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New Considerations for 5G Wireless Systems

The fifth-generation (5G) wireless system is a major transformation from the current cellular network to a network of everything that connects all people and machines in service-based architecture. Accordingly, the 5G network enforces different performance metrics based on the caller type and service requested. Researchers are aiming to improve the deliverables of enabling technologies such as new radio; massive multiple input, multiple output (mMIMO); mobile-edge computing; network virtualization; and more. However, these technologies must be collectively evaluated using end-to-end (E2E) trails to verify the 5G advantages of gigabit downloading speed and ultralow latencies. It is the network slicing and service-based scenarios that drive 5G developers to expand their visions and look beyond the radio access network (RAN) to the 5G core network (5GC). This means that 5GC processing speeds will now need to be considered when evaluating the performance of any 5G service. For instance, vehicle-to-everything (V2X) communications need specific time-delay requirements to obtain geolocational data or updates on the status of the next road junction. This type of communication falls under the ultrareliable low-latency communication (URLLC) framework. Enhanced mobile broadband and massive Internet of Things are the other dimensions of 5G that can be identified using standard slice type value. This service-technology association in 5G requires developing new suites of protocols and interfaces to enable ubiquitous efficient connectivity to end users.

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IT IS THE NETWORK SLICING AND SERVICE-BASED SCENARIOS THAT DRIVE 5G DEVELOPERS TO EXPAND THEIR VISIONS AND LOOK BEYOND THE RADIO ACCESS NETWORK TO THE 5G CORE NETWORK.

The 5G system will be an ultradense network (UDN) that deploys a massive number of small cells to utilize spectrum opportunities locally for every single hertz. Considering the large number of cells and physical layer improvements, the 5G network will require an efficient management of resources and operations. Therefore, software-defined networking (SDN) will be an important component for forwarding traffic between the various entities of future networks. To this end, data centers are the platforms that will blend network control with virtual entities for local efficient resource management at different network sites. Thus, it is time to start considering 5G systems as a whole network rather than fragmented technologies. This vision will help researchers fill in the gaps of wireless-system development and meet the goal of establishing a new network that can boost the digital economy and engage the evolution of technology and society.

This is the second issue of the IEEE 5G Initiative series in *IEEE Vehicular Technology Magazine*. The special issues will be published twice a year and cover different 5G development aspects to help the research community gain a better understanding of the latest findings from both academia and industry. This issue has ten articles that address different 5G technologies and approaches.

The first article, "Full-Duplex Communications" by Animesh Yadav, Georgios I. Tsiropoulos, and Octavia A. Dobre, studies interference in single- and multismall-cell networks to evaluate the feasibility of full-duplex communications in 5G networks. The authors provide the state of the art for intracell cochannel interference mitigation techniques and characterize the spectral-efficiency gains for mMIMO and millimeter-wave (mm-wave) technologies.

Following is the article "Low-Latency C-RAN" by Hong Ren, Nan Liu, Cunhua Pan, Maged Elkashlan, Arumugam Nallanathan, Xiaohu You, and

Lajos Hanzo. It invokes an effective capacity theory for statistical-delay-bounded quality-of-service (QoS) provisions in cloud-RAN (C-RAN) architectures. The authors propose sophisticated power allocation schemes for maximizing the effective capacity of both single-user and multiuser scenarios considering C-RANs.

In the article by Ioannis-Prodromos Belikaidis, Andreas Georgakopoulos, Evangelos Kosmatos, Valerio Frascolla, and Panagiotis Demestichas, titled "Management of 3.5-GHz Spectrum in 5G Dense Networks," the allocation of available spectrums in the 3.5-GHz band is addressed and a new mechanism is provided for the dynamic distribution of network resources to different user satisfaction categories.

The subsequent article, "End-to-End Quality of Service in 5G Networks" by Qiang Ye, Junling Li, Kaige Qu, Weihua Zhuang, Xuemin (Sherman) Shen, and Xu Li, provides a comprehensive network slicing framework for E2E QoS provisioning regarding both wireless and wired segments of the network. The authors propose a dynamic radio-resource slicing for the wireless domain and bottleneck-resource generalized processor sharing to minimize the packet-queueing delay for wired domains.

Next is the article "Unveiling Capacity Gains in UltraDense Networks" by Kishor Chandra, Andrea S. Maracano, Shahid Mumtaz, R. Venkatesha Prasad, and Henrik L. Christiansen. Nonorthogonal multiple access (NOMA) technology requires a higher transmission power due to the cochannel interference intentionally added during the transmissions. This article shows that the additional required power can be accommodated using mm-wave directional antennas. The authors present a system-level analysis to verify that directional antennas maintain NOMA capacity with a lower transmission power in UDNs.

The authors Hamidreza Shariatmadari, Sassan Iraji, Riku Jäntti, Petar Popovski, Zexian Li, and Mikko A. Uusitalo in their article "Fifth-Generation Control Channel Design" study URLLC features and introduce enhancements for designing a flexible slot structure that can detect any early-stage delivery failures of control information and perform immediate retransmissions.

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The following article is "Machine Learning for Vehicular Networks" by Hao Ye, Le Liang, Geoffrey Ye Li, Joon-Beom Kim, Lu Lu, and May Wu. This article explores the advantages of employing artificial intelligence in 5G networks and the potential advances they may bring to autonomous driving. The authors review recent developments in machine-learning applications in vehicular networks and provide examples of problem solving through applied machine learning within such networks. The authors also discuss open issues for future research.

The article "Bandwidth Slicing in Software-Defined 5G" by Zhenyu Zhou, Lu Tan, Bo Gu, Yan Zhang, and Jun Wu studies the advantages of time-dependent pricing in regard to heavy multimedia downloading in peak-time traffic. A new framework for unified pricing is proposed to address the on-demand bandwidth slicing problem in 5G SDN networks.

In the next article, "Heterogeneous Ultradense Networks with NOMA" by Zhengquan Zhang, Guang Yang, Zheng Ma, Ming Xiao, Zhiguo Ding, and Pingzhi Fan, cloud-fog computing is used to achieve efficient computing-resource management. The authors also explore virtual resource coordination through the use of a hybrid UDN with an integrated RAN operating with NOMA technology.

In the last article, "Trusted 5G Vehicular Networks," Victor Ortega, Faîza Bouchmal, and Jose F. Monserrat explore the emerging technology of blockchains and the requirements for content-centric networking in sliced networks. They also study the dynamic control of blockchains to maintain the reliability of the source and the integrity and validity of the information exchanged in V2X networks.

Author Information

Anwer Al-Dulaimi (anwer.al-dulaimi@exfo.com) received his Ph.D. degree in electrical and electronics engineering from Brunel University, London, in 2012. He is a system engineering specialist in the Research and Development Department at EXFO Inc., Toronto, Canada. He has been awarded many grants by the Wireless World Research Forum (WWRF), and the IEEE Standards Association. He has published many academic papers and has been granted the IEEE/WWRF Vehicular Technology Magazine Best Paper Award three times. He received the 2013 Worldwide Universities Network Cognitive Communications Consortium Best Paper Award for his edited book *Self-Organization and Green Applications in Cognitive Radio Networks*. He is an associate fellow of the British Higher Education Academy and was registered as a chartered engineer by the British Engineering Council in 2010. He is an editor of *IEEE Communication Standards Magazine*, *IEEE Communications Magazine*, and *IEEE 5G Tech Focus*, and he is a guest editor for many special issues in IEEE journals. His research interests include fifth-generation wireless systems, with a special focus on dynamic spectrum access, cloud networks, and the Internet of Things. He is the chair of IEEE 1932.1 working group "Standard for Licensed/Unlicensed Spectrum Interoperability in Wireless Mobile Network."

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