Internet of Things and Next Generation Wireless Communication Systems

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Next generation wireless communication systems will connect billions of Internet of Thing (IoT) devices and user elements along with billions of people, enable machine-to-machine communications across heterogeneous and dynamic environment, and provide low-latency computing and storage resources on demand at the deep edge as well as in the cloud. Tremendous research and development efforts have already been emphasized on the enabling technologies toward next generation wireless systems to support a variety of critical and personalized services in multiple application domains, including industry use cases, environment, transportation, education, public health and safety, and defense. Wireless communication networks have been greatly advanced by exploiting technologies such as millimeter wave, dynamic spectrum sharing, massive MIMO, beam forming, network slicing and virtualization, and artificial intelligence and machine learning. These technology breakthroughs can empower wireless networks to support extreme high capacity, massive connectivity, and ultra-low latency communications for new use cases identified for next generation wireless systems. In order to design and deploy wireless communication systems with IoT devices across heterogeneous and dynamic environments to provide next generation wireless services, however, there are many critical technical challenges yet to be addressed. In this issue of *IEEE Wireless Communications*, we are pleased to present two feature topics to bring together researchers, industry practitioners, and individuals working on the related areas to address some of these technical challenges for IoT and next generation wireless systems. One feature topic on "Massive Machine-Type Communications for IoT" includes four articles, and was organized by guest editors W. Ji, T. Ebrahimi, Z. Li, J. Yuan, D. O. Wu, and Y. Xin; the other feature topic on "Emerging Visual IoT Technologies for Future Communications and Networks" includes six articles, and was organized by guest editors L. Liu, E. G. Larsson, P. Popovski, G. Caire, X. Chen, and S. R. Khosravirad. Thanks to the two guest editor teams who did an excellent job in editing these two feature topics for our readers. Please stay tuned for new developments in the research area of IoT and next generation wireless communications and read the editorials and the papers in the feature topics.

In this issue, we are also very glad to present 15 articles accepted from the open call.

The first article, "Single-RF MIMO: From Spatial Modulation to Metasurface-Based Modulation" by Q. Li *et al*., proposes the idea of designing single-RF MIMO systems based on RISs. After revisiting the principle of spatial modulation (SM), the authors present some representative SM-based implementations. Based on the principle of RISs, they discuss some examples of metasurface-based single-RF MIMO. They further make a comparison between antenna-based and metasurface-based modulation and evaluate the BER performance. Finally, they discuss the challenges and opportunities of metasurface-based modulation. The authors show that metasurface-based modulation provides a competitive alternative to antenna-based modulation for single-RF MIMO design.

The second article, "A Vision of Self-Evolving Network Management for Future Intelligent Vertical HetNet" by T. Darwish *et al*., introduces a new framework of "self-evolving networks (SENs)", which utilizes artificial intelligence, enabled by machine learning algorithms, to make future integrated networks fully automated and intelligently evolve with respect to provision, adaptation, optimization, and management aspects of networking, communications, computation, and infrastructure mobility of nodes. To envisage the concept of SEN in future integrated networks, the authors use the Intelligent Vertical Heterogeneous Network architecture as the reference. The paper discusses five prominent scenarios where SEN plays the main role in providing automated network management. Numerical results provide an insight into how the SEN framework improves the performance of future integrated networks.

In the third article, "Advancements in 5G New Radio TDD Cross Link Interference Mitigation", K. Pedersen *et al*. present several enhancements that further improve the performance of 5G New Radio time division duplex (TDD) operation and performance. The focus is on mechanisms to mitigate cochannel cross link interference (CLI) between neighboring cells, providing pointers also to recent advances in remote interference mitigation between cells separated by tens to hundreds of kilometers. A new framework where user equipment is used as sensors detecting CLI problems is outlined, and the underlying design rationales are presented. The authors show that using reinforcement-learning is a promising solution, which offers attractive performance benefits over known TDD adaptation solutions.

In the fourth article, "Wireless Channel Sparsity: Measurement, Analysis, and Exploitation in Estimation", R. He *et al*. present measurement based channel sparsity analysis and estimation. The work focuses on evaluating whether realistic channel is sparse and how the degree of channel sparsity changes in real propagation environments. The data measured in a vehicular urban scenario are used, which include rich degrees of MPC richness. Considering the challenges of accurately measuring channel sparsity, three indicators of DoF, diversity measure, and the Ricean K factor are used to evaluate channel sparsity jointly. The LS and OMP based channel estimations are conducted using the measurement data, representing sparse and non-sparse channel estimations, respectively.

In the fifth article, "A Vision on 6G-Enabled NIB: Requirements, Technologies, Deployments and Prospects", P. P. Ray *et al*. present a visionary augmentation of 6G network-in-a-box (NIB) on top of vital aspects, such as key requirements, technological aspects, use cases, deployment schemes, variants, and open research issues and future directions. The authors demonstrate that 6G-NIB would become feasible, reliable and resilient upon true comprehension of earlier aspects. They recommend that applications related to industry 4.0 might benefit from 6G-NIB when proper connectivity features are sought.

In the sixth article, "Extensive Edge Intelligence for Future Vehicular Networks in 6G", W. Qi *et al*. propose an intelligent service-oriented edge resource management architecture, which makes full use of knowledge extracted from a large amount of sensory data in vehicular networks. As a case study, the authors propose a prediction-based edge resource activation method under this architecture, where resources of parked vehicles are activated based on the predicted user density. Simulation results demonstrate that the prediction model has high accuracy. The prediction-based resource activation approach can reduce deployment cost.

In the seventh article, "Orthogonal Time-Frequency Space Modulation: A Promising Next-Generation Waveform", Z. Wei *et al*. introduce a recently proposed two-dimensional modulation scheme, orthogonal time-frequency space (OTFS) modulation, which accommodates the channel dynamics via modulating information in the delay-Doppler domain. The authors provide an overview of OTFS, highlighting its underlying motivation and specific features. The critical challenges of OTFS and the preliminary results are presented. They also discuss a range of promising research opportunities and potential applications of OTFS in 6G wireless networks.

In the eighth article, "Blockchain and Artificial Intelligence for Dynamic Resource Sharing in 6G and Beyond", S. Hu *et al*. propose a blockchain and AI-empowered dynamic resource sharing (DRS) architecture, where blockchain is used to achieve the functionalities in DRS with improved distribution, security, and automation. AI is implemented to improve the performance of pattern recognition and decision-making in DRS. A case study where dynamic spectrum sharing is implemented within the proposed architecture, and deep reinforcement learning is used and shown to optimize the profit ratio of the users.

In the ninth article, "Artificial Intelligence for Smart Resource Management in Multi-User Mobile Heterogeneous RF-Light Networks", Z.-Y. Wu *et al*. present some new insights into the implementation of realistic indoor mobile optical channels and the impact of crowd mobility on relevant channel statistics. An AI-based framework for efficient resource management in mobile multi-user RF-light HetNets is proposed using a deep learning-empowered optical link predictor and a multiagent reinforcement learning-based link assignment strategy. The proposed AI-based framework helps to lay down the foundations of smart resource management in mobile multi-user HetNets

In the tenth article, "Online Truthful Mechanism Design in Wireless Communication Networks", G. Li *et al*. present several popular online truthful mechanism design methods and the corresponding potential applications in wireless communication networks. The primal-dual based method is best applicable to the scenario where the optimized objective is linear, while the time slotted method is a superior choice when the bidders are not delay-sensitive. If a prior distribution on bidders' valuations can be obtained, the Myerson-based method is preferred for designing revenue maximization online truthful auction. Otherwise, the random-based method is an alternative. The matching-based method is a generic framework, which can be tailored to any specific double online auction problem.

In the eleventh article, "A Blockchain-Based Artificial Intelligence-Empowered Contagious Pandemic Situation Supervision Scheme Using Internet of Drone Things", A. Islam *et al*. propose a blockchain-based Internet of Drones (IoDT)-assisted pandemic situation supervision scheme with incorporated AI technology. A use case of the current global pandemic (i.e., COVID-19) is discussed in detail. Subsequently, a system model illustrating the applicability of the IoDT to such situations is presented. To handle various situations, a combination of dew and edge computing were considered to extend the reach of the proposed system in remote areas. The blockchain is divided into two chains (i.e., main and light chains) to handle the issue of network scarcity. Additionally, a lightweight authentication scheme was developed to reduce the burden on IoDT.

In the twelfth article, "Spectrum Allocation for Task-driven UAV Communication Networks Exploiting Game Theory", J. Chen *et al*. investigate spectrum allocation for task-driven UAV communication networks. Due to the task-driven essence, different kinds of tasks lead to different coupling relationships between UAVs in spectrum allocation. By exploring the task-driven essence, some featured challenges and requirements for task-driven spectrum allocation are discussed. Following the attractive fact that game theory can model the complex interactions among multiple players, the game-based optimization framework, which consists of task decomposition, task-driven feature requirements, game formulation and distributed algorithm, is developed to tackle the task-driven spectrum allocation problem. Some featured game models are also proposed, and some case studies are presented and discussed.

In the thirteenth article, "AI-Enabled Cross-Modal Communications", X. Wei *et al*. propose the federated learning paradigm to solve sparse data collection and privacy protection problems in the immersive experience description of multi-modal services. The authors use the reinforcement learning paradigm to construct a joint optimization framework of caching, communication, and computation, realizing collaborative transmission of audio, visual, and haptic streams. They also use the transfer learning paradigm to extract, transfer, and fuse knowledge, semantics, and characteristics from different modalities, recovering corrupted signals and promoting rendering effects at the receiver. Experimental results validate the efficiency of the AI-enabled cross-modal communications strategies.

In the fourteenth article, "Covert Communication in UAV-Assisted Air-Ground Networks", X. Jiang *et al*. introduce the basics of encryption, physical layer security and covert communications. They investigate the covert communications of UAV-assisted networks, with a discussion of several typical applications of UAV in covert communications. Two typical schemes for UAV-assisted covert networks are proposed, i.e., UAV-assisted multi-user covert data dissemination and jamming-assisted ground-air covert communications with multiple wardens. The solutions and simulation results of these two case studies are presented. Several challenging problems and directions are also pointed out for UAV-assisted covert networks.

In the fifteenth and the last article, "Hybrid Beamforming for Terahertz Wireless Communications: Challenges, Architectures, and Open Problems", C. Han *et al*. study the challenges and features of the THz hybrid beamforming design, including the low SDoF limitation, the blockage issue, the large-scale antenna array constraint, the beam squint effect, and the spherical-wave propagation problem. The authors introduce two traditional FC and AoSA hybrid beamforming architectures and investigate their limitations when being applied to THz band. They analyze three THz-specific hybrid beamforming architectures, i.e., THz WSMS, DAoSA, and DS-FTTD architectures. Simulation results are provided to validate the data rate, power consumption, and array gain for THz communications

I hope you enjoy reading these articles in this issue of *IEEE Wireless Communications*.

Biography

Yi Qian [M'95, SM'07, F'19] received a Ph.D. degree in electrical engineering from Clemson University, in Clemson, South Carolina. He is currently a professor in the Department of Electrical and Computer Engineering, University of Nebraska-Lincoln (UNL). Prior to joining UNL, he worked in the telecommunications industry, academia, and government. Some of his previous professional positions include serving as a senior member of scientific staff and a technical advisor at Nortel Networks, a senior systems engineer and a technical advisor at several startup companies, an assistant professor at the University of Puerto Rico at Mayaguez, and a senior researcher at the National Institute of Standards and Technology. His research interests include wireless communications and networks, and information and communication network security. He has research and industry experience in wireless communications and networks, wireless sensor networks, vehicular communication networks, information and communication network security, smart grid communications, broadband satellite communications, optical communications, high-speed communications and networks, and Internet of Things. He was previously Chair of the IEEE Technical Committee for Communications and Information Security. He was the Technical Program Chair for the IEEE International Conference on Communications 2018. He serves on the Editorial Boards of several international journals and magazines, including as the Editor-in-Chief for *IEEE Wireless Communications*. He was a Distinguished Lecturer for the IEEE Vehicular Technology Society. He is currently a Distinguished Lecturer for the IEEE Communications Society. He received the Henry Y. Kleinkauf Family Distinguished New Faculty Teaching Award in 2011, the Holling Family Distinguished Teaching Award in 2012, the Holling Family Distinguished Teaching/Advising/Mentoring Award in 2018, and the Holling Family Distinguished Teaching Award for Innovative Use of Instructional Technology in 2018, all from the University of Nebraska-Lincoln. He is the principal author of the textbook, "Security in Wireless Communication Networks", published by IEEE Press/Wiley in 2021.