

The Scanning the Literature column provides concise summaries of selected papers that have recently been published in the field of networking. Each summary describes the paper's main idea, methodology, and technical contributions. The purpose of the column is to bring the state of the art of networking research to readers of *IEEE Network*. Authors are also welcome to recommend their recently published work to the column, and papers with novel ideas, solid work, and significant contributions to the field are especially appreciated. Authors wishing to have their papers presented in the column should contact the Editor.

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It is envisioned that future networks will have to accommodate the demand of connecting billions of people and hundreds of billions of devices, which requires the network architecture to be capable of supporting explosively increasing mobile Internet traffic and various applications heterogeneously. A very interesting idea for utilizing the network is to create the digital representation of humans or things in the virtual digital world; the activities or behaviors of those humans or things will be reflected exactly in the virtual world. This is referred to as the "digital twin." To realize the magic essentially involves techniques such as data acquisition, human-machine-product interconnection, knowledge discovery/generation, and intelligent control. The column in this issue focuses on the recent development of digital twin.

With the fast development of IoE and its applications, the ever-increasing mobile Internet traffic and services bring unprecedented challenges, including scalability, mobility, availability, and security, which cannot be addressed by the current clean-slate network architecture. To address this challenge, Yu *et al.* propose their solution in the following paper.

Cybertwin: An Origin of Next Generation Network Architecture

Quan Yu, Jing Ren, Yinjin Fu, Ying Li, Wei Zhang, in *IEEE Wireless Communications*, vol. 26, no. 6, pp. 111-117, December 2019

In this article, a cybertwin-based next generation network architecture is proposed to accommodate the evolution from end-to-end connection to cloud-to-end connection in the future network. As a digital representation of humans or things in the virtual cyberspace, cybertwin serves in multiple capacities, such as communications assistant, network behavior logger, and digital asset owner. The new and unique characteristics of the cybertwin make the proposed network flexible, scalable, reliable, and secure. Further, the authors advocate a new cloud network operating system that can work in a distributed way through a real-time multi-agent trading platform to allocate 3C (computing, caching, communication) resources. They also propose a cloud operator, a new operator that can provide and manage the resources to the end users, and offer location and authentication services for humans and things in cyberspace. Some promising and open research topics are discussed to envision the challenges and opportunities of the cybertwin in the future network architecture.

With the recent advances in the Internet of Things (IoT), the significance of information technologies to modern industry is upgraded from purely providing surveillance-centric functions to building a comprehensive information framework of the industrial processes. Innovative techniques and concepts emerge under such circumstances, where signal processing techniques are crucial to the aforementioned procedures but face unprecedented challenges when they are applied in complex industrial environments. To fill this gap, He *et al.* propose their idea in the following paper.

From Surveillance to Digital Twin: Challenges and Recent Advances of Signal Processing for Industrial Internet of Things

Yuan He, Junchen Guo, Xiaolong Zheng, in *IEEE Signal Processing Magazine*, vol. 35, no. 5, pp. 120-129, Sept. 2018

This article surveys the promising industrial applications of IoT technologies, and discusses the challenges and recent advances in this area. The authors also share their early experience with Pavatar, a real-world industrial IoT system that enables comprehensive surveillance and remote diagnosis for an ultra-high-voltage converter station (UHVCS). Potential research challenges in building such a system are also categorized and discussed to illuminate the future directions.

In the fifth generation (5G) communication systems, there are diverse applications ranging from high data rate delay-tolerant services to ultra-reliable and low-latency communications (URLLC). To reduce processing time at the local server of each device and to avoid delays in backhauls and core networks, mobile edge computing (MEC) is one promising solution. However, achieving ultra-high reliability and ultra-low latency is very challenging in MEC systems. Motivated by this problem, Dong *et al.* illustrate their idea in the following paper:

Deep Learning for Hybrid 5G Services in Mobile Edge Computing Systems: Learn from a Digital Twin

Rui Dong, Changyang She, Wibowo Hardjawana, Yonghui Li, Branka Vucetic, in *IEEE Transactions on Wireless Communications*, vol. 18, no. 10, pp. 4692-4707, Oct. 2019

This paper develops a mobile edge computing system with ultra-reliable and low-latency communications services as well as delay-tolerant services to minimize the normalized energy consumption. The authors propose a deep learning (DL) architecture, where a digital twin of the real network environment is used to train the DL algorithm offline at a central server. From the pre-trained deep neural network (DNN), the MME can obtain a user association scheme in a real-time manner. Considering that real networks are not static, the digital twin monitors the variation of real networks and updates the DNN accordingly. For a given user association scheme, the authors propose an optimization algorithm to find the optimal resource allocation and offloading probabilities at each AP. The simulation results show that the method can achieve lower normalized energy consumption with less computation complexity compared to an existing method and approach to the performance of the global optimal solution.

The cyber-physical system (CPS) is a new trend in Internet-of-Things-related research works, where physical systems act as the sensors to collect real-world information and communicate them to the computation modules (i.e., cyber layer), which further analyze and report the findings to the corresponding physical systems through a feedback loop. Contemporary researchers recommend integrating cloud technologies in the

CPS cyber layer to ensure the scalability of storage, computation, and cross-domain communication capabilities. Although there are a few descriptive models of the cloud-based CPS architecture, it is important to analytically describe the key CPS properties: computation, control, and communication. To fill this gap, Qi *et al.* introduce their ideal in the following paper.

C2PS: A Digital Twin Architecture Reference Model for the Cloud-Based Cyber-Physical Systems

Kazi Masudul Alam, Abdulmoteleb El Saddik, in *IEEE Access*, vol. 5, pp. 2050-2062, 2017

This paper presents a digital twin architecture reference model for the cloud-based CPS, C2PS, where the authors analytically describe the key properties of the C2PS. The model helps in identifying various degrees of basic and hybrid computation-interaction modes in this paradigm. The authors have designed a C2PS smart interaction controller using a Bayesian belief network so that the system dynamically considers current contexts. The composition of fuzzy rule base with Bayes network further enables the system with reconfiguration capability. They also describe, analytically, how the C2PS subsystem communications can generate an even more complex system-of-systems. Later, they present a telematics-based prototype driving assistance application for the vehicular domain of C2PS, VCPS, to demonstrate the efficacy of the architecture reference model.

Smart factory is an environment where machinery and equipment are able to work together to improve processes through automation and self-optimization. Connectivity in smart factory is the key enabler to optimize operations through the collection of data to accelerate automation in a factory setting. Motivated by this problem, Lam *et al.* illustrate their idea in the following paper.

Bluetooth Mesh Networking: An Enabler of Smart Factory Connectivity and Management

Terence Ching Yang Lam, Sherlyn Shi Ling Yew, Sye Loong Keoh, in *proc. 2019 20th Asia-Pacific Network Operations and Management Symposium*, Matsue, Japan, 2019, pp. 1-6

This paper proposes the use of Bluetooth wireless mesh networking to realize the vision of smart factory, providing efficient connectivity to collect data from the shop floor in real time. Downstream communication to the sensor devices can also be performed, thus creating a digital twin of the shop floor and its process. A web-based visualization dashboard is implemented to monitor the status of sensors and machinery in real time. The developed system is also integrated with an indoor localization mechanism to provision new sensors into the mesh network. An augmented reality dashboard enables a user who is physically patrolling the smart factory to view sensor status in real time.



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