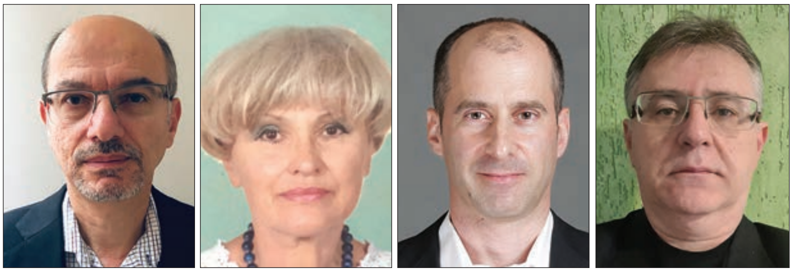
Digital Divide: Closing the Gap



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The promise of ubiquitous connectivity has been a utopian goal for several decades. And yet, to this day, the digital divide not only persists, but in many cases continues to widen. According to the United Nation's report [1], less than half of the population in underdeveloped areas has access to fourth generation mobile networks. Furthermore, the inequality between urban and rural areas exists even in developed countries [2, 3]. As a result, bridging the digital divide has been identified as a goal for sustainable development by the United Nations [4]. The problem of digital information and communication technologies (ICT) access divide has especially been amplified in the last two years, when COVID-19 forced the majority of the world's workforce to work from home.

The persistence of the digital divide is not for lack of trying. Academia has looked into this problem for a long time. The industry, led by the Third Generation Partnership (3GPP), has gradually improved their solutions to provide better coverage for both mobile broadband and Internet of Things (IoT) connectivity. For example, the most recent work in 3GPP Releases 16 and 17 relates to non-terrestrial networks (NTNs), addressed in several articles in this Feature Topic. Similarly, the Next Generation Mobile Networks (NGMN), with their current focus topics on the route to disaggregation/operating disaggregated networks, green future networks, and 6G activities, among others, focuses on societal requirements including the objective to provide more even-handed access to rural and underdeveloped areas.

For operators, the main challenge to bridging the digital divide remains the economic feasibility of deploying networks in areas where the population density is low and/or present affordable backhaul connectivity challenges. However, new players may be entering the market soon. We are probably at the cusp of technological advances that enable cheaper and more energy-efficient deployments of networks that will allow for ubiquitous connectivity on a global scale.

In this Feature Topic, which covers the digital divide problem, we have six excellent articles that address technological advances, discuss the challenges that still remain, and chart the way for regulatory developments that need to take place to bridge the digital divide.

The first article, written by Yaguang Zhang *et al.*, examines the motivations and challenges of providing broadband access in rural areas and presents a comprehensive list of wireless technologies that can help to bridge the digital divide gap. It highlights that even in highly developed countries such as the United States, significant digital divide challenges exist, which is effectively shown by comparing the cellular site density between urban and rural areas that can be, in some cases, greater than 30. This article first describes applications and opportunities for rural wireless communications, with the focus on residential welfare, digital agriculture, and transportation. Next, it outlines diverse use-case-specific requirements that are often contradictory, which highlights the challenges of solving the digital divide. Finally, it provides a list of emerging wireless technologies that are intended to address coverage extension, enablers for low-cost implementation, and facilitation of network construction and maintenance.

Technological changes go hand in hand with regulatory changes. The second article, by Janaki Parekh *et al.*, showcases a data science study where massive crowdsourced data is used to further elaborate on the current state of the digital divide in North America. The median reference signal received power in the Long Term Evolution (LTE) technology has been used as a proxy for digital connectivity, which provides an excellent way to quantify the disparity between the urban/connected and rural areas. The article addresses some of the technological advances but goes beyond that as it charts the way for regulators and policymakers to enable better connectivity in rural areas.

Significant research effort in recent years has been put into NTNs. The third article is the first of a series of three articles that focus on NTNs. It addresses the topic of High Altitude Platform Stations (HAPSs). Specifically, HAPSs with International Mobile Telecommunication base station functionality, with an altitude of about 20 km, are the focus of this article. It discusses results on coexistence analysis between HAPSs and fixed service point-to-point in an adjacent channel scenario. This article also provides an excellent overview of the digital divide challenges on a global scale.

The next NTN article addresses a complementary emerging technology that aims to address the digital divide: low Earth orbit (LEO) satellites. It provides an overview of the current state of LEO satellite access, and discusses technical challenges and solutions and how the evolution of LEO fits into 5G and 6G standardization efforts. This article acknowledges that interest in LEO is not new, but previous success was hampered by high launch costs, which has changed significantly in recent years. The biggest contributor to the success of future LEO systems will likely be alignment with 3GPP standards, thus relying on the massive global mobile ecosystem. An excellent overview of the state-of-the-art solutions and projected evolution toward 6G is this article's key contribution.

Successful operation of satellites depends on proper network management. The fifth article (the third related to NTN), by Peng Hu, explores advances in network management of intelligent satellite-integrated community networks (SICNs). It features a machine-learning-based hierarchical approach with anomaly identification and mitigation phases to enable self-maintenance of SICNs and improve system performance, scalability, and reliability.

While the NTN can provide ubiquitous access with reduced need for terrestrial infrastructure, the data rates may not be high enough to compete with urban solutions. A potential cost-efficient solution for regions with high wind energy potential is discussed in the sixth article, which explores usage of wind-turbine-mounted base stations. The uniqueness of this solution is that wind-turbine-mounted towers would take advantage of being connected to power grids, thus providing an easily implemented backhaul solution (e.g., fiber wrapped around the power line). Of particular interest are case studies that involve central Ethiopia and southern Argentina.

We would like to thank each and every author for their excellent and timely contributions. We would also like to express our deep appreciation to our reviewers for their forensic reviews and invaluable feedback, which substantially improved the quality of these articles. Finally, our gratitude goes to Dr. Tarek El-Bawab, Editor-in-Chief of *IEEE Communications Magazine*, along with Telex Magloire Nkouatchah, Tammy Remington, Joseph Milizzo, and the whole IEEE Communications Society publishing team.

References

[1] UN, "2020 Report of the Secretary-General"; https://unctad.org/system/files/official-document/a76d64_en.pdf, accessed July 29, 2021.

[2] "Digital Divide Persists Even as Americans with Lower Incomes Make Gains in Tech Adoption"; https://www.pewresearch.org/fact-tank/2021/06/22/digital-divide-persists-even-as-americans-with-lower-incomes-make-gains-in-tech-adoption/, accessed July 29, 2021.

[3] "What the Coronavirus Reveals About the Digital Divide Between Schools and Communities"; https://www.brookings.edu/blog/techtank/2020/03/17/what-the-coronavirus-reveals-about-the-digital-divide-between-schools-and-communities/, accessed July 29, 2021.

[4] "Sustainable Development Goals by United Nations, Goal 9: Build Resilient Infrastructure, Promote Sustainable Industrialization and Foster Innovation"; https://www.un.org/sustainabledevelopment/infrastructure-industrialization/, accessed July 29, 2021.

Biographies

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