NABEA AL-AJYAL FOUNDATION PRESS
Online ISSN: 0000-0000 PRINT ISSN: 0000-0000
CyberSystem Journal (CSJ)

CyberSystem Journal *Review Article*

Edge Computing Vs. Cloud Computing: Evaluating Performance, Scalability, and Security in Modern Applications

Alaa Hamza Omran[1], Yaser M. Abid[1*], Mohammed Salih Mahdi[1], and Bilal Ibrahim Bakri[1]

[1] University of Information Technology and Communication, Baghdad 10011, Iraq

***** Corresponding Author: Yaser M. Abid, Email: yasseralasady@uoitc.edu.iq

***Abstract*:** Emerging computing paradigms such as edge computing and cloudlet computing offer distributed computing resources in proximity to the sources and end users. By moving the processing closer to the data source and consumer, these novel paradigms improve the performance by decreasing latencies, and thus by enabling a faster and real-time provision of services. In addition, they can be used to offload massive amounts of raw data for processing on more powerful computing resources instead of sending all the data through the network towards the clouds, thus saving network bandwidth and mitigating congestion. These computing paradigms also enable more flexible service provision, as the resources can be easily scaled based on the demand in a productive and cost-effective way compared to the traditional cloud computing infrastructures. The rapid evolution of modern technologies has led to the emergence of a myriad of applications in different domains such as Industry 4.0, the Internet of Things, smart cities, health-care, and transportation. The typical processing approach in these applications involves data travel from sources to machines or servers for processing and then back to the end users. Since the data travel distance might be long depending on network and topological structures, traditional cloud computing is found to be insufficient to fulfil the performance, scalability, and security requirements of many modern applications. Therefore, there is an urgent need for novel computing paradigms which close the processing gap between data sources and consumers.

***Keywords*:** Cloud computing, Edge, Scenarios

Access this article online

1. Introduction

Edge computing has emerged as a cost-effective extension of cloud computing to meet the ever-increasing demands of big data and real-time applications. Cloud computing has been widely adopted for its virtually unlimited resource provisioning, pay-as-you-go pricing model, and automated service management. Large cloud infrastructures with thousands of servers have been built to ease the burden of application management from end users [1]. However, there are some shortcomings of offloading everything to a cloud. First, there often exist concerns about privacy and security of sensitive information being processed in the cloud [2]. Second, the latency for accessing cloud services may be unacceptable for real-time applications. The network latency to the cloud is often over 100 ms, and round trip delays in such latency prone applications (e.g., vehicles, robots) can cause catastrophes [3]. To address these issues, edge computing has emerged as a new computing paradigm that processes data closer to where it is generated. As a consequence, the burden on the cloud is alleviated, enabling the cloud to run more complex applications efficiently.

Received February 06, 2024; Revised March 7, 2024; Accepted April 12, 2024; Published June 30, 2024

https://doi.org/10.57238/fpj44896

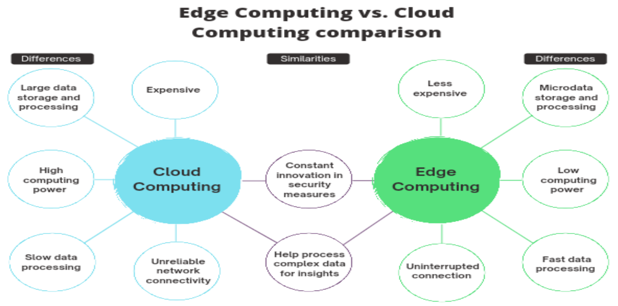

Figure 1. Edge computing vs. cloud computing comparison

The main characteristics of edge computing are as follows:

- Location - edge computing aims to provide computation, storage, and communication resources close to end users unlike cloud computing which is based on large data centers often located far away;
- Offloading decision - in edge computing, users can decide whether to keep computation at edge or migrate the computation to cloud for further processing. Such decisions depend on the characteristics of the data;
- Wireless - the communication from user to edge is typically wireless and thus has much higher latency compared to wired communication from the edge to the cloud;
- Heterogeneity - edge resources are likely to be heterogeneous and dynamic, allowing the infrastructure to adapt to changing conditions;
- Fog computing is often used interchangeably with edge computing. However, fog computing is more a complementary paradigm that extends cloud capabilities towards the edge, and covers a wider area [5].

1.1 Definition and Characteristics

Edge computing can be considered a distributed computing architecture positioned between cloud computing and end-users. It not only pushes data storage and computations away from the edge cloud but also brings computation, storage, and services closer to the datacenter. In edge computing, data is generated and processed at or close to the edge of the cloud [6]. The cloud is, therefore, used for analyzing, reporting, and storing data, and the edge acts as an intermediate layer. Typically, the edge cloud is located in a private or remote cloud where data travels through multiple hops before alternate access routes across the network. Such access can suffer from delayed service due to latency and jitter, which can impact user experience. Overall, edge computing can reduce latency, bandwidth consumption, and privacy risks, and can ensure operational continuity of services. Furthermore, improved performance can make edge computing more attractive economically and help maximize investments in wireless infrastructure [7].

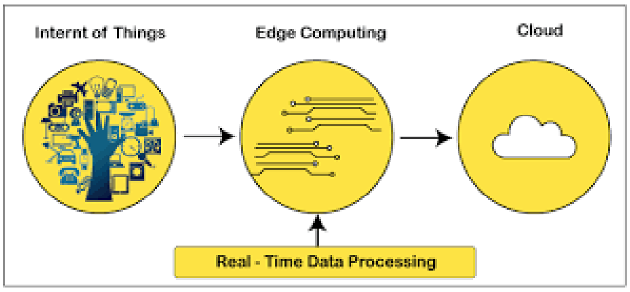

Figure 2. Advantages of edge computing

There are three levels of edges along dimension processing. Fog nodes form the first level and are composed of publicly accessible resources such as base stations, Wi-Fi routers, Access Points, and Network Function Virtualization (NFV) gateways aggregated to the edge of the core network. Micro data centers form the second level and comprise low latency fog servers, processing data closer to users. The IoT layer forms the third level, composed of personal mobile devices or smart things that are typically resource-constrained. There are three types of edges that take place in edge computing applications: cloud edge, telecom edge, and device edge. Cloud edge refers to edge services provided at the edge of a cloud or a datacenter farm, taking the advantage of resource orchestration at the cloud. Such global orchestration enables complex tasks to be performed without expensive investments at the edge [8]. Telecommunication edge refers to edge services provided under a public telecommunications network infrastructure and service ecosystem owned by telecom operators. Resources to be pooled together for edge service provision may include fog servers deployed at base stations and NFV gateways privately owned by the telecom operators, as well as public fog servers whose resource utilization and revenue are shared between multiple telecom stakeholders. Device edge refers to edge services provided at the device layer, which do not rely on an external edge infrastructure.

2. Key Technologies and Architectures

Edge computing is a technology that allows data processing and storage to occur closer to the user, leveraging a network of devices at the edge of the Internet. Edge resources can be accessed within one hop of a wireless gateway, in contrast to the several hops to be taken before reaching the farthest cloud computing data center [9]. The modeling perspectives include offloading or replication tasks at the edge, mobile clients with different bandwidth and delay constraints accessing content close to them, and cooperative computing efforts amongst users, sensors, or actuators at the edge. For infrastructure offloading, either all of the components of a particular application have to be migrated onto the same edge node, causing it to become a local cloud, or individual services from a cloud application are replicated at the edge [10]. In between, there is a deep space of possibilities, for instance, a mobile augmented reality application that computes meshes on a fog node and streaming video to the user, where the meshes are computed at another cloudlet.

A key approach to edge computing is an architecture composed of cloudlets, fog computing nodes or mobile base stations, and devices at the edge managed within an application deployment. To support real-time processing and data delivery, edge-computing CPU, latency, bandwidth, and distance constraints have to be considered, depending on use cases and scenarios. Another thing to have in mind is the existence of two sides, one on network operators and the other on companies deploying services. Both would provide financial incentives to support the architecture when properly dimensioned [8]. Different architectures have specific characteristics making them more or less prone to a given application. Cloudlets are a group of computers that represent a small data center dedicated to providing services to IoT devices located within the same geographical area. Fog computing is a decentralized infrastructure of computing nodes in which the services provided to end-users are located between end-users and the cloud. Fog-computing nodes could be located anywhere from end-users to the cloud. Comparing a cloudlet and fog-computing node, the former is a static node close to the end-users, while the latter could be either a static or mobile computing node located anywhere in the network. In general, fog-computing nodes also transfer small payloads faster than cloudlets do. Mobile edge computing (MEC) is a network that provides cloud-computing services to mobile devices at the edge of a mobile network to reduce latency. MEC enhances cellular network services with low latency and high bandwidth and provides context-aware services. Unlike fog-computing nodes, MEC servers could be deployed at a 3G radio controller or an LTE macro base station [11].

3. Fundamentals of Cloud Computing

3.1 Overview of Cloud Computing and Its Characteristics

The concept of cloud computing gained heightened attention from academia and industry due to its growth and provision of on-demand computing resources. Cloud computing is a technology that utilizes the Internet for providing data storage, servers, and other application services, such as software and analytics. Accessing cloud services does not require direct intervention with the infrastructure. As such, cloud computing can serve as a viable alternative to traditional computing paradigms [10]. Creeping Internet bandwidth availability, virtualization technology, and rapidly falling hardware costs have bolstered the boom in cloud computing. Computing as a service is a shared resource managed by highly competent providers [12]. On-demand resources and outsourcing are two characteristic properties of cloud computing.

Characteristics of a cloud system include on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service. On-demand self-service refers to the ability to automatically provision computing resources without human intervention, including server time and storage. Broad network access allows services to be accessed through the Internet by various devices. Resource pooling allows a cloud service provider to pool resources to serve multiple consumers, and similar requirements can be grouped to use a similar resource. Rapid elasticity refers to the ability to provision a cloud service with minimum effort. A service can be extended with more restrictions than its limitation if needed. Also, a consumer can return services and previously provisioned resources. Measured service refers to the ability to automatically monitor and control cloud service usage through metering capabilities. It is crucial for improvements in resource efficiency [13].

3.2 Key Technologies of Cloud Computing

Cloud computing has gained increasing attention from both academia and the industry due to the huge potential it presents in terms of money and convenience. In recent years, several cloud systems have been implemented, but there remains a fundamental lack of knowledge about them. As such, the underlying technologies that make up cloud computing are analyzed.

- Virtualization Technology: A hypervisor running on top of the host machine's operating system manages it along with the Virtual Machines (VMs) running on it. Each VM has an Operating System (OS) running on it as if there were separate physical machines for every VM. The hypervisor manages the host system's resources and allocates them to the VMs flexibly. The hypervisor manages the migration of VMs from one host to another by transferring all their context [13];
- Multicore Technology: Different processing units are built into one physical chip. Each core can perform instructions separately and independently from the others. Also, it allows including various architectures on one chip, such as a combination of general-purpose and special-purpose cores. Advanced Discrete Event Systems Specification is a high-level language to represent discrete event systems deterministically [14]. It can specify both sequential systems and concurrent systems. It can also deal with incomplete specifications, resulting in non-determinate systems;

- Service-oriented Architecture: It allows complex interactions and automatic discovery of heterogeneous services by means of pre-defined interaction protocols. Each interaction has a service as an interaction point and consists of a request followed by a response. To find a service capable of fulfilling a request, a description of the interaction is specified using an ontological language. An ontological language is used to describe the functionalities and properties of a service and the domain of knowledge it operates in. Semantic web agents can be used to automate service discovery and selection via ontological reasoning.

3.3 Definition and Characteristics

Cloud computing is an emerging model that uses the internet and the World Wide Web to provide various services [15]. It is also a novel computing paradigm that allows everything as a service, including computation, storage, information, and data. Nowadays, most service providers use cloud computing for almost everything that requires computing resources, such as searching and sharing information, and online social networking. This dramatic paradigm shift has necessitated the rise of new threats to deny clouds of service. The extensive use of virtual machines as a service denies and requires resources to be allocated to others. The term cloud computing is an umbrella term that encompasses other related terms. An early concept for cloud computing is the grid computing model, in which distributed resources/autonomous systems are coordinated automatically using cheap and low-cost components. This model showed how to apply all sorts of resources and on-demand services. The success and application of grid computing used it as a tested proposal to launch the next stage: cloud computing.

Cloud computing involves the delivery of hosted services over the internet 1. It enables new and easy solutions in computing and networking, allowing end-users with Internet access to “consume” sophisticated applications, storage, processing power, and functionality as a utility/service without capital investment in the underlying infrastructure [16]. It also provides infrastructure, platform, or software-as-a-service models and allows services to be rapidly provisioned and released, paying only for what is used. Similar to conventional services, services in the cloud are dynamically scalable, on-demand, measurable, and location-independent. The resource pool is shared across multiple users or tenants to enable economic-of-scale advantages in a service environment. There is a broad spectrum of financial models for billing and pricing, ranging from pay-per-usage per hour, month, or year, with penalties for over-use or contracting, to simple monthly flat fees [17].

3.4 Key Technologies and Service Models

Cloud computing is an emerging technology that allows for on-demand availability of computer resources without direct managerial effort from users [18]. The National Institute of Standards and Technology describes five essential characteristics, three service models, and four deployment models. The five essential characteristics are on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service. These characteristics allow the cloud provider to offer elastic services to thousands of users via internet technologies. The three service models are Software as a Service, Platform as a Service (PaaS), and Infrastructure as a Service. This layer allows deploying either applications or virtual machines at the expense of the provider managing physical resources for many users [19]. IaaS supplies virtualized resources to customers that can be configured individually; usually, this is done through a web-based dashboard or API. The cloud provider renews hardware components based on demand and dynamically redistributes resources among users. The four deployment models are private cloud, community cloud, public cloud, and hybrid cloud. In the latter case, an organization relies on different infrastructure providers to enable the highest efficiency and availability. All technologies mentioned above are needed to understand how the cloud works, how these technologies can be used, and how they can fail.

4. Performance Comparison Between Edge and Cloud Computing

An evaluation of performance is performed to compare cloud computing with edge computing. Though cloud computing is well established with a vast number of resources worldwide, edge computing has better latency with response time and is thus more efficient for time-delicate applications. The performance aspect analyzes speed, turnaround time, server utilization, and several factors at the same time [20]. The average response time is calculated for a cloud system that is at a distance from the user’s device. This average response time is 93.29 seconds. The average response time for edge access is 41.80 seconds. Having this if the response time is compared the edge server can deliver a faster output because it has an average response time of 41.80 seconds and cloud computing has a response time of 93.29 seconds. The average turnaround time is calculated similarly to the average response time. For the distributed cloud, the average turnaround time is 133.29 seconds, and for the edge-AliCloud simulation, it is 81.80 seconds. To compare these two performances, edge AliCloud has a better turnaround time than cloud computing.

In terms of resource utilizations, after 30 seconds of a running simulation, a continuous increase of resource utilization is evident. This is influenced by the number of requests. Hence, resource utilization might benefit an adequate distribution mechanism in cloud computing. For edge access, service utilization is less than 75% in all three service types which provides much more scope for requests processing. In cloud computing, the service utilization for edge AliCloud is around 80%. As the number of requests is consistently increasing with no prior knowledge of when and how many requests are expected, it might have the risk of overloading the cloud or edge service.

5. Scalability Comparison Between Edge and Cloud Computing

This section reviews edge computing's scalability compared to the traditional cloud computing. Scalability refers to the ability of a system to accommodate increasing workload amounts or its ability to dynamically modify its resource allocation to changing workloads. Scalability simplifies the design/implementation of processing systems (much like modularity simplifies the design of complex systems) [14]. It allows building/rebuilding processing systems in small increments. For edge computing to be viable, it needs to be evaluated against familiar and traditional processing alternatives, such as cloud computing. Cloud computing has been around for nearly two decades. It has been the panacea for off-loading difficult tasks (e.g., compute-intensive jobs) from personal computers and adopting client-server models for software applications. There are three cloud requirements, and various cloud services can be evaluated against each requirement [7]. The first requirement is performance scalability, defined as a processing system's ability to deploy resources "on demand" in a timely manner to accommodate changing application workloads without any changes to its design/implementation. The second requirement is the technology scalability, whereby the data can move from/to any cloud without significant effort. This is analogous to how applications can move from one computer to another under the same architecture/OS, but much more difficult in heterogeneous processing systems. The third requirement is economic viability, defined as the condition of being able to produce services at a cost that customers are willing to bear.

The elasticity of cloud services meets the performance scalability requirements, whereby cloud resources can be rapidly provisioned in a specific timeframe. With virtualization, cloud services meet the technology scalability requirement, whereby users do not have to worry about the underlying technology of the machines supporting cloud services. Whether using commodity, high-end, or custom-built servers, applications interact with the cloud through APIs, insulating them from changes in the underlying technology. The economic viability of cloud services is unproven, but with much economic and regulatory analysis, these models have the foundations of being economically viable and consequently satisfying the third requirement. A casual glance at edge computing suggests that it resembles many existing processing/communication models. Its use of local processing/decisions to address similar issues to those of other previous models indicates that knowledge about the viability of these existing models would be pertinent to the viability of edge computing. In particular, assessing how both processing alternatives (i.e., edge and cloud computing) handle increasing user requests is of interest. In general, scalability can be classified as "in" (i.e., the addition of more tasks) or "out" (i.e., the system expands to accommodate evolving application requirements).

6. Security Comparison Between Edge and Cloud Computing

Security is one of the most important considerations in modern applications. The aim of this section is to critically evaluate the difference in security between edge computing and cloud computing. With the use of blockchain and distributed ledger technology, cloud storage ensures database security through network redundancy. IoT devices connected to edge servers within short physical proximity automatically cache datasets whenever data is generated and uploaded to cloud storage. The confidential datasets must be encrypted, secured with access control, and anonymized prior to being uploaded to cloud storage. Edge servers protect the occurrences of these datasets by anonymizing data from aggregating nodes prior to storage [21]. Edge computing consists of a number of properties, of which distributed computing, easiness of deployment, and easy management bring enhancement to the level of security offered.

Edge computing also has a number of challenges present in its ecosystem which increase the level of vulnerability of edge computing enabled setups. Much of the challenges are present both in fog computing setups as well as fog computing nodes. The attacks on edge computing are:

- Eavesdropping - An eavesdropper can hide itself behind a network node and maliciously monitor the activity on the channel to steal or overhear the confidential data [22];
- Denial of Service (DoS) Attacks - Allows the intruder to take control over the system or network and make its access unavailable for the legitimate user;
- Distributed Denial of Service (DDoS) Attack - Interrupts the normal services provided by different servers based on compromised edge devices;
- Data Tampering Attack - The attacker can alter the data transmitted over the communication channel;

- Service Manipulation - The adversary takes control over the edge data center, misrepresenting or altering the services;
- False Data Injection - The attacker injects a false code, which on execution gathers stored data from the database;
- Physical Attack - This type of attack occurs when the physical protection of the edge infrastructure is weak;
- Rogue Gateway - An attack that injects high traffic into the edge computing network infrastructure.

7. Use Cases and Applications of Edge Computing

Research has pointed out that edge computing can best be described as an adventurous balancing act between cloud and standalone computing wherein computing resources are brought as close as possible to (mobile) end users and data sources, e.g., within local networks, basements, lamp posts, etc. By these concepts, high-bandwidth and low-latency consumer or industrial applications can bridge very expensive and slow links to today’s cloud computing infrastructures that have mostly been located outside the touch of these users [22]. Additionally, data and computing can be offloaded to storage and compute resources that go beyond the limits of sensing devices or wearables by the heterogeneous nature of these resources that can be exploited in this context. Beyond consumer applications, edge computing concepts could also reduce computation time, energy consumption, and complex architectures for industrial OS or SCADA systems. As the limitations of cloud computing infrastructures become apparent more and more, upcoming applications of edge computing are expected to e.g., augment human perceptions in smart cities or smart homes with a detailed understanding of the surrounding environment (augmented reality), or evaluate and interconnect large-scale sensor data in real-time systems as an enabler of autonomous driving. Such applications also emphasize the importance of distributed systems and decision-making capabilities.

In addition, computing at the edge allows users to leverage the processing power of the same network where IoT devices are hosted in the same locality. The use case inspires the advantages of distributing computation closer to end users:

- Responsiveness, e.g., streaming video IP+analysis across the broadband cellular edge lowers average latency by 30% as compared to cloud delivery;
- Network efficiency, e.g., a recommendation service applied on the wired edge in a cable TV headend recovers 33%-50% of end-user bandwidth;
- Business viability, e.g., application offloading to the cloud for data analysis incurs exorbitant monthly charges ($600K for 400 drones) [23].

8. Challenges and Limitations of Edge Computing

Despite the highlighted advantages of edge computing, there are several technical, infrastructural, and operational challenges that present limitations to the adoption and feasibility of edge computing solutions [24]. With the growth in size of edge networks, routing of services and data, and exposing them to the edge cloud become more challenging. As mesh networks become larger, addressing these complexity patterns in many-entity systems starts to require new self-organizing mechanisms that might exploit decentralization, emergence, and adaptability.

Centralized administration and control possibly becomes impractical, too cumbersome, and expensive. Further exploration is needed to develop a better understanding of what edge computing is, what its architectural components are, what applications and use cases can be addressed, and what new developments in edge computing technology are emerging. Such understanding would diagnose not only the technological edge computing posture of a mobile provider but also its business orientation, objectives, and ambitions.

9. Future Trends and Research Directions in Edge and Cloud Computing

Considering the fast-growing smart sensing, mobile, and smart device applications with emerging ubiquitous technologies (e.g., IoT), edge computing and cloud computing are generating substantial interest in information service systems, ranging from smart wearable, vehicular, home, healthcare, smart buildings, and cities to industrial automation and 5G networks. Here, some potential future research trends and directions for edge computing and cloud computing systems are briefly surveyed, including intelligent edge/cloud application service systems, challenge-and-solution for edge/cloud services co-partitioning, sampling-and-optimization based distributed data and model learning for edge/cloud services, and federated learning based edge/cloud data model intelligence, and privacy and security protection in edge/cloud based federated learning with smart service requirements 9.

By 2025, it is expected that edge computing and fog computing will deploy over 3 million edge devices globally to provide AI-based services for over 50 billion edge-based video and data traffic to over 4.6 billion smart device users with smart service requirements, including timeliness of < 1 ms for medical applications, < 10 ms for industrial real-time control, and < 100 ms for AR/VR video data analysis. Strategies and service models are required to achieve efficient edge service deployment of various edge de-vices in heterogeneous devices, including station-base edge servers, road-side edge servers, mobile base stations, and end-edge smart devices. For data and model learning intensive applications, the movement of raw data from edge devices to cloud systems needs to be avoided and analytics nodes be deployed in the edge environment where data originated, data stored, and learning models be built. Furthermore, strategy- and optimization-based edge and cloud service co-partitioning are needed to achieve good performance for low bandwidth, high latency, and large volume data trawling applications. The use of low-bandwidth sampling and communication optimization based schemes to reduce the edge-cloud information exchange for distributed edge and cloud services and model learning training processes is also required.

10. Conclusion and Key Findings

This essay conducts a comprehensive evaluation of edge computing and cloud computing, particularly focusing on performance, scalability, and security in modern applications. By examining the characteristics, advantages, and disadvantages of both computing paradigms, a better understanding of their suitability for various applications is achieved. The performance comparison covers response time, processing time, and failure tolerance, indicating that edge computing outperforms cloud computing in response time and processing time. However, cloud computing has the advantage in failure tolerance. Concerning scalability, the analysis explores internal and external aspects, revealing that cloud computing can outperform edge computing in external scalability. Regarding security, three types of attacks are discussed: network attacks, resource attacks, and service attacks. It is found that cloud computing is less vulnerable to these attacks compared to edge computing.

In general, edge computing excels in performance, making it suitable for real-time applications where minimal response time is critical. Cloud computing, on the other hand, is applicable to big data-centric applications that do not require real-time processing and can tolerate longer response times. This research is significant as it provides insights into the comparison of performance, scalability, and security between edge computing and cloud computing, which can guide decision-making for choosing a computing paradigm. Despite the extensive evaluation presented in this essay, there are still research gaps to be addressed. For instance, a deeper examination of the environmental impact of both computing paradigms, especially in terms of energy consumption, could be conducted. Additionally, investigating hybrid models that combine edge computing with cloud computing for specific applications might be a fruitful direction.

Edge computing brings computing and storage resources closer to end users and data sources, bypassing expensive and slow links to distant cloud computing infrastructures. These heterogeneous resources can be used to offload data and computations, enabling demanding applications such as augmented reality and autonomous driving. Research has addressed various challenges, from architectural concerns to runtime optimizations. However, we lack widespread availability of edge computing-partly because it remains unclear which benefits are relevant for what types of applications. This article provides a snapshot of the current edge computing landscape, focusing on the application perspective. We outline the characteristics of edge computing and its postulated benefits and drawbacks. Edge computing has recently gained tremendous attention in both academia and industry. The main motivation for edge computing is the shortcomings of today’s cloud computing infrastructures when processing large-volume data for latency-critical applications. Cloud computing often leads to substantial latencies when using services placed at distant locations. Until recently, these drawbacks had a limited impact since most data was produced and consumed in the cloud. Examples of such applications are big data processing and data warehousing.

The centralization of data has decreased tremendously in the past years. More people own personal smart devices connected to the Internet, such as smartphones or smartwatches. These devices will be complemented by smart glasses and various on-body sensors in the near future. The Internet of Things (IoT) captures the idea of devices collecting huge amounts of data. Even though mobile devices today have powerful hardware, it is still inadequate for many demanding tasks like video analytics or high-quality 3D graphics.

For the purpose of this article, we will consider as edge devices those that are in the premises of the end user as well as those outside the premises at the edge of the Internet or of the cellular network. Local device-level computation is offloaded to nearby edge computing devices whenever local processing is either inadequate or costly, or relies on non-local information. The edge paradigm supports the large scale of Internet of Things devices, where real time data are generated based on interactions with the local environment. This structure serves as the backbone for applications, such as augmented reality and home automation, which utilize complex information processing to analyze the local environment to support decision making. In the IoT domain, functional inputs and outputs are physically tied to geographically distributed sensors and actuators. Without drastic network improvements, edge computing is likely to become a cornerstone of IoT. We see that there has been a shifting of the envelope of local versus edge computing based on two dimensions: first, as more demanding applications arise and second, as the locally available resources increase.

In the context of edge computing dependability, we focus on five aspects that we deem most significant: large scale, low latency or soft real-time requirements, authentication and physical security, multi-tenancy on the edge devices, and standardization.

References

[1] J. Gedeon, F. Brandherm, R. Egert, T. Grube, and M. Mühlhäuser, "What the fog? edge computing revisited: Promises, applications and future challenges," *IEEE Access*, vol. 7, pp. 152847-152878, 2019, doi: https://doi.org/10.1109/ACCESS.2019.2948399

[2] R. Roman, J. Lopez, and M. Mambo, "Mobile edge computing, fog et al.: A survey and analysis of security threats and challenges," *Future Generation Computer Systems*, vol. 78, pp. 680-698, 2018, doi: https://doi.org/10.1016/j.future.2016.11.009

[3] P. Wood, H. Zhang, M.-B. Siddiqui, and S. Bagchi, "Dependability in edge computing," *arXiv:1710.11222*, pp. 1-15, 2017, doi: https://doi.org/10.48550/arXiv.1710.11222

[4] S. Hamdan, M. Ayyash, and S. Almajali, "Edge-computing architectures for internet of things applications: A survey," *Sensors*, vol. 20, no. 22, p. 6441, 2020, doi: https://doi.org/10.3390/s20226441

[5] D. K. Verma and T. Sharma, "Issues and challenges in cloud computing," *International Journal of Advanced Research in Computer and Communication Engineering* vol. 8, no. 4, pp. 188-195, 2019, doi: https://doi.org/10.17148/IJARCCE.2019.8431

[6] J. Pan and J. McElhannon, "Future edge cloud and edge computing for internet of things applications," *IEEE Internet of Things Journal*, vol. 5, no. 1, pp. 439-449, 2017, doi: https://doi.org/10.1109/JIOT.2017.2767608

[7] S. Saif and S. Wazir, "Performance analysis of big data and cloud computing techniques: a survey," *Procedia Computer Science*, vol. 132, pp. 118-127, 2018, doi: https://doi.org/10.1016/j.procs.2018.05.172

[8] M. M. Naeem, H. Mahar, F. Memon, M. Siddique, and A. Chohan, "Cluster computing vs cloud computing a comparison and an overview," *Science International-Lahore*, vol. 28, no. 6, pp. 5267-5271, 2016.

[9] P. Mell and T. Grance, "The NIST Definition of Cloud Computing," National Institute of Standards and Technology, Gaithersburg, Maryland, Washington, USA, 2011.

[10] G. P. Bhandari and R. Gupta, "An overview of cloud and edge computing architecture and its current issues and challenges," in *Advancing Consumer-Centric Fog Computing Architectures*: IGI Global, 2019, p. 37.

[11] S. Khan, S. Parkinson, and Y. Qin, "Fog computing security: a review of current applications and security solutions," *Journal of Cloud Computing*, vol. 6, p. 19, 2017, doi: https://doi.org/10.1186/s13677-017-0090-3

[12] F. Hussain, F. Hussain, and A. Al-Karkhi, "Big data and fog computing," in *Internet of Things: Building Blocks and Business Models*: Springer, 2017, ch. 3, pp. 27-44.

[13] P. Hu, S. Dhelim, H. Ning, and T. Qiu, "Survey on fog computing: architecture, key technologies, applications and open issues," *Journal of Network and Computer Applications*, vol. 98, pp. 27-42, 2017, doi: https://doi.org/10.1016/j.jnca.2017.09.002

[14] W. Shi, J. Cao, Q. Zhang, Y. Li, and L. Xu, "Edge computing: Vision and challenges," *IEEE Internet of ThingsJjournal*, vol. 3, no. 5, pp. 637-646, 2016, doi: https://doi.org/10.1109/JIOT.2016.2579198

[15] N. Khan and A. Al-Yasiri, "Cloud security threats and techniques to strengthen cloud computing adoption framework," in *Cyber security and threats: Concepts, methodologies, tools, and applications*: IGI Global, 2018, p. 15.

[16] Q. K. Kadhim, R. Yusof, H. S. Mahdi, S. S. Ali Al-shami, and S. R. Selamat, "A review study on cloud computing issues," *Journal of Physics: Conference Series*, vol. 1018, p. 012006, 2018, doi: https://doi.org/10.1088/1742-6596/1018/1/012006

[17] Y. Al-Dhuraibi, F. Paraiso, N. Djarallah, and P. Merle, "Elasticity in Cloud Computing: State of the Art and Research Challenges," *IEEE Transactions on Services Computing*, vol. 11, no. 2, pp. 430-447, 2018, doi: https://doi.org/10.1109/TSC.2017.2711009

[18] Y. Ai, M. Peng, and K. Zhang, "Edge computing technologies for Internet of Things: a primer," *Digital Communications and Networks*, vol. 4, no. 2, pp. 77-86, 2018, doi: https://doi.org/10.1016/j.dcan.2017.07.001

[19] C. Puliafito, E. Mingozzi, F. Longo, A. Puliafito, and O. Rana, "Fog computing for the internet of things: A survey," *ACM Transactions on Internet Technology (TOIT)*, vol. 19, no. 2, pp. 1-41, 2019, doi: https://doi.org/10.1145/3301443

[20] V. Kumar, A. A. Laghari, S. Karim, M. Shakir, and A. A. Brohi, "Comparison of fog computing & cloud computing," *International Journal of Mathematical Sciences and Computing*, vol. 1, pp. 31-41, 2019, doi: https://doi.org/10.5815/ijmsc.2019.01.03

[21] R. Beri and V. Behal, "Cloud computing: a survey on cloud computing," *International Journal of Computer Applications*, vol. 111, no. 16, pp. 19-27, 2015.

[22] S. Rac and M. Brorsson, "At the edge of a seamless cloud experience," *arXiv:2111.06157*, p. 7, 2021, doi: https://doi.org/10.48550/arXiv.2111.06157

[23] A. Ometov, O. L. Molua, M. Komarov, and J. Nurmi, "A survey of security in cloud, edge, and fog computing," *Sensors*, vol. 22, no. 3, p. 927, 2022, doi: https://doi.org/10.3390/s22030927

[24] A. M. Alwakeel, "An overview of fog computing and edge computing security and privacy issues," *Sensors*, vol. 21, no. 24, p. 8226, 2021, doi: https://doi.org/10.3390/s21248226

How to cite this article

A. H. Omran, Y. M. Abid, M. S. Mahdim, and B. I. Bakri, "Edge Computing Vs. Cloud Computing: Evaluating Performance, Scalability, and Security in Modern Applications," *CyberSystem Journal*, vol. 1, no. 1, pp. 1-8, 2024. doi: 10.57238/fpj44896

Access this article online