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Editorial

5G Communications: Energy Efficiency

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As the era of 5th Generation (5G) networks is dawning, several pertinent issues associated with the ambitious improvements that have to be achieved in future communications are attracting increasing research attention, including the following: scalability, throughput, capacity, end-to-end delay, heterogeneity of requirements, and security. Nonetheless, 5G technologies should also become key enablers for the environmental sustainability of modern societies, as is happening in the case of other frameworks and initiatives such as Smart Cities, Smart Grids, and the Internet-of-Things. Hence, energy efficiency should be treated as an integral part of all proposed 5G solutions and technologies.

The goal of energy efficiency, apart from its ecological value, is also associated with the reduction of operational expenses for mobile network operators, as well as with greater customer satisfaction thanks to increased battery life. At present, however, it is not clear how 5G network technologies, as they are mostly focused on higher bandwidths and are expected to be deployed as an overlay on top of (rather than a replacement of) preexisting network equipment, could bring forward a reduction in power consumption.

To promote basic and applied research in this important field of energy efficiency in 5G, we invited investigators from around the globe to contribute original research articles as well as review articles that will stimulate further efforts to explore energy efficiency trade-offs and achieve energy savings in 5G. In this special issue, we focus on recent advances that bring about considerable energy efficiency benefits in 5G communications and networks.

In the article "Limiting Energy Consumption by Decreasing Packets Retransmissions in 5G Network," L. Apiecionek focuses on the exploitation of the Multipath Transmission Control Protocol (MPTCP), together with fuzzy logic techniques, so as to limit energy consumption in 5G network infrastructures. MPTCP can be used in conjunction with Multiple-Input Multiple-Output (MIMO) transmitter/receiver systems or on its own, and although it is not widely used today, it is gaining traction in the research community, mainly for its ability to provide more reliable connectivity and higher throughput. The author presents the idea of coupling the use of MPTCP with a specially designed fuzzy logic technique for transmission control. The employed technique is an adaptation of the less-known generalized fuzzy logic method called Ordered Fuzzy Numbers (OFN), a concept developed by Kosiński and his coworkers, allowing the association of the change of trend to a fuzzy number. The outcome is a novel MPTCP scheduler powered by an OFN-enabled decision support system, permitting fuzzy observation of transmission errors. Using data transmission simulations, the scheduler's performance is validated in terms of destination reachability and network reliability. Furthermore, the author analyzes the effect of the proposed solution on energy consumption. The major strength of the presented algorithm is that it achieves high performance without requiring complex calculations, meaning that it is lightweight enough so that it does not cause significant power dissipation. In parallel, the proposed algorithm allows reducing the number of retransmissions, as fewer packets are transferred over the unreliable connection links, leading to increased energy efficiency in the entire system. This is because, for a complex communication network, such as 5G, the process of data transmission is power-consuming not only for the sender device, but also for the entire ecosystem (comprising numerous devices, including transmitters, switchers, and routers). As articulated, in the case of a retransmission, the data are sent twice, and, moreover, additional signaling overhead takes place. Hence, avoiding retransmissions through lightweight decision-making algorithms is essential for achieving better power management in 5G networks.

Accurate classification of network traffic is essential for emerging 5G network applications. Recently, a number of researchers have proposed machine learning models to find out the effective packet number for classification of Internet traffic at early stage. However, this problem is still unsolved. To reach a solution, in the article "Effective Packet Number for 5G IM WeChat Application at Early Stage Traffic Classification," M. Shafiq and X. Yu study the WeChat Instant Messaging (IM) application (which supports text messages, picture messages, audio call, and video call traffic) and use five Internet traffic datasets. They consider packet sets of 2–20 packets and then carry out an information analysis to identify the mutual information of each packet flow type. Thereafter, M. Shafiq and X. Yu examine ten well-known machine learning algorithms using the twofold cross-validation method. According to the experimental results, M. Shafiq and X. Yu conclude that the nonzero payload packets carry enough identification information to perform traffic classification in WeChat Instant Messages and that the packet numbers 13–19 are effective for 5G WeChat application traffic identification. The results of the machine learning classifiers analysis reveal that the most effective machine learning classifier at the early stage of Internet traffic classification is the Random Forest classifier. Nevertheless, the authors emphasize that there are still open issues for further research in the area, in particular for the development of methods for optimizing the selection of effective packet numbers in 5G network traffic classification.

5G communication networks are characterized by a number of new features, such as millimeter-wave frequencies, massive antenna arrays, beamforming, and dense cells. In the article "Performance Evaluation of 5G Millimeter-Wave Cellular Access Networks Using a Capacity-Based Network Deployment Tool," M. Matalatala et al. investigate the use of beamforming techniques through various architectures and evaluate the performance of 5G wireless access networks, using a capacity-based network deployment tool. The application of the deployment tool is carried out in a realistic setting (in Ghent, Belgium), in which a realistic 5G network is simulated to support bitrate values corresponding to actual user requirements. Subsequently, the 5G network performance with and without beamforming is analyzed, particularly in comparison with a 4G reference scenario. The key finding is that the 5G network with beamforming consumes 4 times less power in comparison to the 4G reference network, while achieving higher capacity and the same coverage performance. On the other hand, it requires 15% more base stations to be deployed. The authors explain that there is a need for finding a balance between increasing performance and reducing power consumption. This challenge can be addressed by application of the hybrid beamforming architecture that is comparable to the digital beamforming architecture (in terms of performance parameters) and requires about two times less power consumption.

The article "An Energy-Efficient Scheme for Multirelay Cooperative Networks with Energy Harvesting" by D. Yang et al. considers the usage of an energy-efficient scheme in multirelay cooperative networks with energy harvesting where multiple sessions need to communicate with each other via the relay node. The authors decompose this complex problem into a power allocation problem and an energy-efficient transmission optimization problem and introduce a two-step approach. In the first step, the optimal power allocation for relay nodes is determined, based on the directional water-filling algorithm with the aim of maximization of the system throughput. In the second step, the joint optimization of relay node selection and session grouping is proposed based on quantum particle swarm optimization (QPSO). The authors present the reference network model including the throughput and power-consuming models employed for further examination and validation of their method. According to the numerical results, the proposed scheme is a promising solution for improving the energy efficiency in comparison to direct transmission and opportunistic relay-selected cooperative transmission.

In the article "Energy Efficiency Maximization of Full-Duplex and Half-Duplex D2D Communications Underlaying Cellular Networks" by Y. Cheng et al., the authors investigate the issue of energy efficiency maximization for the systems providing full-duplex device-to-device (D2D) communications in cellular networks. The authors consider a full-duplex D2D communication scheme with uplink channel reuse and compare it with the half-duplex counterpart, to determine which mode is more energy-efficient. The second goal is to find the optimal transmission power levels to maximize the system energy efficiency with respect to the required signal-to-interference-plus-noise ratios (SINRs) and transmission power constraints. To solve this optimization problem, a game-theoretic approach is employed and the iterative bisection-alternate method with lower complexity is proposed. According to the simulations performed, the authors find that the passive suppression (PS) full-duplex scheme (i.e., with passive suppression self-interference mitigation scheme used) can outperform the half-duplex mode in terms of energy efficiency, in particular for short distances between user devices. Moreover, the full-duplex passive suppression and digital cancellation (PSDC) communication mode is more energy-efficient than the plain PS full-duplex. Experimental results show that, under the more advanced self-interference mitigation techniques of PSDC, the full-duplex D2D mode can achieve 36% increase of energy efficiency comparing to the half-duplex D2D mode with a short distance of devices pair.

In the article "Strategic Control of 60 GHz Millimeter-Wave High-Speed Wireless Links for Distributed Virtual Reality Platforms" by J. Kim et al., the authors focus on the stringent requirements of wireless communication between a virtual reality (VR) server and VR head-mounted devices. They propose a strategic and stochastic queue control algorithm to minimize the time-average expected power consumption subject to queue-stabilization, assuming mmWave wireless communication links and, in particular, 60 GHz (IEEE 802.11ad) wireless channels. As noted by the authors, there is a trade-off relationship between queue-stabilization and energy efficiency, so that achieving higher queue stability points (useful for time-critical VR video contents) requires more energy. A future challenge is how to automatically set appropriate values for tuning the power-delay (queuing-delay) trade-offs.

In conclusion, as evident from the high-quality articles that we received, energy efficiency is a research field in 5G that will gain significant attention over the coming years. Studies reveal that important energy efficiency trade-offs exist in the operation of 5G systems, and the design of any optimization algorithm should not be agnostic of such trade-offs. Moreover, the articles we received cover a large range of aspects and advanced techniques; investigators have a large spectrum of choices and promising approaches to explore in the future. The range of proposed solutions that this special issue offers to its readers includes MPTCP schedulers, fuzzy logic decision support engines, machine learning classifiers, hybrid beamforming, device-to-device communication with self-interference mitigation, multirelay cooperative networks with energy harvesting based on quantum particle swarm optimization, and stochastic queue control algorithms. 5G is going to combine a very interesting blend of heterogeneous and highly advanced technologies, and this pluralism is certainly for the benefit of both the scientific community and the society as a whole.

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