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EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: MOBILE EDGE COMPUTING AND MOBILE CLOUD COMPUTING: ADDRESSING HETEROGENEITY AND ENERGY ISSUES OF COMPUTE AND NETWORK RESOURCES

Mobile applications are advancing toward higher network and compute requirements, which are similar to the requirements of server applications. Users prefer to perform their tasks on the go from mobile devices instead of stationary desktop and server systems. Modern mobile applications limit mobile battery times as charging is lost quickly due to high processing and data demands. Resources other than energy are also limited in mobile devices (memory, CPU millions of instructions per second, etc.). Mobile edge computing (MEC) technologies facilitate resource-scarce mobile devices to enhance their capabilities and execute data/compute-intensive applications while collaborating with resource-rich network servers to enable ubiquitous computing. On the other hand, mobile cloud computing provides higher resources for applications that have low response requirements (noninteractive applications). Both mobile edge computing and mobile cloud computing enable technologies for Internet of Things (IoT), smart grids, and e-health applications.

Smartphone applications rely on offloading techniques to leverage high-performance computing opportunities available on edge and cloud servers. Two main research challenges arise due to the heterogeneity of network and compute resources. Compute resources are unable to execute offloading and collaborative tasks without considering heterogeneity. The heterogeneity of computer resources can be in the form of architecture (ARM, Intel), processing power, and network capabilities. To address these issues, solutions based on application and system virtualization need to be proposed [item 1] in the Appendix]. Network heterogeneity results in varying radio capabilities for the end devices. Network access and collaboration algorithms need to consider this heterogeneity for optimal performance of applications executing on end devices. Moreover, energy is a persistent issue for most of the computing paradigms. Energy optimization techniques in mobile edge and mobile cloud computing can help mobile devices function longer without battery charging [item 2] in the Appendix].

Each article in this Special Section underwent a rigorous peer-review process. At the end, 27 articles were accepted

based on their relevance to the Special Section and positive reviews.

In the article “Delay-aware accident detection and response system using fog computing,” by Dar *et al.*, the authors presented an emergency response system that leverages smartphone and fog computing resources. An Android application is developed to identify nearby incidents with the help of its sensors. A nearby hospital is located with the help of GPS, while ambulances are provided to the exact location of the incident.

In the article “Towards energy-efficient heterogeneous multicore architectures for edge computing,” by Gamatie *et al.*, the authors evaluated low-power multi-core architectures for edge computing. A flexible multi-task programming model is also proposed for the multi-core architecture to enhance its capabilities for out-of-order execution.

The article by Awan *et al.*, “HoliTrust-a holistic cross-domain trust management mechanism for service-centric Internet of Things,” provides a framework for trust management for IoTs. The centralized trust management framework forms communities based on similarity and assigns a trust server to each of them. The trust server manages certificates, trust values, and other information about its domain, while coordinating with other trust servers across the domain.

The article by Lee *et al.*, “Fog-assisted aggregated synchronization scheme for mobile cloud storage applications,” proposed a fog assisted cloud storage synchronization technique that provides a trade-off between access latency and synchronization traffic.

The article by Jing *et al.*, “User-centric delay-aware joint caching and user association optimization in cache-enabled wireless networks,” describes a content placement and delivery strategy in cache-enabled wireless networks. User activity levels and preferences are considered in the problem of content caching. User-BS association problem is formulated on user mobility for content delivery problem.

In the article “Privacy management in social Internet of Vehicles: Review, challenges, and blockchain based solu-

tions,” by Butt *et al.*, a review of challenges faced in managing privacy in SIOV is performed. The article analyzes the privacy issue in SIOV based on parameters such as user behavior and action, communication, data and image, thoughts, location, and space.

The article by Jing *et al.*, “Data loss and reconstruction of location differential privacy protection based on edge computing,” proposes a solution for data loss and privacy protection in edge networks. In the proposed solution, a data query model captures the structure information and the data center connection weight for the relationship between the edge node and the client. The edge node uses differential privacy to protect user location. Finally, data reconstruction methods are used to minimize the data loss uncertainty.

In the article “Secret sharing-based energy-aware and multi-hop routing protocol for IoT based WSNs,” by Haseeb *et al.*, an energy-aware and secure multi-hop routing (ESMR) protocol is proposed. Cluster heads and sinks are selected from devices based on vicinity criteria to share cryptographic keys for light-weight communication.

The article by Khalil *et al.*, “Energy efficient indivisible workload distribution in geographically distributed data centers,” proposes a workload distribution for energy efficiency in geo-distributed data centers. The article presents an energy optimization framework based on constraints of time and available renewable energy levels.

The article by Bukhsh *et al.*, “An efficient fog as-a-power-economy-sharing service,” describes a proposal that interconnects distributed batteries with the help of fog computing and forms the unified energy storage system for a smart community.

In the article “A novel bio-inspired hybrid algorithm (NBIHA) for efficient resource management in fog computing,” by Rafique *et al.*, a hybrid of modified particle swarm optimization (MPSO) and modified cat swarm optimization (MCSO) is proposed with the objective of reducing response time.

The article by Long *et al.*, “PUF-based anonymous authentication scheme for hardware devices and IPs in edge computing environment,” considers heterogeneity of hardware and software for designing an authentication scheme for edge computing. The scheme utilizes double physical unclonable function to generate a challenge that cannot be used in replay attacks for forged authentication.

The article by Sun *et al.*, “An event-driven mechanism coverage algorithm based on sensing-cloud-computing in sensor networks,” presents a coverage algorithm for heterogeneous sensor networks. A coverage model is utilized to compute boundary relationships between sensor nodes and coverage area. Afterward, a Poison distribution model is analyzed for coverage performance of randomly deployed sensors.

The article “Jamcloud: Turning traffic jams into computation opportunities—Whose time has come,” by Xiao *et al.*, describes a vehicular mobile cloudlet architecture that utilizes mobile devices stuck in a traffic jam. The proposed work

analyzes the computational power of the vehicular cloud based on mobility traces from various resources.

In the article “A ‘joint-me’ task deployment strategy for load balancing in edge computing,” by Dong *et al.*, the authors present a joint task scheduling strategy for edge and cloud computing for load balancing. The resources are clustered from the current task set based on their size. A heuristic-based task clustering method and glowworm swarm optimization algorithm is proposed for task deployment on cloud-edge resources.

The article by Mavromoustakis *et al.*, “A mobile edge computing model enabling efficient computation offload-aware energy conservation,” describes an application offload recommendation scheme for edge computing aimed at energy optimization. The article utilizes M2M offloading and presents a mathematical formulation for the framework.

The article by Ghobaei-Arani *et al.*, “ControCity: An autonomous approach for controlling elasticity using buffer management in cloud computing environment,” proposes a framework to control cloud resources elastically. The buffer management module of the framework controls the input queue of user requests, while the elasticity management module utilizes learning automata technique for controlling cloud resources.

In the article by Sobral *et al.*, “Improving the performance of LOADng routing protocol in mobile IoT scenarios,” the authors present a modified Lightweight On-demand Ad hoc Distance-vector Routing Protocol-Next Generation (LOADng). The modified LOADng protocol enables a node to be aware of the availability of its neighbors through control messages. This mechanism enables nodes to follow shorter paths and avoid broken routes to their destination.

In the article by Zhang *et al.*, “Edge caching and resource allocation scheme of downlink cloud radio access networks with fronthaul compression,” an edge caching scheme is proposed with the objective of minimizing the average user delay in a downlink C-RAN. The caching scheme is based on user preference, mobility, and BS association. A resource allocation and fronthaul compression technique is adopted to reduce the user response time.

The article by Kang *et al.*, “Using cache optimization method to reduce network traffic in communication systems based on cloud computing,” presents a cloud-enabled cache-optimization scheme. The scheme utilizes network data mining for similarity analysis and clustering to group data and cache at the user end to reduce network traffic.

The article by Hassan *et al.*, “Edge computing in 5G: A review,” provides a survey of Edge computing in 5G networks. The survey provides taxonomy of edge computing in 5G to highlight existing state-of-the-art solutions. The survey discusses key requirements and applications for the deployment of edge computing in 5G. The survey also highlights recent advancements and research issues in Edge Computing in 5G.

In the article by Qiao *et al.*, “An effective data privacy protection algorithm based on differential privacy in edge

computing,” the authors present a two-phase data privacy protection mechanism. In the first phase, a partitioned histogram data publishing algorithm is used to optimize differential privacy. In the second phase, wavelet transform is used on partitioned data to ensure availability of provider data.

The article by Zhang *et al.*, “Arrival rate-based average energy-efficient resource allocation for 5G heterogeneous cloud RAN,” describes a resource allocation framework for 5G-based heterogeneous C-RAN. The objective of the study is to make energy-efficient resource allocation based on arrival rate of tasks, maximum transmit power, average power, etc. The NP hard optimization problem is divided and solved in real-time using fractional programming and norm approximation.

The article by Mustafa *et al.*, “SLA-aware best fit decreasing techniques for workload consolidation in clouds,” presents a workload consolidation technique for cloud computing. The technique optimizes energy within the constraints of service level agreements. The study presents a modified best first decreasing algorithm to allocate task to computer resources.

In the article by Mukhurjee *et al.*, “Task data offloading and resource allocation in fog computing with multi-task delay guarantee,” the authors present a task offloading framework for fog computing. The primary fog node decides what part of the task is executed on fog and cloud while meeting the delay constraints of each task. The optimization problem is formulated as Quadratically Constraint Quadratic Programming problem.

The article by Liu *et al.*, “Center-less single sign-on with privacy-preserving remote biometric-based ID-MAKA scheme for mobile cloud computing services,” presents a remote, single sign-on biometric-based authentication scheme. The scheme is center-less as the server does not participate in the authentication procedure. An elliptic curve cryptography based token is used along with fuzzy extractor to authenticate the user across multiple cloud platforms.

The article by Zhao *et al.*, “Multi-user MAC protocol for WLANs in mmWave massive MIMO systems with mobile edge computing,” explores the potential of mmWave MIMO systems for WLAN in edge computing. The study proposes a medium access protocol with space division multiplexing to adapt to the unique nature of mmWave MIMO systems.

In the article by Liaqat *et al.*, “Characterizing dynamic load balancing in cloud environments using virtual machine deployment models,” a thorough investigation of OpenStack scheduler for virtual machine placement is presented. A lightweight extension of the compute service is composed to compare the proposed scheduler with the OpenStack nova scheduler. The scheduler is analyzed for the enhancement of cloud performance and shows improvement in CPU utilization and application execution time among other parameters.

In conclusion, the Guest Editors hope that this Special Section will benefit the scientific community and contribute to the knowledge base. They would like to take this

opportunity to applaud the contributions of the authors to this Special Section. We highly appreciate the contributions of the reviewers for their constructive comments and suggestions. We also would like to acknowledge the guidance from the Editor-in-Chief and staff members.

APPENDIX RELATED WORK

- 1) J. Shuja, A. Gani, K. Ko, K. So, S. Mustafa, S. A. Madani, and M. K. Khan, “SIMDOM: A framework for SIMD instruction translation and offloading in heterogeneous mobile architectures,” *Trans. Emerg. Telecommun. Technol.*, vol. 29, no. 4, p. e3174, 2018.
- 2) F. Zhang, J. Ge, C. Wong, C. Li, X. Chen, S. Zhang, B. Luo, H. Zhang, and V. Chang, “Online learning offloading framework for heterogeneous mobile edge computing system,” *J. Parallel Distrib. Comput.*, vol. 128, pp. 167–183, Jun. 2019.

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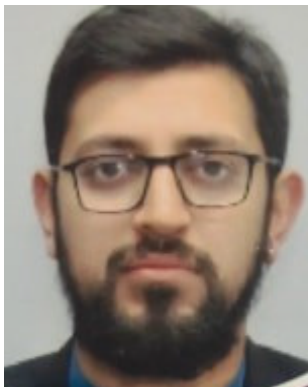
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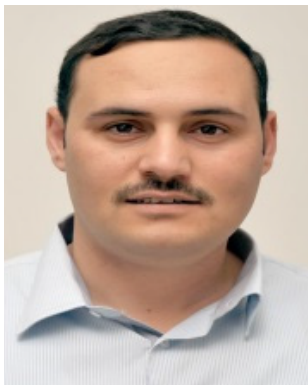


MUHAMMAD KHURRAM KHAN (Senior Member, IEEE) is currently a Full Professor with the Center of Excellence in Information Assurance (CoEIA), King Saud University, Saudi Arabia. He is one of the founding members of the CoEIA and served as the Research and Development Manager from 2009 to 2012. He has published more than 375 research papers in internationally reputed journals and conferences. In addition, he is an inventor of ten U.S./PCT patents. He has edited seven books/proceedings published by Springer–Verlag and the IEEE. His research interests include cyber security, digital authentication, biometrics, multimedia security, and technological innovation management. He has secured an Outstanding Leadership Award at the IEEE International Conference on Networks and Systems Security, Australia, in 2009. He received the Gold Medal for the Best Invention and Innovation Award from the Tenth Malaysian Technology Expo, Malaysia, in 2011. Moreover, his invention recently received a Bronze Medal at the 41st International Exhibition of Inventions, Geneva, Switzerland, in 2013. In addition, he received the Best Paper Award for the *Journal of Network and Computer Applications* (Elsevier)

in 2015. He was a recipient of the King Saud University Award for Scientific Excellence (research productivity) in 2015 and the King Saud University Award for Scientific Excellence (inventions, innovations, and technology licensing) in 2016. Moreover, he is one of the organizing chairs of more than five dozens of international conferences and a member of the technical committees of more than ten dozens of international conferences. He was the Editor-in-Chief of a well-esteemed international journal, *Telecommunication Systems* (Springer–Verlag, since 1993) with an impact factor of 1.7 (JCR) in 2019. He is also a full-time Editor/Associate Editor of several international journals/magazines. He has also served as the Guest Editor of several international ISI-indexed journals of Springer–Verlag and Elsevier Science.



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Throughout his career, he received three teaching awards and four research awards. He also received the IEEE Communications Society WTC Recognition Award in 2017 as well as the AdHoc Technical Committee Recognition Award in 2018 for his contribution to outstanding research in wireless communications and *ad hoc* sensor networks. He was the Chair of the IEEE Communications Society Wireless Technical Committee and the TAOS Technical Committee. He guest edited a number of special issues in IEEE journals and magazines. He is currently the Editor-in-Chief of *IEEE Network*. He serves on the editorial boards of several international technical journals and is the Founder and Editor-in-Chief of *Wireless Communications and Mobile Computing* (Wiley).



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