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EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: SUSTAINABLE INFRASTRUCTURES, PROTOCOLS, AND RESEARCH CHALLENGES FOR FOG COMPUTING

Cloud computing continues to provide services related to storage and computation by managing a pool of resources that usually costs more financially as well as in terms of latency. On the other hand, due to the distribution of applications and services closer to the end-users, academics and industry experts are now advocating for going from large, centralized cloud computing infrastructures to a range of computing nodes located at the edge of the network. Principally, fog computing extends the services and resources of the cloud closer to users, which facilitates the leveraging of available services and resources in the edge networks. Fog computing is an attractive solution to delay- and resource-constrained large-scale wireless and real-time applications, with its features such as low latency, location awareness, and its capacity to process large numbers of nodes with wireless access.

The concept of separating the network slices requires a number of technologies to be in place. Software-defined networking (SDN), network function virtualization (NFV), fog, and cloud technologies enable networks to be broken down from their underlying physical infrastructures so that they can programmatically provide connectivity as a service. The devices, which will vary greatly in nature, will need to use connectivity in a smart way, with minimal signaling, maximized sleep cycles and lean data transmission—sending only the information needed for the given service. The networks will need to simultaneously support several radio access technologies (RATs), and the radio environment will need to support service flexibility, while maintaining control over costs and energy consumption. Furthermore, the benefit of SDN lies in its ability to provide an abstraction of the physical network infrastructure.

The goal of this Special Section in IEEE ACCESS on ''Sustainable infrastructures, protocols, and research challenges for fog computing'' is to address the following research issues:

- How to handle different protocols and data format from highly dissimilar data sources in fog layer.
- How to determine which data should be processed in cloud or in fog layer while designing computation offloading strategies.
- Moreover, the privacy and security mechanisms within fog servers are also key design considerations.
- Developing sustainable infrastructures and protocols are major research challenges for fog computing.

Our Call for Papers received an enthusiastic response with more than **25** high-quality submissions. Per IEEE ACCESS policy, it was ensured that handling editors did not have any potential conflict of interest with authors of submitted articles. All articles were reviewed by at least two independent referees. The articles were evaluated for their rigor and quality, and also for their relevance to the theme of our Special Section. We considered articles that both proposed solutions tailored particularly in the context of the developing world, and also those that were applicable globally. After a rigorous review process, we accepted nine articles to form the Special Section.

The first article, titled ''Context-aware data-driven intelligent framework for fog infrastructures in internet of vehicles,'' authored by Iqbal *et al.*, discusses a context-aware data intelligent framework for fog infrastructure by extending the fog layer of the traditional Internet of Vehicle (IoV) architecture to enable delay-sensitive IoV applications. A data-driven intelligent framework deals with issues such as high mobility, scheduling and safety applications in real-time or near real-time by collecting, and preprocessing and analyzing data based on its context at fog layer of IoV architecture. More specifically, the proposed framework employs push, pull, or publish/subscribe-based service consumption strategies to support real-time, near real-time, and batch data-based IoV applications.

There are a number of fog simulators available today, among which a few are open-source, whereas the rest are commercially available. The existing fog simulators mainly focus on a number of devices that can be simulated. Generally, the existing simulators are more inclined toward sensors' configurations, where sensors generate raw data and fog nodes are used to intelligently process the data before sending to back-end cloud or other nodes. Therefore, these simulators lack network properties and assume reliable and error-free delivery on every service request. Moreover, no simulator allows researchers to incorporate their own fog nodes management algorithms, such as scheduling. In existing work, device handover is also not supported. In the article ''FogNetSim++: A toolkit for modeling and simulation of distributed fog environment,'' Qayyum *et al.* propose FogNetSim++ that provides a framework for researchers to investigate their own resource management techniques, perform resource handover,

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and adopt new algorithms with the complete network stack.

The third article, ''Towards smart parking based on fog computing,'' by Tang *et al.*, proposes fog computing-based smart parking architecture to improve smart parking in real-time. In brief, the fog nodes deployed at parking lots, cooperating with each other, enable real-time parking slot information provisioning as well as parking requests processing. The cloud center further enhances the smart parking capability by enforcing global optimization on parking requests allocation. As a part of future work, the authors highlight the design of humanized parking strategies to incorporate drivers' preferences for the decision-making process.

In the next article, ''HEAP: An efficient and fault-tolerant authentication and key exchange protocol for Hadoop-assisted big data platform,'' Chattaraj *et al.* propose a fault-tolerant authentication protocol suitable for the Hadoop framework, which is called the efficient authentication protocol for Hadoop (HEAP). Basically, the authors introduce a new approach for security credentials distribution and replication policies in order to mitigate server-side single point of failure and single point of vulnerability issues. It is interesting to note that the proposed scheme is user-friendly in nature and the user needs to remember only their identity and password to log into the proposed authentication system.

The fifth article, ''vFog: A vehicle-assisted computing framework for delay-sensitive applications in smart cities,'' by Shah *et al.*, introduces a framework termed vFog that is designed to provide computing facilities from nearby fog vehicles. The framework utilizes the onboard computing facility of vehicles without the support of roadside units (RSUs). Moreover, the proposed framework handles churn behavior and supports multihop communication to improve the task delivery ratio. vFog is built on the top of OMNeT++, which also supports the simulation of mobile devices. Therefore, the proposed framework can be integrated with IoT devices to simulate more complex real-world scenarios.

Due to the increasing number of network devices (sensors, routers, switches, printers, cameras, and mobile phones) and their heterogeneity, network management has become an important task. Basically, the network management provides a way to i) analyze network performance, ii) monitor network devices, and iii) execute operations on the network such as software management (firmware update, bug fix, and others), routing, security management, and load balancing. The article titled ''M4DN.IoT—A networks and devices management platform for Internet of Things,'' by Silva *et al.*, studies different solutions for IoT networks and device management, identifying their characteristics and technical challenges. Moreover, a review of the most relevant IoT management protocols and platform is presented.

The next article, ''Data capsule: Representation of heterogeneous data in cloud-edge computing,'' by Filip *et al.*, considers highly dynamic environments and the execution of complex decision algorithms in real time, with the requirements for batch processing of big data compatible datasets. The authors develop a mathematical model for each type of entity in the proposal and a formal description of a data capsule, which represents a generic and flexible representation for unstructured units of data in time series databases. More interestingly, they evaluate the proposed model in edge-cloud computing platforms designed for robots that run machine learning-related tasks.

The article, ''An energy-efficient clustering and routing framework for disaster relief network,'' authored by Masaracchia *et al.*, proposes a device-to-device (D2D)-based framework, which, starting from some basic information such as positions and battery level of victim's devices, could provide communication from a disaster area towards a functional area. This framework also evaluates the optimal transmission power for each gateway in order to maximize the energy efficiency in the area and to create a multihop path from the disaster area to relay node minimizing the end-to-end delay.

Finally, You *et al.* present the article ''Fog computing as an enabler for immersive media: Service scenarios and research opportunities'' for the immersive media services (such as augmented reality and virtual reality (AR/VR), 360-degree video, and free-viewpoint video) that require massive data storage, ultra-high computing power, and ultra-low latency. They identify the technologies that are required to support the service scenarios under fog-radio access network (F-RAN) and discuss how they can support the proposed scenarios efficiently. Finally, they discuss possible research opportunities and suggest that integrating immersive media into F-RAN will significantly advance future media services and will also bring new business models.

To conclude, we would like to sincerely thank all the authors for submitting their articles to our Special Section, and the large number of reviewers who kindly volunteered their time and expertise to help us curate a high-quality Special Section on this important and timely topic. We would also like to thank the previous IEEE Access Editor-in-Chief Professor Michael Pecht and other staff members for their continuous support and guidance.

MITHUN MUKHERJEE, *Guest Editor*
Guangdong Provincial Key Laboratory of Petrochemical Equipment Fault Diagnosis
Guangdong University of Petrochemical Technology
Maoming 525000, China

MARIA GORLATOVA, *Guest Editor*
Electrical and Computer Engineering Department
Duke University
Durham, NC 27708, USA

JAMES GROSS, *Guest Editor*
School of Electrical Engineering and Computer Science
KTH Royal Institute of Technology
114 28 Stockholm, Sweden

MOHAMMAD AAZAM, *Guest Editor*
Computer Science
Carnegie Mellon University
Doha, Qatar



MITHUN MUKHERJEE (Senior Member, IEEE) received the B.E. degree in electronics and communication engineering from the University Institute of Technology, Burdwan University, Bardhaman, India, in 2007, the M.E. degree in information and communication engineering from the Indian Institute of Science and Technology, Shibpur, India, in 2009, and the Ph.D. degree in electrical engineering from the Indian Institute of Technology Patna, Patna, India, in 2015. He is currently an Assistant Professor with the Guangdong Provincial Key Laboratory of Petrochemical Equipment Fault Diagnosis, Guangdong University of Petrochemical Technology, Maoming, China. He has (co)authored more than 80 publications in peer-reviewed international transactions/journals and conferences. His research interests include wireless communications, fog computing, and ultra-reliable low-latency communications.

Dr. Mukherjee was a recipient of the 2016 EAI International Wireless Internet Conference, the 2017 International Conference on Recent Advances on Signal Processing, Telecommunications and Computing, the 2018 IEEE SYSTEMS JOURNAL, and the 2018 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS) Best Paper Award. He has been an Associate Editor of IEEE ACCESS and a Guest Editor of the IEEE INTERNET OF THINGS JOURNAL, the IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, *ACM/Springer Mobile Networks and Applications*, and *Sensors*.



MARIA GORLATOVA (Member, IEEE) received the B.Sc. degree *(summa cum laude)* in electrical engineering and the M.Sc. degree in electrical engineering from the University of Ottawa, Ottawa, ON, Canada, and the Ph.D. degree in electrical engineering from Columbia University, New York, NY, USA. She is currently an Assistant Professor of electrical and computer engineering and computer science with Duke University, Durham, NC, USA. She has several years of industry experience, and has been affiliated with Telcordia Technologies, Piscataway, NJ, USA; IBM, Armonk, NY; and D. E. Shaw Research, New York. Her current research interests include architectures, algorithms, and protocols for emerging pervasive technologies. She was a recipient of the Google Anita Borg USA Fellowship, the Canadian Graduate Scholar NSERC Fellowships, and the Columbia University Presidential Fellowship. She was a co-recipient of the 2011 ACM SenSys Best Student Demonstration Award, the 2011 IEEE Communications Society Award for Advances in Communications, and the 2016 IEEE Communications Society Young Author Best Paper Award.



JAMES GROSS received the Ph.D. degree from TU Berlin, in 2006. From 2008 to 2012, he was an Assistant Professor and the Head of the Mobile Network Performance Group, RWTH Aachen University, where he was also a member of the DFG-Funded UMIC Research Centre. Since 2012, he has been an Associate Professor with the Electrical Engineering and Computer Science School, KTH Royal Institute of Technology, Stockholm. Until spring 2019, he served there as the Director for the ACCESS Linnaeus Centre, while he is currently a member of the Board of KTH's Innovative Centre for Embedded Systems. He has authored over 150 (peer-reviewed) articles in international journals and conferences. His research interests are in the area of mobile systems and networks, with a focus on critical machine-to-machine communications, cellular networks, resource allocation, and performance evaluation methods. His research has been awarded multiple times, including the Best Paper Award at ACM MSWiM 2015, the Best Demo Paper Award at IEEE WoWMoM 2015, the Best Paper Award at IEEE WoWMoM 2009, and the Best Paper Award at European Wireless 2009. He was a recipient of the ITG/KuVS Dissertation Award for his Ph.D. dissertation, in 2007.



MOHAMMAD AAZAM (Senior Member, IEEE) received the Ph.D. degree in computer engineering from Kyung Hee University, Seoul, South Korea, in 2015. He is currently a Senior Research Scientist with Carnegie Mellon University in Qatar, Doha, Qatar. He has previously worked with Carleton University, Canada, and Ryerson University, Canada, as a Postdoctoral Fellow. In addition to that, he has completed a course Data Science with *R* from Harvard University, Cambridge, MA, USA, in 2017, and a course Internet of Things from King's College London, London, U.K., in 2016. He has more than 100 publications, including three patents. He is a founding member of IEEE SIG Intelligent Internet Edge. For more details, visit: www.aazamcs.com.