

## ACHIEVING ENERGY EFFICIENCY AND SUSTAINABILITY IN EDGE/FOG DEPLOYMENT



Neeraj Kumar

Joel J. P. C. Rodrigues

Mohsen Guizani

Kim-Kwang  
Raymond Choo

Rongxing Lu

Christos Verikoukis

Zhimeng Zhong

The Internet of Things (IoT) has emerged as one of the most advanced and complex technological trends, where more than 50 billion things will be connected (e.g., mobile devices, sensors, wearable devices, and other computing nodes) to the Internet by 2020. Edge/fog computing will play an increasingly important role in handling the information flow of such large and complex networks. An unintended consequence is the impact of their operations on carbon emissions and the resulting electricity costs. Thus, there has been focus on designing energy-efficient solutions for the edge-fog environment.

In this Feature Topic, state-of-the-art research advances in energy efficiency and sustainability for edge/fog deployment are presented. This issue received a total of 31 paper submissions, and after a rigorous review process, only 11 papers were accepted for publication; another seven papers were sent for Open Call publication. Next, we summarize these 11 accepted papers.

The first article, “Secure and Energy-Efficient Handover in Fog Networks Using Blockchain-Based DMM” by Sharma *et al.*, presents a blockchain-based distributed mobility management scheme for efficient handover of services in fog networks. The proposed scheme reportedly achieves both the energy efficiency and security required in a typical setup.

In the second article, “Knowledge-Centric Edge Computing Based on Virtualized D2D Communication Systems” by Wang *et al.*, a knowledge-centric edge-based framework is presented. This framework was designed to detect dynamic changes in the network to automatically manage the communication resources from the information discovered from device-to-device communication systems.

The third article, “Mobile Edge Computing and Networking for Green and Low-Latency Internet of Things” by Zhang *et al.*, presents a mobility-aware hierarchical computing resource framework for computation offloading of mobile devices, as well as an energy-efficient offloading scheme.

The fourth article, “Fog Computing: Architecture, Evaluation, and Future Research Directions” by Aazam *et al.*, discusses cloud-IoT integration challenges and provides a comparative summary between fog and cloud computing paradigms. The authors also provide an overview of fog computing architecture and its typical layers.

In the next article, “Mobility Support for Fog Computing: An SDN Approach” by Bi *et al.*, an SDN-based approach designed to support mobility in fog computing architecture is proposed. Specifically, the authors designed an efficient signaling operation to provide seamless and transparent mobility support to mobile users, and present their proposed route optimization algorithm.

The sixth article, “Secure and Sustainable Load Balancing of Edge Data Centers in Fog Computing” by Puthal *et al.*, presents a novel secure and sustainable load balancing solution for edge data centers. In their approach, the edges are authenticated prior to load balancing.

The seventh article, “Flight Security and Safety of Drones in Airborne Fog Computing Systems” by He *et al.*, discusses security and safety vulnerabilities of drones in airborne fog computing systems, with an emphasis on GPS spoofing attacks.

The eighth paper, “A Study of Green Development Mode and Total Factor Productivity of Food Industry based on Industrial Internet of Things” by Zhang *et al.*, examine the mode

of the food industry's green development in China based on Industrial IoT.

The ninth article, "Semantic Multimedia Fog Computing and IoT Environment: Sustainability Perspective" by Rahman *et al.*, proposes a smart city solution consisting of fog nodes in order to solve always-available sustainability through incentives, and energy-aware cloud computing challenges in a smart city.

The 10th article, "Energy-Optimal Edge Content Cache and Dissemination: Designs for Practical Network Deployment" by Lien *et al.*, proposes an efficient edge content cache and data dissemination technique to reduce energy consumption.

The 11th article, "On Enabling Sustainable Edge Computing with Renewable Energy Resources" by Li *et al.*, proposes an energy management framework that integrates edge computing and microgrid to increase the effectiveness and use of energy resources, while still satisfying the requirements of IoT applications.

The last article, "Saving Energy on the Edge: In-Memory Caching for Multi-Tier Heterogeneous Network" by Xu *et al.*, focuses on the improvement in energy efficiency for edge caching by using in-memory storage and processing. For this purpose, the authors propose two time-to-live designs for data caching at the routers.

The Guest Editors would like to thank the Editor-in-Chief (Dr. Tarek S. El-Bawab) for approving this Feature Topic, and all the authors for submitting their findings for consideration. We are also extremely grateful to the reviewers who devoted their time and effort to conduct thorough reviews and provide timely responses. We hope that the articles published in this Feature Topic will benefit the research community working in this domain.

#### BIOGRAPHIES

NEERAJ KUMAR [M'16, SM'17] (neeraj.kumar@thapar.edu) is an associate professor in the Computer Science and Engineering Department, Thapar University. He received his M.Tech. from Kurukshetra University, India, followed by his Ph.D. from SMVD University, Katra, in CSE. He was a postdoctoral research fellow at Coventry University, United Kingdom. He has more than 160 research publications in leading journals. He is an Associate Editor of *IJCS*, *Wiley*, *JNCA*, *Elsevier*, and *Security*

& *Communication*, *Wiley*. He is an Associate Technical Editor of *IEEE Communications Magazine*.

JOEL J.P.C. RODRIGUES [S'01, M'06, SM'06] is a professor at the National Institute of Telecommunications (Inatel), Brazil and senior researcher at IT, Portugal. He is the leader of the Internet of Things Research Group (CNPq), Director for Conference Development (IEEE ComSoc Board of Governors), IEEE Distinguished Lecturer, and Past Chair of the IEEE ComSoc eHealth and Communications Software TCs. He is the Editor-in-Chief of three international journals, and he has authored or coauthored over 550 publications.

MOHSEN GUIZANI [F] received his B.S. (with distinction) and M.S. degrees in electrical engineering, and M.S. and Ph.D. degrees in computer engineering from Syracuse University, New York, in 1984, 1986, 1987, and 1990, respectively. He is currently a professor and the ECE Department chair at the University of Idaho. His research interests include wireless communications and mobile computing, computer networks, mobile cloud computing, security, and smart grid. He is the author of nine books and more than 500 publications in refereed journals and conferences. He is a Senior Member of ACM.

KIM-KWANG RAYMOND CHOO [SM'15] (raymond.choo@fulbright-mail.org) holds the Cloud Technology Endowed Professorship at the University of Texas at San Antonio. His awards include ESORICS 2015 Best Research Paper Award, 2015 Winning Team of Germany's University of Erlangen-Nuremberg Digital Forensics Research Challenge, 2014 Australia New Zealand Policing Advisory Agency's Highly Commended Award, 2010 Australian Capital Territory Pearcey Award, Fulbright Scholarship, 2008 Australia Day Achievement Medallion, and British Computer Society's Wilkes Award. He is an Australian Computer Society Fellow.

RONGXING LU [S'09, M'11, SM'15] (rlu1@unb.ca) is an assistant professor at the Faculty of Computer Science, University of New Brunswick. He was awarded the Governor General's Gold Medal, Canada, in 2012, and the IEEE ComSoc Asia Pacific Outstanding Young Researcher Award in 2013. He is Secretary of IEEE ComSoc CIS-TC. His research interests include applied cryptography, privacy enhancing technologies, and IoT-big data security and privacy.

CHRISTOS VERIKOUKIS (cveri@cttc.es) (Ph.D., UPC, 2000) is a Fellow researcher at CTTC/CERCA and an adjunct associate professor at the University of Barcelona. He is a co-author of 4 books, 18 chapters, 2 patents, 108 journal papers, and over 180 conference papers. He has participated in more than 30 competitive projects and served as the principal investigator of national projects. He has supervised 15 Ph.D. students and 5 postdoctoral researchers. He received Best Paper Awards at IEEE ICC 2011, IEEE GLOBECOM 2014 and 2015, and EUCNC/EURACON 2016, and the EURASIP 2013 Best Paper Award for the *Journal on Advances in Signal Processing*. He is currently Chair of the IEEE ComSoc CSIM TC.

ZHIMENG ZHONG received his B.Sc., M.Sc., and Ph.D. degrees from Xi'an Jiaotong University in 2002, 2005, and 2008, respectively, all in electronic engineering. From 2009 to 2013, he was an algorithm engineer with Huawei Technologies Ltd., Xi'an. After working with the Research Institute of Aerospace Radio Technology in 2014, he rejoined Huawei Technologies Ltd., Shanghai. His current research interests include digital wireless communications, wireless channel measurement and modeling, and multiple-input multiple-output systems.