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# Editorial: Towards 6G Technologies, Networks, Hardware, and Architectures

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5G is going to be launched, becoming a commercial reality with far-reaching benefits. Building on the successful steps of 5G, 6G is envisaged go beyond the three major pillars of 5G, i.e., enhanced mobile broadband (eMBB), ultra-reliable and low-latency communications (URLLC), and massive machine-type communication (mMTC), to reach the revolution of ubiquitous intelligence of everything. In the 6G era, the physical, cyber, and biological worlds are intelligently connected throughout the so-called societal digitalization which enables an entire transformation from connected people and things to connected sense and intelligence. In this context, achieving the ultimate user experience in all applications and services requirements, 6G needs to provide a disruptive set of KPIs and goals such as peak rate (1Tbps), experienced data rate (10-100Gbps), capacity (1000X w.r.t. 5G), location precision (50 cm outdoor and 1 cm indoor), user plane latency (0.1 ms), reliability (nine 9's), connection density (10millions/km$^2$), energy and cost efficiency (100X w.r.t 5G), coverage (10 dB gain w.r.t. 5G), battery life (20 years for sensors), etc.

Reaching the aforementioned KPIs and goals, which represents challenging tasks for 6G, is in turn calling for the introduction of new efficient groundbreaking solutions. To date, the solutions to address the challenges of 6G can be grouped into four main areas including new spectrum technologies, AI and ML networks, innovative hardware designs, and emerging network architectures, which will get the numerous research threads involved in the 6G roadmap to 2030. Following the key solutions, designing the technologies, networks, hardware and architectures, that represent challenging goals, is strongly fostered. Obviously, applying digital twins to simulating and pairing the physical, cyber, and biological worlds can accelerate the design phase to identify the difficulties in advance, but requiring the real-time integration of communications and sensing techniques. Therefore, there is an urgent need for conducting state-of-the-art researches, prototypes, and simulations towards 6G technologies, networks, hardware, and architectures.

To overcome the challenges of 6G, this special issue focuses on (but are not restricted to) the following topics: Analog and digital IC design; RF/THz electronics for sensing/imaging; Multi-band/multi-purpose circuits; AI-assisted circuit design; Digital Twin for 6G networks; Autonomous systems and various interconnected 6G networks; Sub-millisecond latency, high reliability and time-sensitive designs in 6G networks; Vertical services and applications for digitized society of tomorrow; High accuracy localization and high-resolution sensing services in 6G networks; Machine learning in 6G networks; Trust, security and privacy in 6G networks; 6G technologies, services and applications for smart cities; Edge intelligence for 6G networks; Terahertz communications and networks; Massive connectivity in communication systems; 6G integrated satellite and terrestrial networks; UAV-ground and UAV-to-UAV communications; 3D beamforming for cellular-connected UAVs; UAV-aided eMBB +, mMTC +, URLLC +; UAV swarm in 5G and beyond; Massive MIMO/Millimeter wave communications for cellular-connected UAVs; Quantum communications for 6G.

The special issue includes five high-quality papers. In the first paper entitled "Hardware-based Satellite Network Broadcast Storm Suppression Method", the authors have considered a severe situation of satellite networks in which multitudinous loop links may cause broadcast storms. In this situation, the broadcast packets keep propagated along the loops paralyzing the satellite networks. To address this

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problem, a hardware-based method is proposed to mitigate the storms by selectively suppressing the redundant broadcasts. While the conventional method, namely minimum spanning tree (MST) algorithm, introduces higher forwarding latency and low bandwidth utilization, the proposed method is much better by not only judging each broadcast packet one by one, preserving the bandwidth of all valid links, and eliminating the need to record the information about neighbor-nodes or updating the global information, but also adopting the pipeline processing mode. As a result, by incorporating a time-stamp recording function, memory polling function, and storm detection function using Simple Dual RAM, the proposed method significantly reduces the redundant transmissions while conserving the network resources with higher bandwidth utilization compared to the MST algorithm.

The second paper studies a secure uplink non-orthogonal multiple access (NOMA) Internet of Things (IoT) system using an energy harvesting (EH) unmanned aerial vehicle (UAV). In this system, a relay UAV (RU) and IoT devices (IDs) harvest the radio frequency energy from a base station (BS). The IDs transmit the information to the RU for being forwarded to the BS in the presence of an eavesdropper UAV (EU). The authors derive the closed-form outage and intercept probabilities for secrecy performance evaluation. A random-cut continuous genetic algorithm is applied to minimize the outage probability under the security constraints and create the training data. Based on the training data, a deep learning (DL) model is designed to predict the optimal working parameters that can adapt to the rapid changes of environmental parameters in reality. The results in terms of analysis, simulation, and accuracy are discussed to validate the system formulations and the feasibility of the DL model.

In the third paper, many emerging techniques have been integrated into mobile edge computing (MEC) networks. Particularly, the authors studied a RF power station, a simultaneous transmitting and reflecting reconfigurable intelligent surfaces (STAR-RIS) mounted on the building, the UAV with NOMA assisted, two access points (APs) acting as MEC servers. The RF power station transfers the wireless power to the UAV so that it can apply NOMA to offload the tasks to the APs via the STAR-RIS. The approximate closed-form expressions for successful computation and energy outage probabilities are derived by using the statistical characteristics of channel gains for system performance evaluation. Furthermore, a real-coded genetic algorithm is used to find the optimal resource parameters to maximize the system performance. The detailed analysis and discussion enable us the understand the behaviors of system with respect to time switching ratio, transmit power, power allocation coefficient, data dividing ratio, number of elements of STAR-RIS, and altitude of the UAV. The paper also provides the insightful and useful investigations for designing a powerful MEC network assisted by UAV with energy harvesting, STAR-RIS, and NOMA techniques.

As fractal antennas have emerged as a promising solution and played an important role in the evolution of wireless communication technologies, the authors in the fourth paper have provided a comparative analysis of fractal antennae for sub-6 GHz and 5G bands in wireless and IoT applications. The advantages of unique geometric structures, miniaturization, multiband operation, and enhanced radiation characteristics together with artificial neural networks, optimization algorithms, and resonators have leveraged to design the compact, efficient, and versatile antennas across various applications in 6G networks. This paper has provided a comprehensive analysis of fractal antennas designed by using IE3D. The proposed antennas are with a height of 1.6 mm for use in multiple bands with the gain increased up to 5 dBi. The designed quad-band antenna has commendable matching results, as verified by VNA, with bandwidths ranging from 2.1 GHz to 2.3 GHz, 2.8 GHz to 3.1 GHz, 3.6 GHz to 4.6 GHz, and 7.1 GHz to 7.9 GHz, while exhibiting higher radiation levels at fundamental frequencies (2.2 GHz, 2.92 GHz, 4.1 GHz, and 7.5 GHz) and concentrated current distribution in slots with maximum radiation emission. The proposed antennas are investigated to demonstrate the suitability, compatibility, compact size, and robust performance for S-band, X-band, C-band and even beyond 5G (B5G)-band applications.

In the last paper, a survey on smart optimization techniques for 6G-oriented integrated circuits design is presented. It is certain that integrated circuit (IC), especially the sizing phase of analog IC design, is one of the important aspects for the full roll-out 6G technology. The objective is to make the IC design process much faster with automated approach. This paper provides a recent research on analog IC design optimization, the fundamental concepts of formulating the optimization problems from analog IC requirements, and the state-of-the-art methods for solving such an analog IC sizing optimization problem. A comparison between analytical-based and simulation-based methods has been investigated to show that the later methods including Bayesian-based, metaheuristic-based, and reinforcement-learning-based approaches have become prevalent alternatives to the traditional analytical ones. Aiming to provide insights on the utilization of optimization algorithms for the IC sizing process, the authors introduced various metaheuristic algorithms to design a bandgap reference circuit, i.e., an essential analog IC component. The potential future research directions, e.g., multi-agent RL or quantum computing applications to address the curse of dimensionality problem effectively, are discussed in detail to fulfill the smart optimization techniques in 6G-oriented IC design.

In summary, the special issue has presented many disruptive solutions for 6G technologies, networks, hardware, and architectures ranging from the broadcast storm suppression, NOMA, energy harvesting, STAR-RIS, fractal antennae for sub-6 GHz and 5G/B5G bands, IC design to the advanced optimization solutions, for 6G satellite, MEC, and IoT networks. Although it is challenging for covering all the topics and overcoming the 6G problems and requirements, the works in this special issue have contributed in filling the key research gap within the literature of the emerging field of 6G technologies, networks, hardware, and architectures.

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