Guest Editorial Complex Network Analysis and Applications in Next-Generation Consumer Electronics

CONSUMER Electronics (CE) has experienced remarkable advancement in transformative technologies, to name a few, Internet-of-Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), cloud computing, etc.

The modern CE is transforming into next-generation (next-gen) CE with higher connectivity and smarter intelligence. Such transformation would eventually lead to extraordinary expansion in the CE market and data volume in the consumer ecosystem, influencing the behavioral analysis of consumers and CE network development. For instance, thanks to the proliferation of intelligent services and the pervasive influence of social networking platforms, smartphones are gradually overtaking televisions as the most commonly owned consumer products.

Complex network analysis is an essential research field for modeling networks that exhibit irregularities and are not purely random. It could be further exploited to analyze the behaviors of consumers in response to technological advancement, underlying patterns of the connections between various CE objects, complex data flow, etc. The adoption of complex network analysis could cover a wide range of aspects, including demand-and-supply analysis, market trends, network optimization, etc. Those fields are crucial and huge research topics in sustaining the growth of the next-gen CE applications.

The Guest Editors are delighted to introduce the Special Section on "Complex Network Analysis and Applications in Next-Generation Consumer Electronics" of the IEEE TRANSACTIONS ON CONSUMER ELECTRONICS. The selected nine high-quality contributions cover the hostile solutions of trusted architecture, cybersecurity in high-traffic CE networks, optimal resource balancing, social network clustering, data flow optimization, and data modeling.

The Special Section opens with a state-of-the-art paper on the development and research opportunities for next-generation consumer electronics. In [A1], the next-gen CE, for the first time, was defined as the devices and equipment developed for consumer-grade purposes, equipped with connectivity and intelligence capabilities. Afterward, the state-of-the-art architecture of the next-gen CE in compliance with the standard of IEEE 2668 was presented, manifesting guidance on solving interoperability and security problems in rapidly growing CE markets. The contribution also discussed the foreseen challenges in the next-gen CE in terms of publicity, privacy, intelligent threats, and behavioral modeling, directing future research opportunities to foster the evolution of CE reliably and sustainably.

The exponential growth of data traffic in CE networks, along with the nature of high diversity and decentralization, would eventually lead to emerging cyber threats. In [A2], Javeed et al. developed an intelligent Intrusion Detection System (IDS) using Software-Defined Network-(SDN) orchestrated Deep Learning (DL) to identify the upcoming threats that could be encountered in future CE networks. SDN, owing to its flexibility of separating control and data planes, was proposed to become the backbone for CE networks. A Cuda-enabled Bidirectional Long Short-Term Memory (Cu-BLSTM) was then designed and incorporated with the SDN for detecting various attacks in CE networks. This contribution provides essential insight into cyber risks in the next-generation CE networks as well as potential solutions to mitigate the risks.

With the rapidly expanding traffic and applications in CE networks, task offloading to neighboring fog nodes could be one of the feasible solutions to achieve high utilization efficiency of computational resources and low response latency. However, improper offloading strategies may introduce impulsive traffic at certain fog nodes, resulting in a degradation in quality-of-service (QoS). Thus, the contribution in [A3] proposed a matching theory-based protocol, namely A-DAFTO, to achieve high-efficiency load assignment. The proposed protocol deliberated offloading latency preferences and pre-defined application deadlines and delivered an efficient and fair offloading model using the Artificial Cap Deferred Acceptance (ACDA) algorithm. The contribution gave a prospective idea of offloading strategies with the demonstration using static preferences. Based on the proposed idea, researchers could enhance the offloading model by considering dynamic preferences and additional metrics.

In recent years, Physical Layer Security (PLS) has gained extensive attention, thanks to its lightweight and secure transmission. Particularly, the lightweight design would be significantly suitable for networks with low-cost CE devices. In [A4], an optimal Reconfigurable Intelligent Surface (RIS) allocation scheme was designed to split the conventional RIS into two parts. One part aimed to assist legitimate users, while another part targeted suppressing the eavesdropper. Moreover, the optimal element allocation of RIS was deduced to reach a compromise between the secrecy capacity and the number of RIS components, delivering the best practices for PLS configuration.

Digital Object Identifier 10.1109/TCE.2024.3349703

In response to the demands for high-diversity and real-time CE applications, a stream band join system has been raised to match all tuple pairs in two streams that share similar properties within a user-specified range, such as distance, time, and pre-defined score. Those matched data could be grouped for batch processing, improving computational efficiency and time. Nonetheless, the broad range of distributed data could lead to a significant load imbalance among CE instances. Therefore, in [A5], an adaptive range partitioning system, namely Nereus, was proposed to achieve low-cost operation with a controllable number of partitions and load balancing. Nereus exploited the queuing theory to evaluate the total benefits for various load migration schemes based on the newly designed migration benefit model. Ultimately, Nereus accomplished low migration costs and produced an appropriate number of partitions. The proposed system could solve the problem of load imbalance in existing stream band join systems, resulting in better resource allocation efficiency in real-time CE applications.

Internet-of-Vehicles (IoV) is one of the crucial applications in the next-gen CE. The ever-growing number of smart vehicles would overwhelm IoV networks. The integration of IoV networks and cellular networks could be conceived as an effective solution to alleviate the pressure on IoV data traffic. Extra subscription charges and occupancy of cellular resources are the two major shortcomings in such integration. The contribution in [A6] designed a comprehensive massive data download scheme based on a heterogeneous vehicular network (HetVNET). The scheme considered edge cache and relaying to enable intensive data downstream, realizing low network complexity and high data distribution efficiency. Besides, a new pre-cached data downstream distribution mode and load-balancing algorithms among collaborative vehicles were designed to accommodate the hostile constraints of dynamic network topology and limited computing power. The concept of the contribution could be further extended and customized into other CE applications with the requirements of high mobility and data capacity.

The interactions between CE users, which could be formulated as social networks, could provide insight into consumer behaviors. The graph clustering method is a promising technique for analyzing consumer behaviors from a social network. In [A7], a Deep Self-Supervised Attention Convolution Autoencoder Graph Clustering (DSAGC) was proposed for social network clustering in an unsupervised manner. The DSAGC integrated graph convolution neural network, graph autoencoder, and clustering algorithms to estimate graph network division. Without the need for true data labels, the proposed work generated pseudo-labels by unsupervised clustering to assist the downstream label prediction task. Such contribution facilitates the analysis of consumer behaviors, thus proliferating the growth of the CE market with better prediction of market trends and supply and demand.

The next-gen CE would tremendously incorporate intelligent services. Data modeling with massive data support plays a vital role in the development of intelligent CE products. The efficiency of data modeling would greatly influence the sustainability of intelligent products. Thus, the contribution in [A8] developed an automated data modeling method by leveraging a domain knowledge-based classifier to extract high-quality data from the Open Common Single-Document Summarization Dataset (OC-SDS). Also, an iterative optimization strategy was proposed to provide concrete and credible reference summaries for data modeling. The contribution to data modeling could proliferate the progress of smart CE services, particularly in the fields of language processing and generative AI.

The Special Section ends with a paper on a secure architectural model in CE. Most next-gen CE devices could connect to the Internet and other devices, posing the issues of cyber threats. Particularly, most CE devices may reduce the effort on cybersecurity to acquire low-cost design, creating loopholes for cyber attackers. In [A9], a novel approach using a multi-criterion decision-making model (TOPSIS) and a weighted product model was proposed to improve the security and accuracy of CE systems. Meanwhile, blockchain was incorporated for seamlessly monitoring and tracking the malicious behaviors of devices. The trusted mechanism could effectively prevent data breaches and leakage from the next-gen CE devices.

The Guest Editors are deeply grateful to all the authors who submitted their precious contributions with great dedication and to the reviewers who generously shared their expertise and devoted time to provide invaluable reviews and advice for the submitted works. Their collective efforts have been instrumental in shaping the quality and impact of the publications. Finally, the Guest Editors would like to extend their sincere gratitude to the Editor-in-Chief of the IEEE Transactions on Consumer Electronics, Dr. Kim Fung Tsang, for organizing and supporting this Special Section.

Chung Kit Wu
Department of Electrical Engineering
City University of Hong Kong
Hong Kong

Chi-Tsun Cheng
School of Engineering
RMIT University
Melbourne, VIC 3001, Australia

Guanrong Chen
Department of Electrical Engineering
City University of Hong Kong
Hong Kong

Shahid Mumtaz
Department of Engineering
Nottingham Trent University
NG1 4FQ Nottingham, U.K.

Kim Fung Tsang
School of Automation Engineering
Nanfang College
Guangzhou 510970, China

Yoko Uwate
Department of Electrical and Electronic Engineering
Tokushima University
Tokushima 770-8501, Japan

Appendix: Related Articles

[A1] C. K. Wu, C.-T. Cheng, Y. Uwate, G. Chen, S. Mumtaz, and K. F. Tsang, "State-of-the-art and research opportunities for next-generation consumer electronics," *IEEE Trans. Consum. Electron.*, vol. 69, no. 4, pp. 906–917, Feb. 2024, doi: 10.1109/TCE.2022.3232478.

[A2] D. Javeed, M. S. Saeed, I. Ahmad, P. Kumar, A. Jolfaei, and M. Tahir, "An intelligent intrusion detection system for smart consumer electronics network," *IEEE Trans. Consum. Electron.*, vol. 69, no. 4, pp. 918–925, Feb. 2024, doi: 10.1109/TCE.2023.3277856.

[A3] C. Swain, M. N. Sahoo, A. Satpathy, K. Muhammad, S. Bakshi, and J. J. P. C. Rodrigues, "A-DAFTO: Artificial cap deferred acceptance based fair task offloading in complex IoT-fog networks," *IEEE Trans. Consum. Electron.*, vol. 69, no. 4, pp. 926–938, Feb. 2024, doi: 10.1109/TCE.2023.3262995.

[A4] S. Chen et al., "Optimal RIS allocations for PLS with uncertain jammer and eavesdropper," *IEEE Trans. Consum. Electron.*, vol. 69, no. 4, pp. 939–948, Feb. 2024, doi: 10.1109/TCE.2023.3292842.

[A5] S. Yu, H. Chen, and H. Jin, "Nereus: A distributed stream band join system with adaptive range partitioning," *IEEE Trans. Consum. Electron.*, vol. 69, no. 4, pp. 949–961, Feb. 2024, doi: 10.1109/TCE.2023.3249292.

[A6] X. Yin, J. Liu, X. Cheng, and X. Xiong, "A C-V2X compatible massive data download scheme based on heterogeneous vehicular network," *IEEE Trans. Consum. Electron.*, vol. 69, no. 4, pp. 962–973, Feb. 2024, doi: 10.1109/TCE.2023.3330940.

[A7] C. Chen, H. Lu, H. Hong, H. Wang, and S. Wan, "Deep self-supervised graph attention convolution autoencoder for networks clustering," *IEEE Trans. Consum. Electron.*, vol. 69, no. 4, pp. 974–983, Feb. 2024, doi: 10.1109/TCE.2023.3279836.

[A8] Z. Liu, Y. Weng, R. Xu, Chaomurilige, and J. Y. Kim, "An efficient machine-generated data modeling approach based on domain-aware knowledge for intelligent consumer electronics," *IEEE Trans. Consum. Electron.*, vol. 69, no. 4, pp. 984–995, Feb. 2024, doi: 10.1109/TCE.2023.3327216.

[A9] Kumar, G. Rathee, C. A. Kerrache, M. Bilal, and T. R. Gadekallu, "A secure architectural model using blockchain and estimated trust mechanism in electronic consumers," *IEEE Trans. Consum. Electron.*, vol. 69, no. 4, pp. 996–1004, Feb. 2024, doi: 10.1109/TCE.2023.3336597.

Chung Kit Wu (Member, IEEE) received the B.Eng. degree (with First-Class Hons.) in electronic and communication engineering and the Ph.D. degree from the City University of Hong Kong in 2014 and 2020, respectively. His research interest includes Internet of Things (IoT), standardization, digital signal processing, machine learning, healthcare applications, optimization, and complex networks. He is currently the Guest Editor of IEEE Transactions on Consumer Electronics. He is also the Secretary of IEEE Standards Working Groups 2668, P1451.5.5, and IEEE P1451.5.6 and the Vice Chair of the IEEE Standards Working Group P1451.5.10.

Chi-Tsun Cheng (Senior Member, IEEE) received the B.Eng. degree in electronic and communications engineering and the M.Sc. degree in electrical and electronic engineering from The University of Hong Kong, Hong Kong, in 2004 and 2005, respectively, and the Ph.D. degree in electronic and information engineering from The Hong Kong Polytechnic University, Hong Kong, in 2009. From 2010 to 2011, he was a Postdoctoral Fellow with the Department of Electrical and Computer Engineering, University of Calgary, Calgary, AB, Canada. From 2012 to 2018, he was a Research Assistant Professor with the Department of Electronic and Information Engineering, The Hong Kong Polytechnic University. Since June 2018, he has been a Senior Lecturer with the Department of Manufacturing, Materials and Mechatronics, RMIT University, Melbourne, VIC, Australia. He is currently an Associate Editor for the IEEE Transactions on Circuits and Systems—II: Express Briefs, IEEE Access, and *IEICE Nonlinear Theory and Its Applications*.

Guanrong Chen (Life Fellow, IEEE) received the M.Sc. degree in computer science from Sun Yat-sen University, Guangzhou, China, in 1981, and the Ph.D. degree in applied mathematics from Texas A&M University, College Station, TX, USA, in 1987. He has been a Chair Professor and the Founding Director of the Centre for Complexity and Complex Networks, City University of Hong Kong, China, since 2000. Prior to that, he was a tenured Full Professor with the University of Houston, TX, USA. He received the State Natural Science Award of China in 2008, 2012, and 2016, respectively. He was awarded the 2011 Euler Gold Medal, Russia, and conferred Honorary Doctorates by the Saint Petersburg State University, Russia, in 2011 and by the University of Le Havre, Normandy, France, in 2014. He is a Member of the Academy of Europe and a Fellow of The World Academy of Sciences, and has been a Highly Cited Researcher in Engineering according to Clarivate Web of Science since 2009.

Shahid Mumtaz (Senior Member, IEEE) is a Senior 5G Consultant with Huawei, Sweden. He is serving as a Scientific Expert and an Evaluator for various Research Funding Agencies. He has authored four technical books, 12 book chapters, more than 250 technical papers (more than 150 journals/transactions, more than 80 conferences, two IEEE best paper awards—in the area of mobile communications. His research field includes resource allocation, mobile computing, telecommunication network, and telecommunication security. Most of his publication is in the field of wireless communication. He is the recipient of the NSFC Researcher Fund for Young Scientist in 2017 from China and the IEEE ComSoC Young Researcher Award in 2020. He was awarded an Alain Bensoussan Fellowship in 2012. He is the Founder and the EiC of *IET Quantum Communication*, the Vice-Chair of Europe/Africa Region—IEEE ComSoc: Green Communications & Computing Society, and the Vice-Chair of IEEE Standard on P1932.1: Standard for Licensed Unlicensed Spectrum Interoperability in Wireless Mobile Networks. He is an IET Fellow, IEEE ComSoc, and an ACM Distinguished Speaker.

Kim Fung Tsang (Fellow, IEEE) received the Ph.D. degree in microwave engineering from the University of Wales College of Cardiff (formerly known as the University of Wales Institute of Science and Technology), U.K. He has published more than 350 technical papers. He is the Editor-in-Chief of the IEEE TRANSACTIONS ON CONSUMER ELECTRONICS as well as the Chair of the Society Committee on Standards in the IEEE Consumer Technology Society. He is also an Associate Editor of IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, and *IEEE Industrial Electronics Magazine*.

Yoko Uwate (Member, IEEE) received the B.E., M.E., and Ph.D. degrees in electrical and electronic engineering from Tokushima University, Tokushima, Japan, in 2003, 2005, and 2006, respectively, where she has been working as an Assistant Professor since April 2010. Her research interests include complex phenomena in chaotic circuits and neural networks.