Guest Editorial Special Issue on Edge Intelligence for Sustainable Smart Environments

THIS special issue, organized by Carlo Mastroianni, Franco Cicirelli, Min Jia, Sabita Maharjan, and Ian Taylor, offers a selection of excellent articles in the field of Edge Intelligence and its exploitation for the design and development of sustainable and smart environments. Edge Computing is emerging due to the widespread availability of computational resources, mobile devices, sensors and actuators that are pervasively deployed and today amount to more than 7 billion interfaces in the network. Edge Computing enables the pushing of computation to the edge of the network, away from data centers and close to people and data sources. Edge Intelligence derives from the convergence of Edge Computing with the exploitation of artificial intelligence methodologies and cognitive technologies, involving sensing/actuation, learning and reasoning on distributed data and Internet of Things (IoT) devices.

A new generation of smart environments, empowered with Edge Intelligence capabilities, can assist the effective management of modern society by combining the development of advanced services able to satisfy user needs and preferences dynamically, with urgently needed aspects, like better exploitation of renewable energy sources, energy optimization, environment sustainability, people's safety, quality of life and comfort. Edge Intelligence helps service provisioning, computation and communications to become efficient, green and sustainable in different ways, among which: (i) Edge Intelligence can contribute to optimize data center usage and reduce the amount of data needing to traverse the network, leading to a reduction of energy consumption and carbon emissions; (ii) applications enriched by Edge Intelligence can satisfy user needs through a more sustainable use of environmental resources; (iii) based on predictions performed by Edge Intelligence algorithms, data and computation can be brought closer to the sites where green energy is available.

At the end of the review process, 11 articles have been accepted for publication in this special issue, out of 25 that were submitted. In the following, to help the reader identify the research works that are most interesting for him/her, the articles are categorized into four classes: (i) articles on mobile edge computing; (ii) articles on computing and communications with unmanned aerial vehicles (UAVs) and drones; (iii) articles on smart grids and (iv) articles covering various aspects of IoT systems and Wireless Sensor Networks (WSNs).

Mobile edge computing (MEC) is the main area of interest of the first two articles included in this issue. [A1] starts from the consideration that mobile edge computing has emerged as a promising computing platform that can address the problem of high bandwidth and low latency requirements of IoT applications. The main role of MEC is to provide computing, storage, network, and communication resources at the edge of mobile networks, which help to decrease the energy consumption of data centers and mobile devices as well as the network load. The authors propose an energy consumption model for MEC servers, based on intelligent learning approach, specifically on Elman Neural Network (ENN) and feature selection. The accuracy of the model was trained on three different types of tasks, i.e., CPU-intensive, Web transaction, and I/O-intensive, and evaluated on several test datasets.

In [A2], the authors address the problem of efficiently supporting Deep Neural Networks (DNN) intelligent applications on mobile devices. Due to the challenges of insufficient computing power and small storage space in mobile devices, the DNN training is often demanded to the cloud or the edge layer. When the client device is mobile, we first need to determine which cloud/edge server(s) the client is connected to, and then migrate the DNN model from the client to the chosen server(s). The paper addresses the joint optimization problem of DNN migration and DNN upload in a local-edge-cloud collaborative environment. A set of experiments confirm that the presented approach is suitable for large-scale DNN parallelism in a multi-user local-edge-cloud environment with limited computing resources.

The focus of the successive three articles is on computing and communication issues in the application domain of UAVs and drones. In [A3], hovering UAVs are considered, which are in charge of collecting data coming from mobile sensor nodes scattered in multiple data-collection areas. In this scenario, various performance metrics are optimized jointly, including: (i) the collected data's age of information and the signal to interference plus noise ratio, (ii) the data collection areas' completeness, and (iii) the mobile sensor nodes' energy consumption. The joint optimization problem is firstly formulated, then a coalition formation game model is established. To reach the Nash equilibrium of the game model, two algorithms are proposed, which aim to optimize the mobile sensor nodes' coalition formation and their position, respectively. Extensive simulation experiments are carried out in order to assess the correctness and effectiveness of the proposed algorithms.

Digital Object Identifier 10.1109/TGCN.2022.3148565

Irtija *et al.*, [A4] introduces an energy-efficient edge computing framework, which relies on approximate computing and on the theory of satisfaction games. The goal is to collaboratively utilize Multi-access Edge Computing and Fully Autonomous Aerial Systems (FAAS) to support the execution of machine learning tasks on IoT computing nodes residing in some areas of interest. The satisfaction games are used to establish whether some of the nodes' tasks should be offloaded to an Edge server or to a FAAS hovering above the considered areas. The decision is taken by considering latency, energy consumption, and the acceptable inference level of the adopted deep neural network. A distributed learning algorithm is also introduced, in which the satisfaction equilibrium of the system (obtained when all the IoT nodes satisfy their latency and energy consumption constraints) is determined. The algorithm determines the generalized satisfaction equilibrium, where part of the nodes satisfy their constraints, while accepting that some other nodes are unable due to the limitations on computing resources.

Alsamhi *et al.*, [A5] focuses on technological solutions enabling drone edge intelligence in the domain of sustainable smart IoT environments. The research effort is devoted to studying the synergy among drone management, Federate Learning (FL) and blockchain technology. Drones can be used as relay mobile stations to gather data from low-power short-range IoT devices while enhancing their energy efficiency. They can help to extend the network coverage, by improving the quality of service and moving computation capabilities closer to the IoT devices. FL enables edge devices (i.e., drones) collaboratively train a global model, while preserving data privacy. The blockchain technology ensures high-level security and enables decentralization, thus supporting on-drone federate learning. The contribution of the article is threefold: (i) it reviews existing work on blockchains and FL for green and smart environments; (ii) it discusses the exploitation of blockchains and FL to improve the smartness, connectivity and energy efficiency of the IoT environment; (iii) it outlines the challenges, opportunities and future trends regarding the adoption of blockchains and FL in smart environments assisted by drone edge intelligence.

Two articles highlight the support of edge computing to the efficient management of smart grids. Xia *et al.*, [A6] focuses on fog computing-based smart grids, where a reliable communication network is deployed in parallel to the power transmission and distribution grid. In this context, a set of fog nodes, connected to smart meters, enable the utility company to dynamically obtain the electricity consumption data, and adjust the price according to the dynamic needs of electricity users. This helps to improve the balance of electrical load and the efficiency of energy usage. This research work presents an approach that allows the utility company to obtain more fine-grained electricity data while protecting the privacy of users. The smart meters and the fog nodes concur to structure, encrypt and aggregate the electricity consumption data through a super-incremental sequence matrix and a homomorphic Paillier cryptosystem, which send the ciphertexts to the control center. The control center decrypts the aggregated ciphertext to obtain multi-dimensional and multi-angle electricity data, which is accurate to the types of household appliances and energy efficiency indexes.

Gunaratne *et al.*, [A7] illustrates how the increasing access to green and renewable energy, and the large number of distributed energy resources (DER) connected to the grid, allow reducing the usage of fossil fuels and cutting carbon emissions. A more refined management of the grid is required, including the monitoring of environmental parameters such as carbon footprint, temperature, weather conditions. The presented approach, based on edge intelligence, identifies the dynamic changes in the edge layer during the local decision-making process. A Multivariate Exponentially Weighted Moving Variance (MEWMV) technique is used to identify the subset of significant variables that are responsible for the out-of-control signals during the monitoring process.

Four articles address various aspects of IoT systems and WSN networks, where the exploitation of edge intelligence can help to improve energy efficiency. In [A8], fog computing emerges as a viable solution for applications that need fast data processing, since data analytics is embedded into network nodes that are placed close to the data sources. The FPGA (field-programmable gate array) technology can be utilized profitably to implement fog nodes, as this technology can provide the architectural flexibility that is needed for timely functional updates, since the internal circuitry can be adapted at run-time. Moreover, an FPGA-based fog node exhibits high energy efficiency for both network packet and data analytics processing. As a case study, a fog node was configured by the authors as a network switch with a Windowed Gaussian anomaly detection analytics, which was then replaced at run-time with a k-nearest neighbors Conformal Anomaly Detector (KNN CAD) algorithm that offers better accuracy for anomaly detection in time-series data.

The work presented in [A9] promotes the Named Data Networking (NDN) paradigm as an efficient way to increase the sustainability of the IoT ecosystem in presence of increasing data volumes and more demanding application requirements. NDN supports name-based content delivery, thus enabling in-network caching by all the Internet routers. This paradigm opens new caching opportunities for IoT applications, where limiting the exchanged data traffic with IoT devices and the amount of data needed to traverse the network can help to reduce energy consumption and carbon emissions, thus contributing to green and sustainable networking. The authors present and analyze the performance of a novel strategy for caching IoT data streamed by WSNs at Internet-scale, based upon two distinct policies applied, respectively, at the edge and the core segments of the network. Both policies are light and reactive, and jointly account for content popularity and freshness.

The topic addressed in [A10] is the rapid development of services provided by video cameras, for example, related to monitoring, tracking, and surveillance. These cameras produce a massive amount of data and, since capturing and processing multimedia data needs a large amount of resources, they are power-hungry and present a significant carbon footprint. The main idea of the paper is to extend the concept of Network-as-a-Service (NaaS) to video cameras. The authors propose a Green Camera NaaS (G-CNaaS) platform, which decouples the physical camera networks from the end-users, reduces the difficulties related to the procurement and deployment of camera networks, and limits the network traffic by filtering the unnecessary data from the camera nodes. The G-CNaaS platform enables each camera to participate in multiple Virtual-Camera-Networks (VCNs), by selecting an optimal set of cameras for each VCN. The camera nodes are coupled with edge devices, which are equipped with pre-trained learning models giving them essential intelligence to analyze the captured multimedia data and the requirements of the users that need to benefit from video services.

Ghosh *et al.*, [A11] addresses wireless sensor networks (WSNs), where an edge node, or central entity, is connected wirelessly to several sensor hubs. In turn, each sensor hub is equipped with multiple sensors in order to monitor various parameters in the environment. Environmental sensors are highly energy consuming, therefore energy efficiency and sustainability of WSNs is a major concern. An efficient strategy is to shift part of the computation/processing complexity from the sensors to the edge nodes. The proposal of the authors is to predict the values of some parameters from other parameters, by exploiting both temporal correlation and cross-correlation of measured quantities. An optimization function, based on a Gaussian process regression (GPR) prediction model, is devised to derive, at each measurement cycle, the subset of active sensors that allows minimizing the prediction error on parameter values while reducing the amount of consumed energy. This strategy was assessed with a set of experiments on air-pollution monitoring parameters.

We would like to thank all the authors for their outstanding contributions to this special issue, and the reviewers for their efforts and comments, which helped to improve the quality of the articles. Finally, we would like to thank the Editor-in-Chief, Zhisheng Niu, and the Area Editor, Yan Zhang, for their diligence and support along the entire process.

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APPENDIX: RELATED ARTICLES

[A1] Z. Zhou, M. Shojafar, J. Abawajy, H. Yin, and H. Lu, "ECMS: An edge intelligent energy efficient model in mobile edge computing," *IEEE Trans. Green Commun. Netw.*, vol. 6, no. 1, pp. 238–247, Mar. 2022, doi: 10.1109/TGCN.2021.3121961.

[A2] M. Xue, H. Wu, R. Li, M. Xu, and P. Jiao, "EosDNN: An efficient offloading scheme for DNN inference acceleration in local-edge-cloud collaborative environment," *IEEE Trans. Green Commun. Netw.*, vol. 6, no. 1, pp. 248–264, Mar. 2022, doi: 10.1109/TGCN.2021.3111731.

[A3] Y. Yang, X. Wei, R. Xu, and L. Peng, "Joint optimization of AoI, SINR, completeness, and energy in UAV-aided SDCNs: Coalition formation game and cooperative order," *IEEE Trans. Green Commun. Netw.*, vol. 6, no. 1, pp. 265–280, Mar. 2022, doi: 10.1109/TGCN.2021.3114544.

[A4] N. Irtija, I. Anagnostopoulos, G. Zervakis, E. E. Tsiropoulou, H. Amrouch, and J. Henkel, "Energy efficient edge computing enabled by satisfaction games and approximate computing," *IEEE Trans. Green Commun. Netw.*, vol. 6, no. 1, pp. 281–294, Mar. 2022, doi: 10.1109/TGCN.2021.3122911.

[A5] S. H. Alsamhi *et al.*, "Drones' edge intelligence over smart environments in B5G: Blockchain and federated learning synergy," *IEEE Trans. Green Commun. Netw.*, vol. 6, no. 1, pp. 295–312, Mar. 2022, doi: 10.1109/TGCN.2021.3132561.

[A6] Z. Xia, Y. Zhang, K. Gu, X. Li, and W. J. Jia, "Secure multi-dimensional and multi-angle electricity data aggregation scheme for fog computing-based smart metering system," *IEEE Trans. Green Commun. Netw.*, vol. 6, no. 1, pp. 313–328, Mar. 2022, doi: 10.1109/TGCN.2021.3122793.

[A7] N. G. T. Gunaratne, M. Abdollahian, S. Huda, M. Ali, and G. Frontino, "An edge tier task offloading to identify sources of variance shifts in smart grid using a hybrid of wrapper and filter approaches," *IEEE Trans. Green Commun. Netw.*, vol. 6, no. 1, pp. 329–340, Mar. 2022, doi: 10.1109/TGCN.2021.3137330.

[A8] T. H. Tan, C. Y. Ooi, and M. N. Marsono, "RtFog: A real-time FPGA-based fog node with remote dynamically reconfigurable application plane for fog analytics redeployment," *IEEE Trans. Green Commun. Netw.*, vol. 6, no. 1, pp. 341–351, Mar. 2022, doi: 10.1109/TGCN.2021.3122545.

[A9] M. Amadeo, C. Campolo, G. Ruggeri, and A. Molinaro, "Beyond edge caching: Freshness and popularity aware IoT data caching via NDN at Internet-scale," *IEEE Trans. Green Commun. Netw.*, vol. 6, no. 1, pp. 352–364, Mar. 2022, doi: 10.1109/TGCN.2021.3124452.

[A10] N. A. Singh, A. Roy, and S. Misra, "Edge intelligence for rendering green camera-network-as-a-service," *IEEE Trans. Green Commun. Netw.*, vol. 6, no. 1, pp. 365–375, Mar. 2022, doi: 10.1109/TGCN.2021.3126276.

[A11] S. Ghosh, S. De, S. Chatterjee, and M. Portmann, "Edge intelligence framework for data-driven dynamic priority sensing and transmission," *IEEE Trans. Green Commun. Netw.*, vol. 6, no. 1, pp. 376–390, Mar. 2022, doi: 10.1109/TGCN.2021.3136139.

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