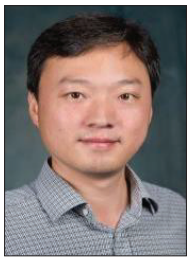
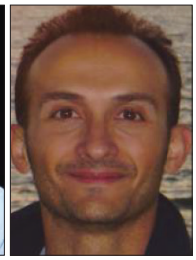
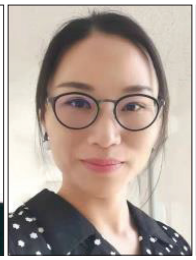
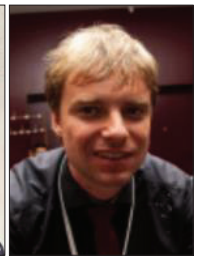
Learning-Based Edge Computing Services



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The recent revival of artificial intelligence (AI) is revolutionizing almost every branch of science and technology. Given the ubiquitous smart mobile terminals and Internet of Things (IoT) devices, it is expected that a majority of intelligent applications will be deployed at the edge networks. Therefore, providing intelligent and sustainable edge computing services will be a hot topic in IoT and 5G services as sustainability of edge systems becomes a necessity with the rapid constant growth of edge devices/sensors.

Edge learning is needed to support edge computing services. However, it faces great challenges when considering the latency-sensitive requirements, network bandwidth limitation, computing power limitation, as well as limited data at each edge device. AI-based technologies, such as statistical learning, feedforward neural networks, and deep recurrent neural networks, among others, are expected to construct the intelligent edge for improving Quality of Services (QoS) and Quality of Experience (QoE). These learning-based methods are implemented for sophisticated decision making, network management, resource optimization, and in-depth knowledge discovery in complex environments. The intelligence built by using edge learning techniques can help promote better decision making and contribute to building greener and more sustainable systems.

To address several major issues regarding the sustainability of edge computing services, this special issue highlights edge learning techniques to provide intelligent and greener edge computing services. Learning-based approaches are required to obtain more clear and in-depth knowledge of the behavior of edge networks. Submissions are expected to address how to build greener and more sustainable edge systems through learning-based approaches.

The scope of this Special Issue (SI) is to present and highlight the advances and the latest intelligent technologies, implementations and applications in the field of learning-based edge computing services, so as to build greener and more sustainable edge systems.

The articles in this special issue are classified into the following categories:

- Innovative architectures, frameworks, and models for learning-based edge computing.
- Theory, standards, protocols, and strategies for learning-based edge computing services in IoT.
- Machine learning, AI and other innovative optimization approaches for learning-based edge computing services.
- Intelligent and interactive IoT services and applications assisted by machine learning and edge computing.
- Intelligent decision-making systems for learning-based edge computing services.
- Smart task caching at edges by joint optimization of computation, caching and communication.
- Security and privacy assisted by learning-based edge computing in IoT.
- Learning-based testbeds, simulations, experiments and evaluation for edge computing.

In the first article, "Edge-Learning-Enabled Realistic Touch and Stable Communication for Remote Haptic Display", the authors propose a novel remote haptic display system enabled by an edge computing platform, and learning-based methods are employed for realistic haptic feedback and stable haptic communication. More specifically, the control algorithm combining PID neural network with decoupling is applied for fast and accurate generation of the referenced magnetic field at the haptic device, and a supervised BiLSTM network with user operations input is constructed for the prediction of missing haptic data in remote transmission. The developed system provides a practical platform for real-time remote haptic data acquisition and display, and experimental results demonstrate the effective sustainability of remote haptic interaction service.

In the second article, "Toward Resource-Efficient Federated Learning in Mobile Edge Computing", the authors investigate the state-of-the-art resource optimization approaches and establish a novel framework for resource efficient federated learning in mobile edge computing. In the proposed module-based federated learning framework with neural-structure-aware resource management, mobile clients are assigned with different subnetworks of the global model according to the status of their local resources. The proposed approach offers an elastic learning framework for emerging applications such as edge computing and Internet of Things, where the clients have limited computation, bandwidth, power, and data resources. The information-theoretical perspective and module-aware approach in this work are inspiring thoughts for the research area of federated learning and edge services.

In the third article, "A Repository of Method Fragments for Agent-Oriented Development of Learning-Based Edge Computing Systems", the authors address the development of Learning-Based Edge Computing Systems by using an

agent-oriented approach where agents autonomously operate on edge devices and coordinate for obtaining a distributed machine learning. This article proposes a repository of method fragments for supporting the definition of development processes that effectively build these systems. This work is illustrated in the context of the estimation of profits and customers, and compares the performance of several combinations of dimensionality reductions and machine learning techniques.

In the fourth article,"Stability-Based Analysis and Defense against Backdoor Attacks on Edge Computing Services", the authors illustrate the negative impact of architecture-independent backdoor attacks on intelligent edge computing services, which can pose huge challenges to security-sensitive application scenarios. To achieve active defense against backdoor attacks, the authors analyze the trade-off between the expected performance and the ability to defend against backdoor attacks from the perspective of stability. Specifically, a novel stability-based defense mechanism is proposed for real-world learning-based edge computing services. The authors verify the defense performance in different proportions of adversary scenarios. Experimental results show that the proposed mechanism can effectively defend against different levels of backdoor attacks without knowing whether there are adversaries. The work will have a huge impact on robustness enhancement of learning-based edge computing services.

In the fifth article, "Intelligent Edge Learning for Personalized Crowdsourced Livecast: Challenges, Opportunities and Solutions", the authors investigate a new scenario of crowdsourced livecast (crowdcast) and focus on providing personalized QoE to different viewers. Specifically, the authors first highlighted the developing trend from providing uniform QoE to offering personalized QoE in crowdcast services. They then pointed out the hidden opportunities of integrating edge computing and deep learning to achieve this goal. Finally, they propos ELCast, an edge learning based framework that applies deep learning for personalized QoE profiling and deep reinforcement learning for viewer assignment as well as transcoding selection among the edge servers. The authors verify the effectiveness of their framework using trace-driven evaluation. This paper provides sufficient insights in improving the viewing QoE of the crowdcast service.

In the seventh article, "Edge Network-Assisted Real-Time Object Detection Framework for Autonomous Driving", the authors develop an edge network-assisted real-time object detection framework (EODF) to guarantee real-time object detection of autonomous vehicles (AVs) in a dynamic channel environment. In the proposed framework, to offload tasks of object detection to edge clouds with low transmission latency, AVs adaptively compress images according to the channel condition by extracting regions of interests (RoIs). Therefore, real-time object detection can be achieved even when the channel quality is poor. Meanwhile, the authors introduce some future research directions to facilitate the further improvement of the proposed framework. The work will provide valuable guidelines for designing edge cloud-assisted autonomous driving systems.

In the sixth article, "Membership Inference Attack with Multi-Grade Service Models in Edge Intelligence", the authors study the vulnerability of the multi-grade edge intelligence (EI) model against membership inference attack (MIA) and propose a flexible multi-grade EI deployment scheme. First, the authors propose an attack model for multi-grade EI. Second, they reveal different grades of EI on vulnerability by comparing inference accuracy and cost in different datasets. In addition, their experiment results show that in multi-grade EI, a low-grade model would leak privacy information of a high-grade model under MIA.

In the 5G era, emergency ambulance service makes it possible to connect patients and ambulance crew at an accident scene with the awaiting emergency department team at the destination hospital seamlessly so as to improve the rescure rate of patients. To solve the issues of lacking reliability of 5G networks in recent existing platforms, the eighth article proposes a 5G-enabled smart ambulance service and then tests the quality of service of the proposed solution. The authors also consider emergency scenarios to investigate the task completion and accuracy of a 5G-enabled smart ambulance, and to verify the superiority of their proposed solution.

In the ninth article, "Spatial-Temporal Learning-Based Artificial Intelligence for IT Operations in the Edge Network", the authors introduce artificial intelligence for IT operations (AIOPS) to SDN-based edge network to tackle the rapid increasing of edge network scale and the complexity of service interaction. This paper is a groundbreaking work in leveraging AIOPS for SDN-based edge networks, which can assist operators in performing anomaly detection, anomaly localization, and root cause analysis by the proposed AIOPS-enabled architecture. The authors highlight spatial-temporal learning which uses graph-based gated convolutional networks to solve the anomaly detection problem of time series with network topology and achieves good results. The work will have an important impact on learning-based edge computing and provide new insights for future edge services.

In the last article, "A Trusted Consensus Scheme for Collaborative Learning in the Edge AI Computing Domain", the authors present a trusted consensus scheme for multi-party collaborative learning in edge artificial intelligence systems. By embedding a reputation layer as an incentive mechanism tool and by leveraging on rewards and punishments to be enforced according to the nodes' behavior, each participant can share its own global reputation list in a distributed environment. Since such a reputation incentive module is loadable on popular X-BFT consensus protocols, it is easy to enforce in real applications. The experimental results also reveal that collaborative learning in edge AI computing can be more trusted and suitable.

In closing, we would like to thank all the authors who submitted their research work to this special issue. We would also like to acknowledge the contribution of many experts in the field who have participated in the review process, and provided helpful suggestions to the authors to improve the content and presentation of the articles. We would in particular like to thank Professor Mohsen Guizani, the former Editor-in-Chief, and the publishing team for their support and very helpful suggestions and comments during the delicate stages of concluding the special issue.

Biographies

Min Chen has been a full professor in the School of Computer Science and Technology at Huazhong University of Science and Technology (HUST) since February 2012. He has 300+ publications, including 200+ SCI papers, 100+ IEEE transactions/journal papers, 34 ESI highly cited papers, and 12 ESI hot papers. He has published 12 books. His Google Scholar Citations reached 25,880+ with an h-index of 80 and i10-index of 240. His top paper was cited 3080+ times. He was

selected as a Highly Cited Researcher in 2018, 2019 and 2020. He received the IEEE Communications Society Fred W. Ellersick Prize in 2017, and the IEEE Jack Neubauer Memorial Award in 2019. His research focuses on cognitive computing, 5G Networks, wearable computing, big data analytics, robotics, machine learning, deep learning, emotion detection, and mobile edge computing, among other areas. He is a Fellow of the IEEE.

Haiyang Wang received his Ph.D. degree in computer science from Simon Fraser University, Burnaby, British Columbia, Canada, in 2013. He is currently an associate professor with the Department of Computer Science, University of Minnesota at Duluth. His research interests include cloud computing, peer-to-peer networking, social networking, big data, and multimedia communications.

Kai Hwang (Life Fellow, IEEE) received the Ph.D. degree from the University of California, Berkeley in 1972. Prior to joining USC in 1986, he taught at Purdue University for 11 years. He is a professor of electrical engineering and computer science at the University of Southern California (USC). He was the Founding Editor-in-Chief of the *Journal of Parallel and Distributed Computing* from 1983 to 2011. He has authored or coauthored eight books and more than 300 scientific papers. According to Google Scholar, his work has been cited more than 20500 times with an h-index of 62. He was the recipient of the Lifetime Achievement Award from IEEE Cloudcom-2012 for his pioneering contributions in the field of computer architecture, parallel, distributed and cloud computing, and cyber security. In 2019 he was awarded with the 70 Person in China's 70th Anniversary prize for scientific and technological innovation achievements.

Giancarlo Fortino (SM'12) is full professor of computer engineering in the Department of Informatics, Modeling, Electronics, and Systems at the University of Calabria (Unical), Italy. He received a Ph.D. in computer engineering from Unical in 2000. He is also a distinguished professor at Wuhan University of Technology and Huazhong Agricultural University (China), high-end expert at HUST (China), senior research fellow at the Italian ICAR-CNR Institute, CAS PIFI visiting scientist at SIAT – Shenzhen, and distinguished lecturer for the IEEE Sensors Council. He was a Web of Science Highly Cited Researcher 2020. He is the director of the SPEME lab at Unical as well as co-chair of the joint labs on IoT established between Unical, WUT, SMU and HZAU Chinese universities, respectively. His research interests include agent-based computing, wireless (body) sensor networks, and IoT. He is the author of 500+ papers in international journals, conferences and books. He is the (founding) series editor of the IEEE Press Book Series on Human-Machine Systems and EiC of the Springer Internet of Things series and AE of many international journals such as IEEE TAC, IEEE THMS, IEEE IoTJ, IEEE SJ, IEEE SMCM, IEEE OJEMB, IEEE OJCS, *Information Fusion*, JNCA, and EAAI, among others. He has organized as chair many international workshops and conferences (100+), was involved in a huge number of international conferences/workshops (500+) as an IPC member, and is/was a guest editor of many special issues (60+). He is the cofounder and CEO of SenSysCal S.r.l., a Unical spinoff focused on innovative IoT systems. He is currently a member of the IEEE SMCS BoG and of the IEEE Press BoG, and chair of the IEEE SMCS Italian Chapter.

Jeungeun Song is a data scientist with more than nine years of data analysis and research experience in Canada, China and Korea. She has been a post-doctoral fellow in the Department of Electrical and Computer Engineering at the University of British Columbia (UBC) since September 2018. She obtained a Ph.D. degree from the School of Computer Science and Technology at Huazhong University of Science and Technology (HUST). Before joining HUST, she received B.E. and Master degrees from Sookmyung Women's University, Korea. She is proficient in the skills of using a variety of computer software (SPSS and SAS) for data analysis. Her research focuses on Internet of Things, satellite communications, emotion-aware computing, healthcare big data, cyber physical systems, and robotics, among others.

Limei Peng is an associate professor with the School of Computer Science and Engineering, Kyungpook National University (KNU), Daegu, South Korea. Before joining KNU, she was an assistant professor with the Department of Industrial Engineering, Ajou University, Suwon, South Korea, from in 2018, an associate professor with Soochow University, China, from 2011 to 2013, and a postdoctoral fellow of the Grid Middleware Research Center, Korea Advanced Institute of Science and Technology (KAIST), South Korea, from 2010 to 2011. Her research interests include cloud computing, fog computing, datacenter networks, IoT/IoV, and 5G communications networks. She has served as a (lead) guest editor of several leading journals such as *IEEE Access*, *Elsevier Optical Switching and Networking*, and *Elsevier Vehicular Communications*, among others. She has organized several international conferences including NaNA'2019, ISAIR'2019, and Cloudcomp'2015, among others.

Jože Guna is an assistant professor at the Faculty of Electrical Engineering, University of Ljubljana. His area of research focuses on Internet technologies, multimedia technologies, IPTV systems and IoT, with special emphasis on user centered design, user interaction modalities and designing the user experience, VR/AR/MR technologies, including gamification and flow aspects. Currently he is involved in a number of projects focusing on user experience design and evaluation focused on interactive multimedia and VR/AR/MR applications. He is an expert in Internet, ICT and IPTV technologies and holds several industrial certificates from CISCO, Comptia and Apple, including trainer licenses from Cisco and Apple. He is a senior member of the IEEE and IEEE Slovenia Section Secretary General. He is a co-founder of the Slovenian XR hub and a technical lead of the first XR lab at the Technology Park Ljubljana.