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# Editorial: Edge Computing for the Internet of Things

**Hao Ran Chi**

Instituto de Telecomunicações, Universidade de Aveiro, 3800-193 Aveiro, Portugal; ytchr@av.it.pt

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Fifth-generation mobile networks (5G) promise higher flexibility compared with 4G, while also fulfilling the service-level agreement (SLA). To achieve this, the European Telecommunications Standards Institute (ETSI) has contributed to the standardization of edge computing [1], which, compared with widely adopted cloud computing, is configured physically closer to its users, providing distributed computation and storage capacity. Therefore, edge computing has been acknowledged to overcome the issues caused by the conventional centralized computation network formed by cloud computing alone, e.g., single point of failure and excessive traffic/computation burden caused by data aggregation. Moreover, thanks to the development of virtualization and pervasive artificial intelligence (AI), edge computing has been foreseen to be further proliferated towards 6G.

Therefore, edge computing has unique strengths compared with cloud computing, including:

- Low latency: with the conceived evolution of 5G towards 6G, an increasing number of emerging applications have been foreseen to be latency-sensitive. In fact, ultra-low latency will be required, i.e., <1 ms [2]. For instance, compared with video streaming and emerging virtual reality in 5G, holographic communications require even larger throughput and much lower latency, with real-time transmission and processing for higher dimensions of data [3]. Therefore, relying solely, or mainly, on cloud computing will lead to long response times caused by data aggregation in cloud servers, which might result in failure to achieve ultra-low-latency performance for these applications. Additionally, the larger scale of the Internet of Things (IoT) system is foreseen to deteriorate data transmission latency with increased physical distance. Therefore, edge computing, with physically closer IoT devices, will be widely deployed to improve the latency issues caused by the aforementioned scenarios [4].
- Low individual computation: although it would shorten transmission latency, an individual edge computing server might have limited computation/storage capacity. Therefore, edge computing would perfectly match latency-sensitive services with relatively low-computation/storage services, e.g., real-time monitoring in Smart Healthcare [5]. On the other hand, latency-insensitive services could be uploaded to cloud servers; regarding latency-sensitive and high-computational tasks, there is high demand for task scheduling strategies among edge computing that target high quality of service/quality of experience (QoS/QoE), which are constrained by the service-level agreement (SLA).
- Traffic offloading: with the conceived ultra-high data rate of 6G (i.e., peak data rate reaching 1000 Gbps), edge computing servers could be configured as backup for cloud computing for temporary excessive computation/storage demands [6]. Although many multi-cloud structures have been developed to maturity [7], the offloading of traffic to edge computing servers has the advantages of lower cost, low latency, and, if feasible, high privacy (e.g., offloading users' services to their own edge computing servers). Moreover, as mentioned in the "low individual computation" section above, peer-offloading among edge computing servers has drawn significant attention recently, relying on the emerging virtualization of 5G and pervasive AI towards 6G. The main research highlights in edge computing-based peer-offloading are foreseen

to include, but are not limit to: the decentralization of peer-offloading strategies (not only physically, but also logically, i.e., the release of centralized data aggregation/sharing) [8], topological analysis [9], offloading efficiency (convergence speed and effectiveness, energy efficiency, latency, etc.) [5], and algorithmic simplicity [10].

Besides of the proliferation of edge computing at the network and data management levels, the Internet of Things (IoT) has been well acknowledged, mainly in the physical layer, to provide pervasive connections among ambient devices (or, things). Many efforts have been made to standardize the infrastructural deployment of IoT. For instance, the recently approved IEEE P2668 provides an emerging indexing standardization for IoT that is capable of generically and objectively quantifying the performance of IoT solutions, and is also known as IDex [11]. Similar to edge computing, it will boost the IoT market by connecting >21.5 billion devices by 2025 [12]. In fact, IoT has been widely predicted to become the Internet of Everything (IoE), which will function simultaneously with pervasive AI embedded in edge/cloud computing for comprehensive automation in 6G.

Many challenges will be faced in the evolution of IoT and edge computing in 6G. The door to this new era has already been opened thanks to cutting-edge research dealing with resource allocation and scheduling for ultra-large-scale edge computing-based IoT networks, energy efficiency optimization for IoT, targeting the conceived goal of "Green 6G" (i.e., 1TB/J), the interoperability of heterogeneous IoT networks, etc. Additionally, towards human–machine harmonization, intent-based networking and emotional sensing will also upgrade conventional network operation and IoT-based sensing technologies, respectively.

Therefore, in this editorial, we posit that, aligned with edge computing-based IoT, some typical emerging services will be supported, including:

- Pervasive automation: AI-based technologies have been widely adopted in 5G and beyond. In particular, for various machine learning algorithms, including supervised learning, unsupervised learning, reinforcement learning, and deep learning, applications have been suggested based on their unique strengths and limitations [13]. Furthermore, future AI technologies (particularly machine learning algorithms) will be highly decentralized and empowered by edge computing, and will thus have relatively low latency, low cost, and high privacy. For instance, federated learning has provided a way to decentralize decision making in AI, relying on edge-based agents [14]; this, compared with conventional centralized structures (e.g., solely relying on the cloud), enables higher reliability and more simplified computation of individual agents. However, the accuracy of edge-based decentralized AI automation might be compromised by the limited computation capacity of edge computing, which prompts two main research directions: the simplification of AI algorithms, and topological convergence optimization.
- Seamless service provision (spatiotemporally): Current ultra-reliable low-latency communications (URLLC) and massive machine-type communications (mMTC) in 5G have validated the future development of edge computing-based IoT towards seamless spatiotemporal service provision. Ultra-low latency will contribute to the real-time on-demand attributes of latency-sensitive services, e.g., holographic telecommunication and remote surgery; on the other hand, ultra-large-scale edge computing networks ensure wide spatial coverage, supporting data collection and processing for ubiquitous IoT devices.
- Human-centric services: Recent research has emphasized the quality of experience (QoE) using direct feedback from users [15,16]. For instance, emotion sensing technologies are highly attractive, and benefit from the maturation of emotion sensing-based IoT devices, e.g., consumer IoT devices such as smart watches and other healthcare wearables. Thus, edge computing functions can provide real-time customized QoE to individual users thanks to their capacity to build local personalized databases, and to interact with well-recognized database from the cloud/Internet.

- Comprehensive systemic optimization: As aforementioned, virtualization in 5G and digital twins in beyond 5G will be fully popularized in the next generation of communications, breaking the barrier caused by conventional pre-defined optimization strategies. Due to their nature, virtualized services are capable of supporting a wide range of ultra-dense IoT networks. Nevertheless, regarding the harsher requirements of 6G, edge computing-based IoT networks cannot be optimized based solely on single- or low-dimensional objectives; instead, systemic optimization that comprehensively considers multiple objectives and high dynamics will be the target. Additionally, determining how to coordinate and cooperate distributed edge computing servers, as well as to harmonize the optimality of local/global goals, will be the next challenge faced in the interoperability enhancement of edge computing-based IoT networks.
- Edge computing/IoT-based security and trust management: Although it has the potential to achieve high privacy levels, edge computing might face unique challenges regarding security and trust management. Research efforts in this area have mainly focused, and will continue to focus, on the following features: (i) the accuracy of the trust values of edge computing/IoT networks [17]; (ii) security against potential cyberattacks [18]; (iii) the availability of the system, even under attacks against certain individual edge computing/IoT devices; and (iv) the flexibility of edge computing server utilization, as well as the configuration and authentication of new edge computing servers/IoT devices/users.

Therefore, this Special Issue focuses on tackling the problems in edge computing and IoT technologies while considering the emerging challenges and opportunities in cutting-edge communication and computing technologies.

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