez-Esguevillas, and the Associate Editor-in-Chief Ravi Subrahmanyan for their help in organizing and preparing this FT.

Biographies

Gunes Karabulut Kurt [StM'00, M'06, SM'15] (gunes.kurt@polymtl.ca) is an associate professor of electrical engineering at Polytechnique Montréal, Quebec, Canada. She received her B.S. degree with high honors in electronics and electrical engineering from Bogazici University, Istanbul, Turkey, in 2000, and her M.A.Sc. and Ph.D. degrees in electrical engineering from the University of Ottawa, Ontario, Canada, in 2002 and 2006, respectively. She is a Marie Curie Fellow and received the Turkish Academy of Sciences Outstanding Young Scientist (TÜBA-GEBIP) Award in 2019. In addition, she is an adjunct research professor at Carleton University. She is also currently serving as an Associate Technical Editor of *IEEE Communications Magazine* and a member of the IEEE WCNC Steering Board.

Ángeles Vázquez-Castro received her telecommunications engineering M.Sc. and Ph.D. degrees from Vigo University, Spain, in 1994 and 1998, respectively. She also received an M.Sc. degree in analytical philosophy from the University

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