Editorial: Third Quarter 2021 IEEE Communications Surveys and Tutorials

I WELCOME you to the third issue of the IEEE Communications Surveys and Tutorials in 2021. This issue includes 18 articles covering different aspects of communication networks. In particular, these articles survey and tutor various issues in "Wireless Communications," "Internet Technologies," "IoT and M2M," "Network and Service Management and Green Communications," "Network Security," "Network Virtualization," and "Vehicular and Sensor Communications." A brief account for each of these articles is given below.

I. Wireless Communications

Optical Orthogonal Frequency-Division Multiplexing (O-OFDM) has found favour in numerous optical communications scenarios, including both Visible Light Communications (VLC), as well as Free-Space Optical (FSO) and Optical Fiber Communications. It has become a popular technique, because it is eminently suitable for mitigating both the linear distortions imposed by multi-path propagation and the chromatic dispersion. Furthermore, since OFDM is also widely used in 4G and 5G radio-frequency systems as well as in copper-fed WiFi systems, low-cost off-the-shelf chips are widely available on the market. The contribution entitled as "The Evolution of Optical OFDM" coauthored by Xiaoyu Zhang, Zunaira Babar, Periklis Petropoulos, Harald Haas, and Lajos Hanzo commences by portraying the conception and historic evolution of O-OFDM designed for both optical wireless and optical fiber systems, outlining the road leading to the conception of its most flexible incarnation, namely Layered Asymmetrically Clipped Optical OFDM (LACO-OFDM). Then the authors demonstrate that it is eminently suitable for intensity-modulation and direct-detection aided optical systems and characterize its design flexibility in terms of supporting almost arbitrary block-length, number of modulated bits/symbol, adaptive subcarrier bit-loading and the number of superimposed LACO-OFDM layers. Hence it exhibits a conveniently configurable throughput, delay, and integrity vs. complexity trade-off. The authors also demonstrate that LACO-OFDM subsumes the entire gamut of optical OFDM schemes conceived in the past, including the popular Asymmetrically Clipped Optical OFDM (ACO-OFDM) and Direct Current Offset OFDM (DCO-OFDM). Finally, suitable forward error correction (FEC) designs complement the LACO-OFDM based discussions, which are capable of striking a flexible coding gain versus complexity tradeoff. The final conclusions are crystallized in the associated design guidelines and by outlining some open research issues.

The large amount of data generated by massive mobile devices can greatly benefit the design and operation of modern wireless communication networks (WCNs), and yet, make the wireless channels more congested. Learning tasks performed at individual devices with their local datasets can reduce data exchange and bandwidth occupation in WCNs and protect data privacy of the devices. The designs of distributed machine learning (DML) frameworks are expected to enhance the performance of WCNs under various application scenarios and make efficient uses of hardware resources. In this context, the article titled "Distributed Machine Learning for Wireless Communication Networks: Techniques, Architectures, and Applications" by Shuyan Hu, Xiaojing Chen, Wei Ni, Ekram Hossain, and Xin Wang presents a survey. The article starts with an overview of algorithms, models and architectures of DML techniques. Then, the article summarizes a wide range of recent studies on the applications of DML to WCNs, in an attempt to provide useful guidelines for researchers. Furthermore, the article discusses the optimality, convergence rate, and cost of popular DML algorithms, and approaches for privacy preserving in DML systems. Finally, the article elucidates key challenges and open issues for future research.

Molecular communication (MC) employs chemical signals to exchange information, and the biological nature of chemical signals makes MC one of the most promising communication paradigms for nano-machines to realize various interdisciplinary applications, such as disease diagnosis, drug delivery, and health monitoring. To unleash the potential of MC for interdisciplinary applications, substantial efforts are required from diverse scientific communities, e.g., biology, chemistry, engineering, and physics. However, due to the distinct approaches to formulating and solving research problems, there is a mismatch between different disciplines, which hinders the translation of research results and impedes the commercialization of MC-enabled applications. In this context, the article titled "A Survey of Molecular Communication in Cell Biology: Establishing a New Hierarchy for Interdisciplinary Applications" by Dadi Bi, Apostolos Almpanis, Adam Noel, Yansha Deng, and Robert Schober presents a survey. First, the article proposes a new communication hierarchy for molecular signaling in cell biology, which is comprised of five levels: 1) Physical Signal Propagation; 2) Physical and

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Chemical Signal Interaction; 3) Signal-Data Interface; 4) Local Data Abstraction; and 5) Application. Then, the article sequentially maps infrastructure and activities in biological signaling to these five levels. Moreover, the article also applies the proposed communication hierarchy to case studies on quorum sensing, neuronal signaling, and DNA communication. Finally, the article discusses a selection of open problems for each level and the integration of multiple levels.

Motivated by the development of metasurfaces and the corresponding fabrication technologies, reconfigurable intelligent surfaces (RISs) have emerged as promising techniques for future wireless networks. Equipped with a large number of low-cost reflecting elements, RISs are capable of proactively modifying the propagation of the incident signals and thus realizing smart radio environment. As a result, the capacity and coverage of wireless networks can be significantly enhanced. Compared with the existing multi-antenna and relaying technologies, the benefits of employing RISs include but not limited to flexible deployment, low cost and energy consumption, and high compatibility. There are also numerous potential application scenarios for RISs, such as indoor communications, intelligent IoT networks, and smart cities. In this context, the article titled "Reconfigurable Intelligent Surfaces: Principles and Opportunities" by Yuanwei Liu, Xiao Liu, Xidong Mu, Tianwei Hou, Jiaqi Xu, Marco Di Renzo, and Naofal Al-Dhahir presents a survey. First, the basic principles of RISs are introduced from perspectives of both physics and communications. Then, performance evaluation for RISs is presented. Next, the existing designs for RIS-enhanced networks relying on conventional mathematical methods and machine learning tools are overviewed, respectively, along with their unique characteristics. Finally, major issues and research opportunities for employing RISs are identified to motivate future work.

II. Internet Technologies

6G network brings extremely high quality of service (QoS) and quality of experience (QoE) requirement such as Ultra low latency, ultra-big throughput and high energy efficiency for end-to-end communications. 6G with intelligent sensing, communication and networking ability is embedded with machine learning technologies to ensure the end-to-end QoS and QoE. various protocols are proposed to optimize network functions crossing data-link layer to the application layer. In this context, the article titled "Survey on Machine Learning for Intelligent End-to-End Communication Towards 6G: From Network Access, Routing to Traffic Control and Streaming Adaption" by Fengxiao Tang, Bomin Mao, Yuichi Kawamoto, and Nei Kato present a survey, where the article overviews the recent machine learning based network optimization methods to guarantee the end-to-end QoS and QoE. The network function intelligentization from network access, routing, traffic Control and streaming adaption are introduced respectively. Finally, the open issues and potential future research directions are discussed.

Neurosciences and wireless communications are converging in the context of several recent wireless and AI developments, where both are going to the edge: wireless communications is quickly heading toward nano communication while brain-inspired AI is moving toward edge intelligence at the sensor itself based on neuromorphic computing and various edge AI techniques. Also, the advance of wireless brain-machine interfaces point to a near future where human brains will be part of the communications grid, interacting directly and seamlessly with other man-made devices but also with other brains. In this context, the article titled "Neurosciences and Wireless Networks: The Potential of Brain-Type Communications and Their Applications" by Moioli *et al.* presents a comprehensive tutorial on two fronts: firstly, what neurosciences will offer to future wireless technologies in terms of new applications and systems architecture (Neurosciences for Wireless Networks); secondly, how wireless communication theory and next generation wireless systems can provide new ways to study the brain (Wireless Networks for Neurosciences). In particular, the authors explore how current scientific understanding of the brain would enable new applications within the context of a new type of service dubbed brain-type communications and discuss how future wireless networks can be equipped to deal with such services.

III. IoT and M2M

Recent years have witnessed the rapid development of the Internet of Things (IoT) which provides ubiquitous sensing and computing capabilities to connect a broad range of things to the Internet. To obtain insights into data generated from ubiquitous IoT devices, artificial intelligence (AI) techniques have been widely used to train IoT data models, but they also have various privacy concerns and limited training performances due to the lack of data learning collaboration. In this context, the article titled "Federated Learning for Internet of Things: A Comprehensive Survey" by Dinh C. Nguyen, Ming Ding, Pubudu N. Pathirana, Aruna Seneviratne, Jun Li, and H. Vincent Poor provides a holistic survey on the integration of Federated Learning (FL) into IoT networks and applications. The article analyzes the potential of FL for enabling a wide range of IoT services. The article then provides an extensive survey of the use of FL in key IoT applications from different use-case domains. Several current challenges and possible directions are also highlighted for future research.

Internet of Things (IoT) has appeared as a paradigm to drive the evolution of modern industries and smart cities. The potential of IoT has encouraged its integration in many fields including smart grid, intelligent transportation system (ITS), industry, mobile crowdsensing (MCS), etc. To fulfill the promise of IoT, the main obstacles exhibit in Communication, Computing, Caching and Control (4Cs) problems. Fortunately, the recent advances in deep reinforcement learning (DRL) have shown great potentials to solve the 4Cs problems. In principle, DRL involves self-learning agents that focus on maximizing the long-term performance and leverages the strong learning ability of deep learning to extract valuable features from high-dimensional sensory observations. In this context, the article titled "Deep Reinforcement Learning for Internet of Things: A Comprehensive Survey" by Wuhui Chen, Xiaoyu Qiu, Ting Cai, Hong-Ning Dai, Zibin Zheng, and Yan Zhang presents a survey. First, the article starts by describing the 4Cs problems of IoT and presenting a review of DRL. Then, the article reviews DRL applications in IoT-enabled smart grid, IoT-enabled ITS, Industrial IoT, IoT-enabled MCS, and blockchain-empowered IoT, respectively. Finally, the article highlights emerging critical challenges and outlines future directions in driving the further success of DRL in IoT applications.

The Internet of Things (IoT) paradigm has been gaining momentum across many heterogeneous fields, providing wireless connectivity to smart and connected objects which collect data from the surrounding environment. Recently, the connectivity has switched from a short-range, mesh-topology approach towards a long-range, start-topology one. However, the coverage of the terrestrial IoT infrastructure results to be insufficient to ensure the service continuity of IoT services covering a large geographical area, e.g., transportation, fleet management, and farming. The exploitation of satellites is considered a good solution to support the deployment of IoT services in remote/rural areas. In this context, the article titled "A Survey on Technologies, Standards and Open Challenges in Satellite IoT" by Marco Centenaro, Cristina E. Costa, Fabrizio Granelli, Claudio Sacchi, and Lorenzo Vangelista presents a comprehensive overview of the technologies involved in making the satellite IoT paradigm real for massive machine-type communication use cases. The survey includes the analysis of architectures and technical solutions, a review of the standardization, regulation, and scientific literature, and a discussion latest and future developments of satellite IoT communications and networking.

Many researchers have tested, studied and proposed improvements on LoRa radio technology, which is appropriate for the domain of IoT Low-Power Wide Area Networks, since its characteristics allow achieving long communication ranges with reduced cost and low energy consumption. A key characteristic of all similar technologies used in this domain is the ability to support numerous event-reporting end devices. The factors influencing the performance of these networks are highlighted along with their effect on LoRa networks' ability to support a sufficient number of end devices, which is the focus of this study. In this context the article titled "Performance Determinants in LoRa Networks: A Literature Review" by Panagiotis Gkotsiopoulos, Dimitrios Zorbas and Christos Douligeris presents a survey in which several research studies are examined and categorized based on their point of focus. Performance affecting factors are underlined, discussed and categorized based on their originating area as follows i) Physical layer characteristics and Phenomena, ii) Deployment features and Hardware selection, iii) End Devices transmission settings and Features, iv) LoRa MAC protocols, and v) Application requirements and Policies. Open issues are also presented in each area.

Machine learning has proven to be an integral part of the Internet of Things (IoT) networks. Machine learning relying on centralized training suffers from a privacy leakage issue because of the migration of end-devices data to the centralized third-party server. Additionally, moving an enormous amount of data to a centralized server requires substantial communication resources. To address these limitations, federated learning can be a promising solution that enables on-device machine learning without the need for transferring the device's data to the third-party server for training. Although federated learning offers several benefits, it has few prominent challenges that must be resolved prior to applying in IoT networks. In this context, the article titled "Federated Learning for Internet of Things: Recent Advances, Taxonomy, and Open Challenges" by Latif U. Khan, Walid Saad, Zhu Han, Ekram Hossain, and Choong Seon Hong presents a tutorial. The authors present a general architecture and rigorously evaluate the state-of-the-art advances of federated learning for IoT networks. Furthermore, taxonomy of federated-learning-enabled IoT networks is also devised. Finally, numerous open research challenges with possible guidelines are also presented.

IV. Network and Service Management and Green Communications

In the era of big data and the Internet-of-Things (IoT), large amounts of data are generated constantly. Distributed computing has been used for large-scale computations due to benefits such as high reliability, scalability, computation speed and cost-effectiveness. However, distributed computing faces two major challenges. Firstly, the computing nodes need to exchange a number of intermediate results over the network, which significantly increases the communication overheads. Secondly, the computation heterogeneity among the computing nodes may result in straggler effects where the straggling nodes run intermittently slower, leading to higher computation latency. Coded distributed computing (CDC), which combines coding theoretic techniques and distributed computing, can significantly reduce communication load, alleviate the effects of stragglers, provide fault-tolerance, privacy and security to the distributed computing systems. In this context, the article titled "A Comprehensive Survey on Coded Distributed Computing: Fundamentals, Challenges, and Networking Applications" by Jer Shyuan Ng, Wei Yang Bryan Lim, Nguyen Cong Luong, Zehui Xiong, Alia Asheralieva, Dusit Niyato, Cyril Leung, Chunyan Miao presents a survey, where the article introduces the fundamentals of CDC and the basic CDC schemes. The survey also reviews and analyses a number of CDC approaches to reduce communication costs, mitigate the straggler effects, and guarantee privacy and security. Furthermore, it discusses applications of CDC in modern computer networks. Finally, it concludes by highlighting important challenges and promising research directions related to CDC.

V. Network Security

Driven by the advancements in deep learning, computer vision has made significant breakthroughs in the last decade. Such breakthroughs are being readily used in many applications such as medical image analysis, autonomous driving, digital agriculture, space science, and media content analysis. On the other hand, network security is an area that needs to be continuously evolving due to ever-increasing threats from attackers. We have witnessed increasing numbers of attacks and data breaches, especially in these pandemic years. Yet, at a glance, network security and computer vision don't appear to be related topics. Therefore, it is unclear how network security solutions can be developed leveraging the advancements of computer vision methods. In this context, the article titled "A Review of Computer Vision Methods in Network Security" by Jiawei Zhao, Rahat Masood, and Suranga Seneviratne surveys the research conducted in the intersection between computer vision and network security. The authors present such work under topics; phishing attempt detection, malware detection, and traffic anomaly detection. They show that there are distinct advantages of using computer vision methods, especially when detecting zero-day attacks and developing more scalable and accurate phishing detection systems. Finally, the authors also discuss the potential new research directions in this domain, such as hybrid methods, building solutions resilient to adversarial attacks, few-shot learning methods to address the scarcity of data, and open set classification methods that are essential to real-world deployments.

As computing becomes ubiquitous in different sectors of society, our cyber and physical worlds are increasingly intertwined. Recognizing the importance of these physical world interacting systems, there have been growing interests in the accompanying security and privacy issues. Past research has demonstrated new threat vectors targeting the transition process between the cyber and physical domains, where the attacker exploits the sensing system as an attack surface for signal injection or extraction of private information. In this context, the article titled "Security and Privacy in the Emerging Cyber-Physical World: A Survey" by Zhiyuan Yu presents a survey that systemizes security and privacy issues arising from the interaction of the cyber world and physical world, with the context of Cyber-physical systems (CPS) and Internet of Things (IoT) applications. Based on the abstracted cyber-physical attack model, the article also points out potential new attack vectors and the corresponding defenses.

The widespread use of mobile devices, applications and services has raised important cybersecurity challenges. The number of cyberattacks is increasing day by day, in number and in complexity. Traditional cybersecurity systems fail in the detection of complex unknown attacks such as zero-day attacks, new malware variants, and on the preservation of user privacy. Meanwhile, Deep Learning (DL) techniques improve learning procedures and provide encouraging results in a wide range of applications. The success of DL relies, to a great extent, on the new achievements in software engineering and the massive generation of training data. This leads cybersecurity systems embrace DL models. In this context, "A Survey of Deep Learning Techniques for Cybersecurity in Mobile Networks" presents a survey of recent DL based cybersecurity works in mobile and wireless networks. First, the article starts by providing a complete overview of the different threats and attacks covering all cybersecurity areas including infrastructure, software and privacy. Then for each cybersecurity threat or attack, the article elaborates on the different DL methods used to detect and classify all the different types of cyberattacks providing details of the implementation and the published results. Finally, given the analysis performed, the article identifies the most effective DL methods for the different threats and attacks.

VI. Network Virtualization

The term "SDN" represents a significant evolution in networking technology and draws attention and support from network operators, vendors, researchers, and industry regulators. Contrary to popular belief that SDN is a recent invention, or is related only to IP technologies, the concept of network programmability and control/data plane separation has its roots in the 1960s and 1970s when the telephone network started its transition to digital. Many iterations followed, leading to applications in packet networks and today's Internet. In this context, the article titled "The Origin and Evolution of Open Programmable Networks and SDN," by Nikos Anerousis, Prosper Chemouil, Aurel A. Lazar, Nelu Mihai and Stephen B. Weinstein, presents early works on network programmability that illustrate how several features of SDN emerged progressively over several decades. The review starts from the early concepts of network control in the telephone network and continues to examine a prolific period of research advancements in the 1990s and early 2000s that led to a number of startup companies that followed, IEEE's own efforts in standardizing network programmability, and finally the arrival of the OpenFlow standard. Finally, the article discusses the importance of this architectural transformation and its influences on modern cloud computing and next-generation networking.

VII. Vehicular and Sensor Communications

The Third Generation Partnership Project (3GPP) has recently published its Release 16 that includes the first Vehicle-to-Everything (V2X) standard based on the 5G New Radio (NR) air interface. The NR V2X standard largely focuses on the sidelink aspects that were not developed in Release 15 where the 5G NR air interface was introduced. Sidelink refers to the direct communication between User Equipments (UEs). In NR V2X, UEs are vehicles, Road Side Units, or mobile devices carried by pedestrians. 5G NR V2X has been developed to complement the Long Term Evolution (LTE) V2X standard, enabling support for more advanced use cases, including those related to connected and automated driving. In this context, the article "A Tutorial on 5G NR V2X Communications" by Mario Castañeda Garcia, Alejandro Molina-Galan, Mate Boban, Javier Gozalvez, Baldomero Coll-Perales, Taylan Şahin and Apostolos Kousaridas presents an in-depth tutorial of the 3GPP Release 16 NR V2X standard, with a particular focus on the sidelink. The article provides a thorough treatment of key aspects of 5G NR V2X: the physical layer, the resource allocation, the quality-of-service management, the enhancements introduced to the Uu interface, and the mobility management for Vehicle to Network communications, as well as co-existence mechanisms between 5G NR V2X and

LTE V2X. The article also discusses the use cases, the system architecture, the evaluation methodology, and the simulation assumptions for 5G NR V2X. Finally, the article provides an outlook on possible 5G NR V2X enhancements, including those already identified within Release 17.

Vehicular network with high mobility vehicles enables feasible and convenient connection to everything and is recognized as one of the elements of future 6G network. Using machine learning to intelligentize network functions is considered as the key technology to future intelligent vehicular network which allows the network self-adaption to various applications, and mutative requirements of users. To embed machine learning in vehicular network from communication and networking includes different kinds of approaches and faces various challenges. In this context, the article titled "Comprehensive Survey on Machine Learning in Vehicular Network: Technology, Applications and Challenges" by Fengxiao Tang, Bomin Mao, Nei Kato, and Guan Gui present a comprehensive survey. This article at first gives a preliminary on communication technologies and machine learning technologies in vehicular network. Then, the article describes the emerging challenges of vehicular network and correspondingly introduces the machine learning based solutions. Finally, the article discusses some open issues for future research.

I hope that you enjoy reading this issue and find the articles useful. It is also worth noting that the JCR Impact Factor of ComST is now 25.24. I would like to give a special thanks to our authors contributing high-quality works to IEEE ComST. Thus, last but not the least, I highly encourage you to submit your work which fit within the scope of ComST. For detailed instructions on the preparation and submissions of manuscripts to ComST, please check the URL below: http://dl.comsoc.org/livepubs/surveys/. I will be happy to receive your comment and feedback on our journal.

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