Anwer Al-Dulaimi and Rose Qingyang Hu

Network Slicing and Intelligent Automation of Resources

It appears that 5G networks will deploy soon and offer impressive improvements in user-experience quality as well as business growth for operators and the digital economy as a whole. However, this does not mean that it will be a fully functional, end-to-end network. In fact, the primary deployments will target nonstandalone models where the gNB (the 5G base station) will interface into the network using the 4G evolved-packet core. Clearly, the 5G-core (5GC) network is still far from being deployed because of a lag in developing the necessary features to support network slicing for various services.

Specifically, the service-based architecture (SBA) will incorporate ultrareliable low-latency communication (URLLC), enhanced mobile broadband, and massive Internet of Things (IoT) services. This means that multiple 5GC SBAs will operate concurrently to handle the services of each of those slices and that the 5GC will assign various requests from connected users subject to receiving standard slice-type values. However, operators are still far from adopting a cloud-based structure to automate 5GC scaling and resource migration in response to traffic changes in a live network.

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5G NETWORKS WILL DEPLOY SOON AND OFFER IMPRESSIVE IMPROVEMENTS IN USER-EXPERIENCE QUALITY AS WELL AS BUSINESS GROWTH FOR OPERATORS AND THE DIGITAL ECONOMY AS A WHOLE.

Therefore, the research community is asked to focus more on logic networks and how they will stretch over the physical networks to support network slicing. This should be combined with powerful new models for service orchestration that can segregate the network into smaller domains and instantiate SBA cores locally within these smaller domains. The result will be fewer delays caused by large-scale networks and the different key performance indicators (KPI) of the underlying physical infrastructure. Consequently, enforcing artificial intelligence deeply in the network design and orchestrator platforms is gaining more attention and funding. In addition, more attention is being paid to blockchain and big data technologies to facilitate data sharing and distribution among 5GCs and associated application servers.

Prior to 5G, operators were able to evaluate an approximate upper limit for their network capacity using various testing and benchmarking tools. The dawn of cloud-dependent 5G has changed this reality forever because we now have new networks that are completely driven by open source software and third-party clouds. For example, 5GCs can be operated on Google clouds to add additional computational resources to handle the incoming traffic from the radio access network (RAN) side. This means that the core network for any operator can be scaled to whatever is requested, making the RAN the bottleneck for unlimited service expansion. Therefore, researchers are still focusing on improving resource allocations for radio-access interfaces. However, RAN and core engineers need to devise new modes for lifecycle management that can support 5G KPI and avoid creating a complicated network that is hard to administrate and too scattered to evaluate. Therefore, the 5G research journey is not over. In fact, the push for innovation has just begun.

This is the fourth issue in the IEEE Future Networks (formerly IEEE 5G Initiative) series for *IEEE Vehicular Technology Magazine*. The special issues are published twice a year and cover different 5G areas to help the research community better understand new ideas and the latest findings from both academia and industry. This issue includes

THE 5G-CORE NETWORK IS STILL FAR FROM BEING DEPLOYED BECAUSE OF A LAG IN DEVELOPING THE NECESSARY FEATURES TO SUPPORT NETWORK SLICING FOR VARIOUS SERVICES.

eight articles that address 5G technologies and approaches.

The first article is "Caching in Heterogeneous Ultradense 5G Networks" by Peng Lin, Komal S. Khan, Qingyang Song, and Abbas Jamalipour. It describes cooperative caching in heterogeneous ultradense cellular networks with a special focus on 5G wireless systems. The authors propose storage- and transmission-level cooperation between access points to improve content placement for single and joint transmissions. In addition, the article presents a virtual cluster for content placement to reduce the redundancy between the cellular and device-to-device (D2D) networks. This work is supported by numerical simulations that validate the performance of the proposed caching schemes.

The second article is "Network Architectures for Demanding 5G Performance Requirements" by Philipp Schulz et al. It presents a flexible system architecture that can be tailored to various 5G use-case requirements and applications, with a special focus on URLLC efficiency. The article addresses all segments and technical features of the proposed architecture, including radio interface, multiconnectivity, latency modeling, and D2D. The authors envision a future network management that considers automated, virtualized platforms and the relevant economic impact of 5G on the market.

The next article, by Zehui Xiong, Yang Zhang, Dusit Niyato, Ruilong Deng, Ping Wang, and Li-Chun Wang, is "Deep Reinforcement Learning for Mobile 5G and Beyond." The article presents the fundamental concepts of deep reinforcement learning (DRL) that support decision making with regard to resource and service allocation challenges in 5G and beyond. The authors explore employing a DRL-based scheme for network-slicing optimization. The proposed scheme is well suited for a heterogeneous, 5G-enabled IoT and considers the diversity of stakeholders and fluctuations in network conditions. The DRL-based scheme interacts with IoT devices to reduce the complexity of network resource assignment and service.

The fourth article is "Toward an Intelligent, Multipurpose 5G Network" by Jin Yang and Yee-Sin Chan. It investigates a self-organizing network (SON) that adapts the network functionality on multiple tiers. Specifically, the authors propose an evolved-distributed SON that controls the lower-layer-split interface and a newly proposed middle-tier SON that controls the high-layer split, while maintaining the traditional centralized SON for resource management. This article explains that these three SON tiers will act intelligently and jointly to support various quality-of-service flows as well as network slicing for a variety of services. The proposed model is assumed to improve the network transformation into a more intelligent, multipurpose 5G network.

The fifth article, "Harmonious Coexistence of Heterogeneous Wireless Networks in Unlicensed Bands" by Tianheng Xu, Mengying Zhang, Yu Zeng, and Honglin Hu, investigates the spectrum coexistence problem in 5G systems by adopting a statistical signal transmission (SST) technique. The SST facilitates many features, such as intersystem data exchange, embedded transmission and spectrum saving, and robust and Doppler tolerance that enables harmonious coexistence in the 5G unlicensed band. In addition to improving conventional spectrum coordination services, SST-aided intersystem information exchanges can also be leveraged to support safety challenges for vehicular communications conducted over the unlicensed band. The authors provide analysis in support of their proposals.

The sixth article, by Richard H. Middleton, Torbjörn Wigren, Lisa Boström, Ramón A. Delgado, Katrina Lau, Robert S. Karlsson, Linda Brus, and Eddie Corbett, is "Feedback Control Applications in New Radio." The authors highlight the impact of delays on increasing the phase angle of a feedback response in real-time feedback applications over new radio communication systems. The article proposes modifications for feedback-control compensators at the application level to reduce the impacts of delays. In addition, the authors propose modifications of flow-management protocols to minimize delay variances and align transmissions for multipoint. This solution is expected to improve data delivery for vehicle-to-vehicle communication and mobile virtual reality.

The seventh article, "IEEE 802.11ax Spatial Reuse Improvement," by Anastasios Valkanis, Athanasios Iossifides, Periklis Chatzimisios, Marios Angelopoulos, and Vasilis Katos, focuses on the IEEE 802.11ax amendment, which addresses the wireless local area network densification problem by improving spatial reuse. The article presents a channel-access algorithm that evaluates the expected interference at nodes that conduct concurrent transmission to decide whether to proceed with transmissions or defer them to later times. The authors compare the superiority of the proposed interference-based, dynamic-channel algorithm with existing channel-access algorithms employed for the IEEE 802.11ax dense deployment.

The last article is "Outage-Limit-Approaching Channel Coding for Future Wireless Communications" by Yi

Fang, Pingping Chen, Guofa Cai, Francis C.M. Lau, Soung Chang Liew, and Guojun Han. The authors review, from a code-design perspective, the full-diversity, maximum-distance separable root-protograph-related codes over block-fading channels. Specifically, a new design for root-protograph, low-density parity-check codes aims to achieve linear-complexity encoding and high-speed decoding with the help of a quasi-cyclic structure. The article describes the superior code performance in slow-fading wireless communications networks. The authors support their proposals with detailed design guidelines for protograph codes and comprehensive results.

THE 5G RESEARCH JOURNEY IS NOT OVER. IN FACT, THE PUSH FOR INNOVATION HAS JUST BEGUN.

Author Information

Anwer Al-Dulaimi (anwer.al-dulaimi@exfo.com) is a technical product owner in the Research and Development Department at EXFO Inc., in Montréal. His research interests include 5G networks, cloud networks, vehicle to everything, and the Internet of Things. He is the chair of the IEEE 1932.1 working group for *Standard for Licensed/Unlicensed Spectrum Interoperability in Wireless Mobile Network* and is an IEEE Distinguished Lecturer.

Rose Qingyang Hu (rose.hu@usu.edu) is a professor in the Department of Electrical and Computer Engineering at Utah State University, Logan. She has been a frequent guest editor for *IEEE Communications Magazine, IEEE Wireless Communications Magazine*, and *IEEE Network Magazine*. She is a Senior Member of the IEEE and a member of the Phi Kappa Phi Honor Society.

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