Edge Computing for the Internet of Things


Ju Ren


Yi Pan


Andrzej Goscinski


Raheem A. Beyah

By moving data computation and service supply from the cloud to the edge, edge computing has become a promising solution to address the limitations of cloud computing in supporting delay-sensitive and context-aware services in the Internet of Things (IoT) era. Instead of performing data storage and computing in a cluster of clouds, edge computing emphasizes leveraging the power of local computing and using different types of nearby devices/architectures as edge servers to provide timely and intelligent services. In this way, it can bring many advantages, including highly improved scalability by timely and intelligent service supply and local distributed computing that makes full use of client computing capabilities to meet the requirements of contextual computing. However, to truly realize edge computing in IoT applications, there are still many challenges that need to be addressed, such as how to efficiently distribute and manage data storage and computing, how to make edge computing collaborate with cloud computing for more scalable services, as well as how to secure and preserve the privacy of the whole system.

The purpose of this Special Issue is to investigate the current research trends, and to help stakeholders in industry and academia to better understand challenges, recent advances, and potential research directions in the developing field of edge computing. Through an open call for papers and rigorous peer review, we selected 20 articles from 63 submissions as representatives of ongoing research and development activities. These 20 articles not only encompass a wide range of research topics in edge computing, but also bring some prominent research outcomes in transparent computing. We briefly divide the accepted articles into the following categories.

Edge Computing Architecture and System Design

The article "A Robust Dynamic Edge Network Architecture for the Internet of Things" by Beatriz Lorenzo *et al.* presents a robust dynamic edge network architecture that can leverage mobile devices to dynamically harvest unused resources and mitigate network congestion. The presented architecture comes with an integrated solution of physical, access, networking, application, and business layers to improve the robustness of the network. The next article, "Multiagent based Flexible Edge Computing Architecture for IoT" by Takuo Suganuma *et al.*, presents a flexible edge computing (FLEC) architecture characterized by environment adaptation ability and user orientation ability to address the "rigidity" of traditional edge-computing-based IoT architectures. The authors utilize COSAP, a system configuration platform based on a multiagent framework, as an implementation procedure for a FLEC architecture. The third article, "Edge Computing Gateway of the Industrial Internet of Things Using Multiple Collaborative Microcontrollers" by Ching-Han Chen *et al.*, designs a multi-microcontroller (multi-MCU) system framework combining a field-programmable gate-array-based hardware bridge and multiple scalable MCUs to realize an edge gateway of a smart sensor fieldbus network. Through distributed and collaborative computing, the multi-MCU edge gateway can efficiently perform fieldbus network management, embedded data collection, and network communication to improve the system performance. The fourth article, "KID Model Driven Things-Edge-Cloud Computing Paradigm for Traffic Data as a Service" by Bowen Du *et al.*, proposes a knowledge-information-data (KID)-model-driven Things-edge-cloud computing architecture to enable edge servers to cooperatively work with the cloud and achieve traffic-data as a service. And the fifth article, "A Cost-Efficient Cloud Gaming System at Scale" by Yiling Xu *et al.*, develops a transparent gaming cloud system that can be implemented at the edge of the network to facilitate cloud gaming at scale. Compared to existing cloud gaming technologies, the authors develop an innovative GPU sharing scheme, named TG-SHARE, to use consumer-level GPU devices without resorting to professional and expensive GPUs.

Computation Offloading in Edge Computing

The article "Multi-User Computation Offloading in Mobile Edge Computing: A Behavioral Perspective" by Ling Tang *et al.* investigates the multi-user computation offloading problem in uncertain wireless environments. Based on the framework of prospect theory (PT), they formulate the decision of whether to offload computation or not as a PT-based non-cooperative game and proposed a distributed algorithm to achieve Nash equilibrium. The next article, "Selective Offloading in Mobile Edge Computing for Green Internet of Things" by Xinchen Lyu *et al.*, proposes a lightweight request and admission framework to improve the scalability of mobile edge computing systems. A selective offloading scheme is also developed to minimize the energy consumption of IoT devices. The third article, "ThriftyEdge: Resource-Efficient Edge Computing for Intelligent IoT Applications" by Xu Chen *et al.*, devises a resource-efficient edge computing scheme to properly offload tasks across local devices, nearby helper devices, and the edge cloud in proximity. The proposed computation offloading mechanism consists of a delay-aware task graph partition algorithm and the optimal virtual machine selection method to maximize the efficiency of edge resource utilization and satisfy QoS requirements. And the fourth article in this category, "Collaborative Mobile-Edge Computation Offloading for IoT over Fiber-Wireless Networks" by Hongzhi Guo *et al.*, presents a generic hybrid fiber-wireless architecture with the coexistence of cloud and distributed mobile edge computing for IoT connectivity. A game-theoretic collaborative computation offloading approach is then proposed to address the problem of task offloading among IoT devices, edge servers, and the cloud.

Resource Allocation in Edge Computing

The article "Joint Admission Control and Resource Allocation in Edge Computing for Internet of Things" by Shichao Lin *et al.* focuses on the joint admission control, computation resource allocation, and power control problem in an edge computing system. They propose a cross-layer stochastic network optimization algorithm based on Lyapunov stochastic optimization theory to maximize the system utility. The next article, "Toward Efficient Content Delivery for Automated Driving Services: An Edge Computing Solution" by Quan Yuan *et al.*, presents a two-level edge computing architecture for automated driving services by fully exploiting the intelligence of the wireless edge for coordinated content delivery. The associated challenges with the proposed architecture and some potential solutions are also presented for wireless edge caching and vehicular content sharing. The third article in this category, "A Tensor-Based Holistic Edge Computing Optimization Framework for Internet of Things" by Huazhong Liu *et al.*, proposes five tensor-based representation models to represent the complex relationships and resolve the heterogeneity of different devices in a triple-plane edge computing system. The authors further develop a generalized and holistic EC optimization framework based on the constructed tensors to improve the energy consumption, execution time, system reliability, and quality of experience of the system.

Deep Learning, Virtualization, and Security in Edge Computing

The article "Learning IoT in Edge: Deep Learning for the Internet-of-Things with Edge Computing" by He Li *et al.* investigates the application of deep learning to edge computing systems. Since edge devices generally have limited processing capability, the authors design a learning task offloading strategy to optimize the performance of edge-computing-based deep learning applications. The next article, "Consolidate IoT Edge Computing with Lightweight Virtualization" by Roberto Morabito *et al.*, presents an in-depth analysis on the requirements of edge computing in the perspective of three selected use cases in IoT. The authors discuss and compare the applicability of two lightweight virtualization technologies, containers and unikernels, as platforms for enabling scalability, security, and manageability in edge computing applications. The third article in this area, "Hyperconnected Network: A Decentralized Trusted Computing and Networking Paradigm" by Hao Yin *et al.*, proposes a decentralized trusted computing and networking paradigm, named the hyperconnected network, to meet the challenge of the loss of control over data. The fourth article in this category, "MECPASS: Denial of Service Defense Architecture for Mobile Networks" by Nguyen Van Linh *et al.*, presents a collaborative distributed denial of service (DDoS) defense architecture based on edge computing, named MECPASS, to mitigate attack traffic from mobile devices. The effectiveness and performance of the presented architecture are validated by various types of application-layer DDoS attacks in the context of web servers.

Transparent Computing

The article "Block-Stream as a Service: A More Secure, Nimble, and Dynamically Balanced Cloud Service Model for Ambient Computing" by Jackson He *et al.* proposes a new cloud service model, named block-stream as a service (BaaS), based on transparent computing to provide nimble and fluid services for lightweight IoT devices. A preliminary implementation of BaaS is then provided to show its advantages and some open challenges. The next article, "COAST: A Cooperative Storage Framework for Mobile Transparent Computing Using Device-to-Device Data Sharing" by Jiahui Jin *et al.*, proposes a cooperative storage framework, named COAST, for mobile transparent computing. Based on a device-to-device data-sharing technique, COAST enables a mobile terminal to fetch applications from nearby terminals without accessing the Internet. The article "A Multi-Level Cache Framework for Remote Resource Access in Transparent Computing" by Di Zhang *et al.* presents a multi-level cache framework for remote resource access in transparent computing. The authors design a hybrid multi-level cache hierarchy and make corresponding cache policies to reduce the resource provisioning delay of transparent computing systems. The article "Transparent Learning: An Incremental Machine Learning Framework Based on Transparent Computing" by Kehua Guo *et al.* investigates how to exploit transparent computing to build an incremental machine learning framework, where the data training burden is offloaded from lightweight devices to edge servers. Further, the models of the devices can be updated with incremental learning. A caching mechanism is also designed to divide the training set to optimize the system performance.

We believe that this Special Issue delivers state-of-the-art research on current edge computing topics, and will encourage researchers to devote continuous efforts in addressing remaining open challenges. Finally, we would like to express our appreciation to the authors of all submitted articles and the reviewers for their contributions to this Special Issue. We also sincerely thank Prof. Nei Kato, Editor-in-Chief, for his support of the Special Issue, and Peggy Kang for her guidance and great help in the whole production process.

Biographies

Ju Ren [S'13, M'16] (renju@csu.edu.cn) is a tenure-track professor with the School of Information Science and Engineering, Central South University, China. He received his B.Sc. (2009), M.Sc. (2012), and Ph.D. (2016) degrees, all in computer science, from the same university. His research interests include the Internet of Things, transparent computing, and edge computing. He serves/has served as an Associate Editor for *Peer-to-Peer Networking and Applications* and a TPC member of many international conferences, including IEEE INFOCOM '18, GLOBECOM '17, WCNC '17, and others.

Yi Pan [SM'91] (yipan@gsu.edu) is currently a Regents' Professor and Chair of Computer Science at Georgia State University. He has served as an Associate Dean and Chair of the Biology Department during 2013–2017 and Chair of Computer Science during 2006–2013. He has served as an Editor-in-Chief or Editorial Board member for 15 journals including seven IEEE transactions. His research interests include parallel and cloud computing, wireless networks, and bioinformatics.

Andrzej Goscinski [SM'10] (andrzej.goscinski@deakin.edu.au) is a professor in the School of Information Technology, Deakin University, where he directs research in cloud, edge, and fog computing, service computing; in general, distributed systems and applications. Currently, he concentrates his research on exposing HPC applications as services, publishing them to a broker, and executing them in an SaaS cloud by non-computing specialists; and IoT. He serves as Associate Editor for *IEEE Transactions on SC*, *IJCC*, and *FGCS*.

Raheem Beyah [M'00, SM'11] (rbeyah@ece.gatech.edu) is the Motorola Foundation Professor and Interim Steve W. Chaddick School Chair of the School of Electrical and Computer Engineering at Georgia Tech. He is also the founder of Fortipyhd Logic, Inc. He received the NSF CAREER award in 2009 and was selected for DARPA's Computer Science Study Panel in 2010. He is a member of AAAS and ASEE, a Lifetime Member of NSBE, and an ACM Distinguished Scientist.