Guest Editoral
Signal Processing Advances in Wireless Transmission of Information and Power

WIRELESS POWER TRANSFER (WPT) and wireless information and power transfer (WIPT) have received growing attention in the research community in the past few years. In this special issue, a total of fourteen papers present state-of-the-art results in the broad area of wireless transmission of information and power with a special emphasis on signal processing advances.

The special issue starts with a guest editor-authored tutorial overview paper that reviews the signal processing, machine learning, sensing, and computing techniques, challenges and opportunities in future networks based on WPT and WIPT. The tutorial paper is then followed by thirteen technical papers.

The tutorial overview paper first reviews recent signal processing techniques to make WPT and WIPT as efficient as possible. Topics include high-power amplifier and energy harvester nonlinearities, active and passive beamforming, intelligent reflecting surfaces, receive combining with multi-antenna harvester, modulation, coding, waveform, large-scale (massive) multiple-input multiple-output (MIMO), channel acquisition, transmit diversity, multi-user power region characterization, coordinated multipoint, and distributed antenna systems. Then, the paper looks at two different design methodologies: the *model and optimize* approach relying on analytical system models, modern convex optimization, and communication/information theory, and the *learning* approach based on data-driven end-to-end learning and physics-based learning. The pros and cons of each approach are discussed. Finally, the paper identifies new emerging wireless technologies where WPT may play a key role—wireless-powered mobile edge computing and wireless-powered sensing—arguing WPT, communication, computation, and sensing must be jointly designed.

Next, thirteen technical papers are presented.

Yu *et al.* take simultaneous information and energy transmission into the air, making use of intelligent reflecting surfaces on both UAVs and ground building to enhance the wireless channel and facilitate greater information rates. The basic mathematical problem is to jointly optimize power splitting ratio, transmit beamforming, phase shifts, and trajectories of UAVs. Efficient algorithms and results are given initially for perfect channel state information but then extended to the practical setting of statistical channel state information.

Malik and Vu have designed a multi-access edge computing (MEC) system powered by wireless charging. Specifically, the operations of wireless charing and computation offloading are jointly designed to minimize the sum mobile energy consumption. The design is formulated as a problem of jointly optimizing data partitioning, time allocation, transmit power control, and energy beamforming under the constraints on latency and server power. Solving the problem has yielded a resource allocation scheme outperforming the conventional designs.

Wang and Zhang have proposed a distributed data off-loading and resource allocation scheme for the ambient backscatter (AB) communication, through which mobile users (MUs) accessing nearby WiFi access points can backscatter ambient RF signals for data transmission. Then, they consider the WiFi-offloading and resource-allocation by adopting the concurrent AB transmission, based on which multiple MUs can backscatter data concurrently using the AB communication, leading to a further reduction in the energy consumption. Moreover, the long-range bistatic backscatter communication is also employed to support the data transmission between MUs and the cellular base stations, through which MUs can convey data by backscattering RF signals from dedicated carrier emitters.

Chu *et al.* have proposed a scheme to enhance the throughput of a wireless-powered wireless sensor network. The architecture considers an energy station (ES), an access point (AP), some wirelessly powered sensors, and finally, an intelligent reflecting surface (IRS). The IRS supports the wireless energy transfer (WET) from the ES and the uplink to the AP by operating at energy-then-harvest mode. The obtained results demonstrate the effectiveness of the proposed policy and validate the beneficial role of the IRS in comparison to some benchmark schemes.

Luo *et al.* have studied the simultaneous wireless information and power transfer (SWIPT) system using the power splitting scheme. Markov chains were used to model both power and information outages for two cases: with and without storage. Hardware experiments and numerical results have demonstrated the validity of the proposed model and have confirmed a new solution offering the optimal splitting ratios under different signal and channel conditions.

Monteiro *et al.* have studied a WPT system equipped with a large antenna array at the base station that charges a large number of devices. The challenge is to maximize the total energy at the devices by optimizing the transmit precoders using only the statistical knowledge of the channel, for instance in the form of the first and second order statistics. This can find applications in the presence of a large number of low power devices for which acquiring accurate instantaneous channel state

Digital Object Identifier 10.1109/JSTSP.2021.3095601

information would be too challenging. Results are supported by numerical evaluations.

Mukherjee *et al.* have investigated a chaotic waveform-based WPT architecture that employs an analog correlator at the receiver in order to boost the energy harvesting performance. The analysis accounts for nonlinearities of the harvester and demonstrates that the energy harvesting performance depends on the chaotic waveform parameters. Numerical evaluations confirm the benefits of chaotic waveforms for WPT.

Abeywickrama *et al.* have studied the optimization of waveform for WPT from a multi-antenna energy transmitter to multiple single-antenna energy receivers in frequency selective channels. They have refined the modeling of the rectifier nonlinearity and used it to optimize multisine waveform for single user and multiuser scenarios. Simulations demonstrate the benefits of the refined model and the optimized waveforms.

Kwon *et al.* have studied a wideband millimeter wave SWIPT downlink system where the transmit power allocation, beamforming, and receive power splitting are jointly designed. The proposed scheme relies on the limited feedback of channel information. The authors have analyzed the rate-energy region of the proposed millimeter wave SWIPT system and demonstrated the performance by simulations.

Garg *et al.* have considered a two-way relay system with multiple transmitters and receivers utilizing simultaneous wireless information and power transfer (SWIPT). For a system utilizing amplify and forward (AF) relaying technique, the paper designs precoders and decoders to minimize the minimum mean squared error (MMSE). The paper studies the rate-energy trade-off using chordal distance (CD) decomposition.

Tan *et al.* have considered multi-group multi-casting transmission in cloud radio access networks (C-RANs) with simultaneous wireless information and power transfer (SWIPT), where remote radio heads (RRHs) cooperatively provide information and energy services for information users (IUs) and energy users (EUs), respectively. The paper considers the problem of joint beamforming in order to maximize information rates. The focus of the paper is on converting the non-convex optimization problem into a sequence of convex problems.

Kim *et al.* have considered the power allocation problem to maximize the achievable sum rate under imperfect channel state information (CSI), by using a reinforcement learning (RL) approach in an energy harvesting system. In order to reduce the computational cost, which is necessary in low-energy energy-harvesting systems, this paper uses a shallow RL architecture as opposed to the conventional deep RL architecture. The paper studies the optimal structural properties pertaining to the optimal power allocation policy, and finds the partial monotonicity and bounds of the policy and value function.

Zhang *et al.* have considered a wireless communication system and have utilized several techniques, such as, massive MIMO (m-MIMO), cell-free (CF) access, simultaneous wireless information and power transfer (SWIPT), finite block length (FBL) communications, to achieve massive ultra-reliable and low-latency (mURLLC), time-sensitive communications relevant for future communication systems. The paper finds the tradeoff between effective capacity and amount of harvested energy.

The tutorial paper and the thirteen papers in this special issue provide an overview of the state-of-the-art as well as new results in the broad area of WIPT. The breadth of the topics reported in this issue demonstrates the interest of the community in this active research area. It is our hope that this special issue will stimulate and encourage further research in the broad area of wireless transmission of information and power.

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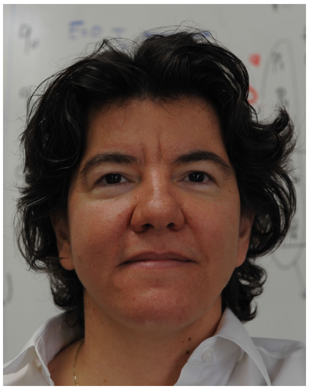

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