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Signal Processing for the 5G Revolution

Cellular communication systems are continuing to incorporate advanced signal processing techniques. Third-generation cellular systems are already widely deployed and are being followed by fourth-generation (4G) systems. Since 4G cellular technology development is considered to have concluded in 2011, the attention of the research community is shifting toward what will be the next set of innovations in wireless communication technologies that are now broadly known as fifth-generation (5G) technologies.

Given a historical ten-year cycle for every generation of cellular advancement, it is expected that networks with 5G technologies will be deployed around 2020. While 4G standards were designed to meet requirements issued by the International Telecommunication Union-Radio, no definition for 5G is currently available. Experts vary in opinion whether the next generation of cellular networks will continue to enhance (peak) service rates further, focus on spectral efficiency enhancements, or move to newer metrics such as energy efficiency, cost- and utilization-efficiency, or even define new metrics around service quality experience. There is also the possibility that 5G will enable digital sensing, communication, and processing capabilities to be ubiquitously embedded into everyday objects, turning them into the Internet of Things (IoT) or machine-to-machine (M2M). In this new paradigm, smart devices will collect data, relay the information or context to each other, and process the information collaboratively over the 5G cellular networks. No matter what the eventual metric or system, it is certain that signal processing will play an important role in the features that define 5G.

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This issue of *IEEE Signal Processing Magazine* (*SPM*) provides an overview of recent advances in signal processing for communication with an emphasis on signal processing techniques that will be relevant for 5G cellular systems. It covers a wide range of topics including modulation, beamforming, cross-layer optimization based on different performance metrics, location-aware communication, cloud computing, and cloud radio access networks. The articles provide a diverse perspective on the potential challenges in 5G cellular systems.

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The first set of articles addresses challenges related to the optimization of 5G systems.

The article by Björnson et al. considers the problem of operating a 5G system with conflicting performance metrics including higher peak rates, improved coverage with uniform user experience, higher reliability, lower latency, and better energy efficiency. The authors review a mathematical framework known as multiobjective optimization that can be used to solve problems with multiple competing objectives. The article concludes with an example application to massive multiple-input, multiple-output (MIMO) systems.

Cavalcante et al. consider optimizations related to energy efficiency, arguing that reducing the transmit energy per bit may increase the total energy consumption in the network. Traffic patterns and interference calculus are used to suggest algorithms for energy efficiency. The article concludes with a detailed example where an interference calculus approach is used to adaptively select a subset of active base stations based on prior traffic history, using the majorization–minimization algorithm.

The second set of articles addresses challenges related to cloud computing and cloud radio access networks.

The article by Wübben et al. reviews the benefits that cloud computing can offer in 5G cellular networks. Signal processing issues related to the cloud implementation of three representative parts of the signal processing chain are described in detail: hybrid automatic repeat request, forward error correction, and multiuser detection.

In the article by Barbarossa et al., the authors approach cloud computing from the perspective of offloading computations. They provide a mathematical formulation of a computation offloading problem aimed at jointly optimizing the communication and computation resources subject to latency and energy constraints. They consider computation offloading strategies and different ways to jointly optimize communication and computation resources.

Baligh et al. look at cloud computing from the perspective of interference management and network provisioning. They propose a cross-layer optimization framework for joint user admission, user base station association, power control, user grouping, transceiver design as well as routing and flow control, suggesting that they should be treated in a unified way for 5G networks.

Park et al. consider the topic of fronthaul compression for cloud radio access networks. The fronthaul is the connection between remote radio heads and the centralized control unit with cloud computing technology. This article surveys work on fronthaul compression, especially multiterminal compression and structured coding, leveraging insights derived from network information theory.

The third set of articles focuses on more traditional physical-layer signal processing techniques relevant to 5G cellular systems.

The article by Banelli et al. considers the topic of modulation, speculating that 5G may employ another modulation strategy besides orthogonal frequency-division multiplexing. It reviews other competing modulation strategies including filter bank multicarrier, faster-than-Nyquist/time-frequency packing, and single-carrier modulations. The article concludes with a review of the potential interactions between the choice of modulation and other 5G requirements: high data rates, small cells, IoT, low latency, and energy efficiency.

Razavizadeh et al. examine a multiple antenna technique known as three-dimensional beamforming, where antenna elements in both horizontal and vertical directions are used. It reviews the concepts of two- and three-dimensional beamforming and discusses various challenges including channel modeling and array design.

The final article by Di Taranto et al. considers how 5G networks might benefit from precise location information at different layers of the protocol stack. Different applications of location are discussed including radio channel prediction and the ways that it can be used at the physical, medium access control, and higher layers.

In summary, we received many contributions in response to the call for papers of this special issue. Based on relevance and fit, many high-quality papers were not invited for full-paper submission. We would like to express our appreciation to all the authors who submitted white papers and full articles to this special issue. We would also like to thank all the reviewers who provided critical reviews of the diverse set of papers that we received. Finally, we would like to acknowledge Abdelhak Zoubir, *SPM's* editor-in-chief, who was very supportive of our issue, and Fulvio Gini, the special issues area editor who provided assistance and encouragement along with countless reminders, and, of course, Rebecca Wollman for her assistance with the entire process. We hope that you will enjoy the articles in this special issue of *SPM*.

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