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# Edge Computing Research – A Review

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### Abstract

As the world is moving towards digitalization and automation, a large amount of data is being generated from various domains. In most of the data-driven applications, the large-scale data must be quickly processed in order to assist the state-of-the-art technologies like Internet of Everything (IoE). To increase the response speed and bandwidth load, the existing cloud computing models are not sufficient. This has led to the development of edge computing. The edge computing paradigm extends its support to the diversified requirements of today's digital society. In contrast to cloud computing, edge computing remains more closer to both the data source and end-user remaining at the edge of the network as a small-scale and local data processing unit. This research study reviews the concept of edge computing and how it varies from cloud computing. First, the article describes the purpose and necessity for edge computing, as well as the differences between edge and cloud computing. Then, highlights the advantages of potential edge computing architectures. Finally, a summary of the new edge computing initiatives is provided.

**Keywords:** Networking, Cloud Computing, Edge Computing, Internet of Things, Data Analysis

## 1. Introduction

As the number of internet-connected smart devices increases, the real-time implementation of Internet of Everything (IoE) models will also increase resulting in generating a large-scale data. This demands for the development of advanced data processing models. While processing the large-scale data, the existing cloud computing technologies will face number of challenges such as insufficient bandwidth, lack of security, and delayed response [1]. As a potential solution for the emerging data processing challenges, the new edge computing paradigm has been developed.


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Edge Computing enables data processing and computation at the network's edge, which remains close to the data sources. Edge devices are capable of performing two different operations such as data processing and data generation. Edge computing is a system with which the cloud centres, data processing units, and storage will be made available at the edge and interact with each other. It enables network computation at the edge, which can remain as close as the smartphones, mobile and surveillance devices. This reduces the extra load on the network bandwidth and limit the increased network energy consumption. Edge is capable of working with both downstream and upstream data for performing cloud and IoT services respectively. The proximity and location aware computing characteristics of edge computing models will provide users with faster and secure real-time services in different fields such as smart home, healthcare, energy, industries, and transportation [2].

The main purpose of using edge computing is:

**Speed:** In case of time-sensitive event, there will not be enough time to send a signal to the cloud and obtain a valid response. For instance: If a man walks in front of a self-driving car, it needs to be stopped immediately and pass the data. In such a situation, edge computing can be used to monitor the activities on the roads as well as intersections before the occurrence of a problem.

**Optimization:** Edge computing allows data centres to run time-sensitive processes, take immediate local decisions and then transmit data to the cloud periodically when bandwidth requirements are optimal. The cloud may then evaluate data from the edge and return proposed decisions and rules to cloud for further analysis.

**Uptime:** Edge computing is based on connecting individual sensors to the data centre present in a local region. This action will dramatically minimize the possibility of interruptions.

## 2. Concept of Edge Computing

Edge computing is an evolving novel computing technology that refers to a wide-range of communication networks and devices present with or near the user. Edge deals with processing the network data in an area closer to the data generation device for increasing the data processing speed and optimization. [3] Unlike traditional centralized topology, edge remains as a decentralized topology with its advanced capability of processing traffic loads and increased Quality of Experience (QoE).

Edge computing has now been increasingly used to transfer all centralized components close to the end user(s) as shown in Fig 1. This will lead to a reduced latency and increased efficiency with a proper bandwidth utilization.

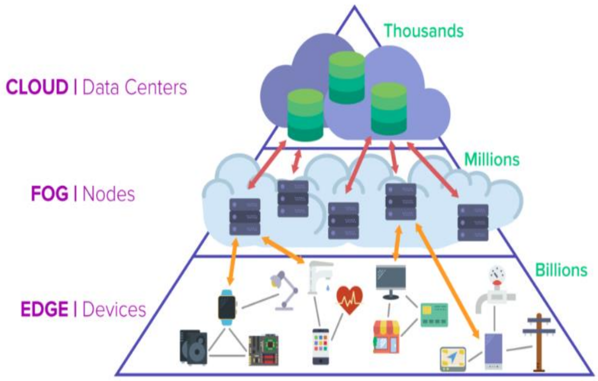


**Figure 1.** Edge Computing Illustration

Initially, [4] Gartner has defined the term edge computing as "a part of a distributed computing topology in which information processing is located close to the edge, where things and people produce or consume that information". Shi et. al [5] have introduced the concept of edge computing as "a new computing mode of network edge execution. The downlink data of edge computing represents cloud service, the uplink data represents the Internet of Everything, and the edge of edge computing refers to the arbitrary computing and network resources between the data source and the path of cloud computing centre". Progressing further, as illustrated in Fig 1, Narayanan et. al [6] have described "Edge computing is a new computing model that deploys computing and storage resources (such as cloudlets, micro data centres, or fog nodes, etc.) at the edge of the network closer to mobile devices or sensors".

Peter Levine points out the transition of a centralized architecture to a decentralized architecture with the history and refers it as a pattern-based transition. From Fig 2, the transition from centralized to decentralized and decentralized to centralized has been observed. Finally, the tracing concludes that currently the computing era is moving towards developing an advanced distributed architecture called edge computing [7].

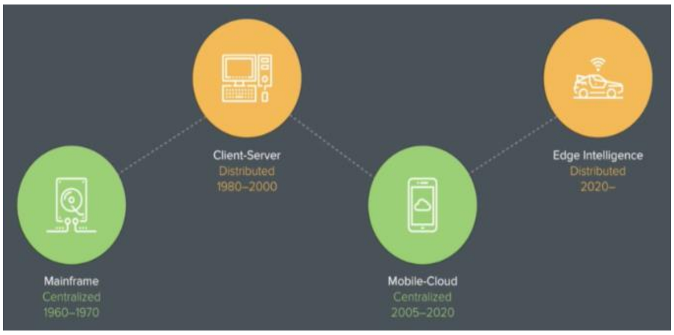


**Figure 2.** The Transition Towards Edge Computing

## 3. Edge Computing VS Cloud Computing

With the introduction of cloud computing technology in the recent past, the majority of the data processing functionalities were moved to centralized clouds. This data virtualization process results in developing a resource-enhanced platform. Despite, the cloud computing technologies has not delivered more attention on the location awareness and optimal resource utilization. Additionally, the distance between cloud and data sources increases the network latency [8]. Even though the centralized data processing model is easy to handle, it has not met all the performance standards like increasing traffic congestion, network error, user preferences etc. To solve these challenges, the edge computing has introduced the network edges which remain more closer to the data generation module.

The emergence of edge computing will not completely replace the cloud computing architectures, instead it will work collaboratively and coordinatively in different aspects of computing, networking, intelligence and applications. Moreover, the data present in edge nodes should be later fed into the cloud computing framework in order to perform in-depth analysis to generated appropriate and satisfiable results. [9] Edge computing architecture can analyse different types of data obtained from different sources by uploading the data into cloud in order to realize its control over the edge nodes. In order to meet the requirements of emerging smart devices like Internet of Everything (IoE), the intertwined implementation of edge and cloud computing can uninterruptedly promote the progress of internet.

The main focus of edge computing technologies will be on performing real-time analysis to meet the local and small-scale business requirements. For intelligent and large-scale applications, the centralized cloud computing technologies will remain more suitable. Both edge and cloud computing play a significant role in the development of intelligent IoT applications. The primary difference between edge computing and cloud computing are shown in Table 1 [10-12].

| Parameter Analysis | | |
|---|---|---|
| **Characteristics** | **Cloud Computing** | **Edge Computing** |
| Network Access | Wide Area Network | Wireless Access Point |
| Network Distribution | Centralized | Distributed |
| Network Management | Centralized Service Provider | Local Service Provider |
| Node Location | Internet-based | Localized Network Edge |
| Data Transmission | Device-to-Cloud | Device-to-Device |
| User Density & Distance | Low Density & Covers Large Distance (Multi-Hop) | High Density & Covers Small Distance (Single-Hop) |
| Data Storage | Huge | Limited |
| Data Aggregation | Completely carried out at cloud | Partially at edge and partially at cloud |
| Location Awareness & Deployment | No Location Awareness & Centralized Deployment | Location Aware and Distributed Application Oriented Model |
| **Performance Analysis** | | |
| Energy Utilization | High | Low |
| Scalability | Supported | Limited |
| Mobility | Limited | High |
| Delay | High | Low |
| Latency | High | Low |
| Cost | High | Low |
| Security | Low User-Defined Security | High User-Defined Security |
| Application | Suitable for Delay Tolerant Applications | Suitable for Latency Sensitive Applications |
| Real-time Implementation | In Centralized applications like Amazon | In decentralized private environments like restaurants, shops, offices, college/universities etc. |

## 4. Edge Deployment in Real World

Recent years have witnessed the increasing interest on the edge computing and processing techniques in order to reduce the latency and eliminate the uncertain workloads such as content/data caching to appropriately utilize the bandwidth. More real-time distributed edge computing applications have emerged along with proof-of-concepts for industrial applications.

As shown in Fig 3, The four main parameters that were considered in edge deployment are: (i) Constrained edge device (ii) Distributed edge cloud (iii) User-centric edge devices (iv) Data-centric secured edge cloud.

The constrained edge devices are characterized by the lightweight sensors and devices like sensors. These devices establish a connection and handle only up to megabytes of data and remains as the most suitable solution for basic data link and communication operations. Due to this resource constrained nature, it demands a highly advanced edge device management. The distributed edge cloud supports the cloud-based architectures without being present in the traditional cloud data centres. The next type, the data centric secured edge cloud mimics the tradition cloud data centre tools for enhancing the security, data manageability and service orchestration. Finally, the recently developed user-centric edge devices satisfies the increasing requirements of end-users by getting integrated with the windows, android and iOS applications.

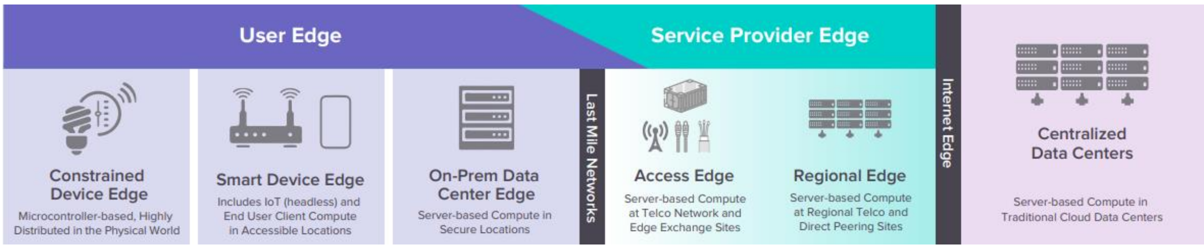


**Figure 3.** Edge Deployment Paradigms [13]

Edge Computing leverages potential benefits to its users, they are [14]:

- Edge clouds can also be hosted by third party cloud service providers and also in small-scale applications.
- Due to its distributed deployment, the total cost of ownership (TCO) will be highly reduced and the technology become affordable for small-scale industries.
- Increased Quality of Experience (QoE).
- The backhauling internet traffic will be highly reduced by using the edge topology.
- Due to the hosting of information in local edge-driven data centres, the network reliability will be highly increased.

## 5. Edge Computing Architectures

In this section, the recent edge computing initiatives are reviewed and compared.

### 5.1 Edge Computing Models Supported by Samsung Electronics & Linux

Samsung Electronics has recently initiated 110 open-source projects, which covers some edge computing initiatives. The two potential edge computing technologies seeded by Samsung are: Home Edge and EdgeX Foundry

### 5.1.1 Home Edge

Home Edge [14] is an open-source project hosted by Linux Foundation. To establish connectivity among devices in a confined ecosystem, Home Edge provides a reliable and reliable framework which can connect almost all the devices at home. As shown in Fig 4. Home Edge is composed of three different phases

- Network Edge Orchestration Phase
- Data Storage Phase
- Device Control Phase

**Network Edge Orchestration Phase** discovers the edge devices, develops an edge setup, balances the load between different devices and finally monitors the edge services. For instance: The devices that are connected to Home Edge networks will be assigned with a Home Edge node by the network orchestrator. The role of network orchestrator is to continually scan the Home Edge ecosystem and if it finds any new device, the device will be assigned with a Home Edge node.

**Data Storage Phase** provides a determined storage for both primary data generated and also the metadata to recognize an edge node. This phase includes an input/output module for accessing the data by utilizing APIs.

**Device Control Phase** establishes a connection between home devices and the cloud interface.

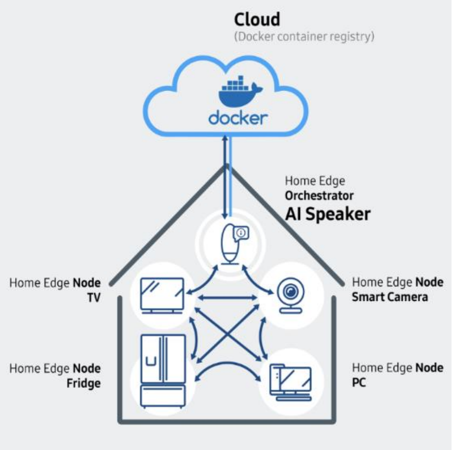


**Figure 4.** Home Edge Framework [14]

### 5.1.2 EdgeX Foundry Architecture

EdgeX Foundry [16] is an open-source platform developed by Linux. It is a highly robust, scalable and flexible architecture, which can enable interoperability between various devices and edge-driven applications. The framework is totally independent of operating systems and hardware enables a connector component ecosystem to streamline the computationally open platform at the edge of the Internet of Things (IoT) and accelerate solution implementation.

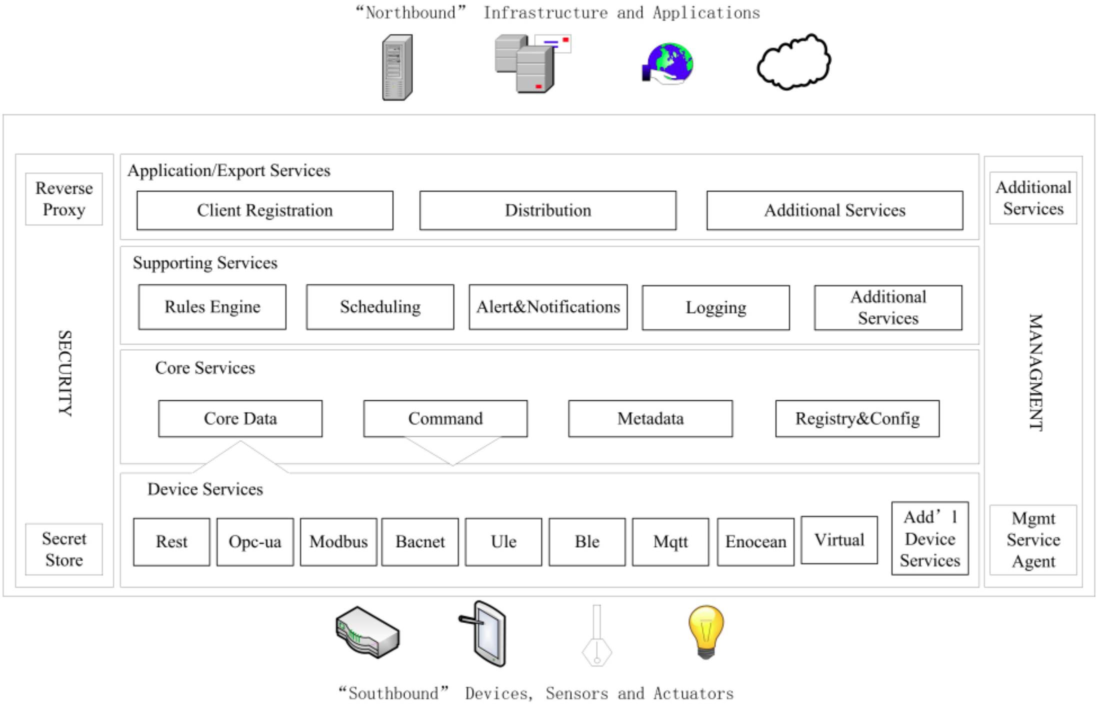


**Figure 5.** EdgeX Foundry [15]

The lower part of the EdgeX Foundry architecture mentioned in Fig 5 includes all the IoT enabled devices, which can directly establish a communication link with the edge architecture. The upper part represents the communication serves and cloud computing data centres. The upper part will always collect the data from the lower part for performing the process of data analysis. The architecture between upper and lower part encompasses four different layers. Further, a service management architecture is included in the left and right side of the architecture for assisting in establishing a communication link. The service layer present in the architecture converts the raw data obtained from the IoT devices and send it for further process and vice versa. EdgeX Foundry architectures can also be integrated with message transmission process, telemetry method, virtual data transmission, and Bluetooth based applications. Further, the application/service layer is used to connect to the cloud data centres to transfer data and perform independent data processing operations. Here, the information will also be recorded and stored in the back-up storage system.

This EdgeX Foundry architecture has been developed with a primary intent to standardize and simplify the edge computing processes and its implementation in Internet of Things (IoT) applications. The EdgeX Foundry models are currently applied in diverse real-time applications such as transportation, retail, manufacturing, energy management, and other such smart city applications.

## 6. Recent Research Trends in Edge Computing

### 6.1 Multi-Access Edge Computing

Multi-access Edge Computing (MEC) provides cloud-based computing capabilities and an advanced information processing environment to the users and application developers at the edge of a mobile network. MEC is an innovative technology that emerges from the rise of mobile base stations and the integration of information technology and communication networks. MEC is characterized by higher bandwidth and lower latency for leveraging a localized and real-time access to the network information. MEC assists in enabling third-party access to the network edge to deploy innovative applications for mobile network users and industries [17].

The potential use-cases of Multi-access Edge Computing (MEC) are:

- Optimized Local Content Distribution
- Data Caching
- Internet of Things
- Augmented/Virtual Reality

MEC enables different tools to access local content as well as real-time information over local-access network frameworks. With the integration of MEC architecture, mobile networks can work efficiently without any additional congestion and serve the local requirements by processing various services and data caching at the network edge. MEC has the ability to handle both wireless (WLAN) and wired/fixed access.

The global market of MEC is now mainly focused on the “Phase III”, which primarily focuses on assisting the heterogenous and complex cloud computing environment. MEC based data management techniques will highly benefit the intermittent and mobile connected devices and consumer-enable local cloud resources.

Furthermore, data available in the MEC platform is highly optimized by allowing the content to be automatically adjusted based on network's real-time information (connection quality, network load, throughput rate, etc.), resulting in leveraging an improved network efficiency and Quality of Experience (QoE).

### 6.2 Predictive Maintenance

Predictive maintenance plays a significant role in industry 4.0 by ensuring the good working condition of the industrial equipment and eliminating the scheduled maintenance with the integration of condition-based monitoring technique [18].

In order to establish a condition-based monitoring, a large number of sensors should be deployed and data from these sensors should eb collaboratively integrated at the edge to appropriately predict the defect conditions in the industrial equipment. The edge driven solutions engineering will enable the industries to accurately know when the devices may fail; which assists the industries to effectively optimize the process of fleet maintenance and use case services. Edge computing reduces the time taken to transfer the information obtained from large number of sensors to cloud by processing them at edge. Also, edge computing techniques are capable of delivering quick decisions when sudden changes are noticed in the regular industrial processes. This type of edge based predictive maintenance will abruptly reduce the downtime faced by industries and at the same time it will also increase the return assets. According to Gartner's most current predictions, the adoption and investment of Edge-IoT-based predictive maintenance will increase 4-fold from $3.2 billion to $13.1 billion by the end of 2022.

### 6.3 Multimedia Edge

As the internet industry is advancing at an unprecedented rate, the internet applications are connecting people irrespective of their place and time. This internet revolution has also led to the gradual increase in the internet traffic. According to the Cisco Forecast, due to the increased sharing of video content, the total global IP traffic has grown 4-fold from the year 2017-2022 with a 34% annual growth rate. By the end of 2022, the internet traffic will reach to 3.6ZB (309.58 EB/Month). Figure 6 shows the Cisco’s annual forecast on global internet traffic [19].

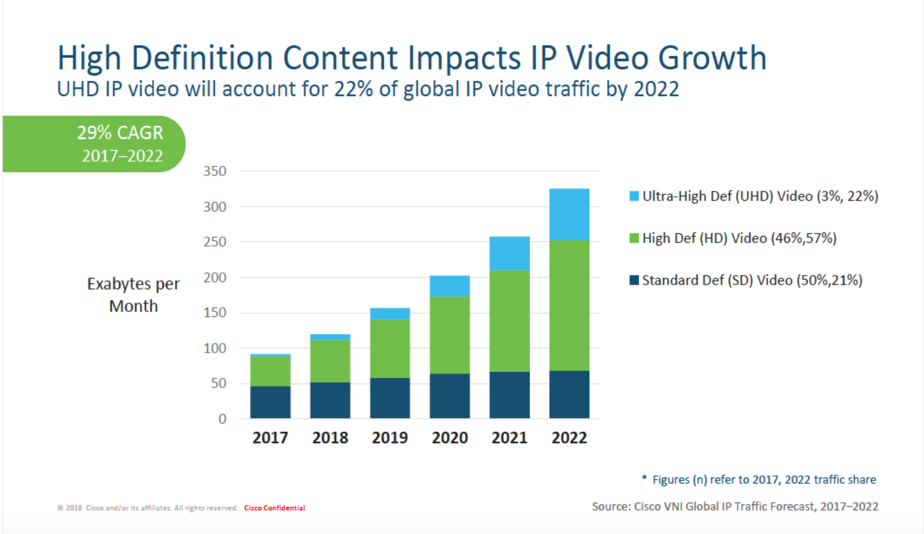


**Figure 6.** Annual Forecast on Global IP Video Growth [20]

The high amount of internet video traffic tends to consume higher internet bandwidth resources. With the available limited bandwidth, incorporating edge computing techniques will highly assist in eliminating the local video cache.

Employing edge computing for video analysis and caching process, the high traffic generated in residential areas, towns, event gatherings, commercial area will be optimized. The local edge also assists in managing the frequent playback requests generated by users. The search based intelligent analysis carried out in edge computing platform will cache the popular and most searched content with a comparatively higher download frequency and saves it in the nearby MEC local server to reduce the internet traffic. This process saves a large amount of bandwidth and highly reduces the user waiting time and latency.

## 7. Conclusion

This article covers the edge computing concept step-by step from stating the basic edge computing concepts, advantages, key edge computing technologies & architectures and the recent real-time applications of edge computing technology. Edge computing architectures provide the computing operations and data storage models at the network edge to leverage intelligent services by supporting the global adoption of Industry 4.0, digital transformation (Society 5.0) and develop diversified data processing services. From the inference gained form the article, it is known that Edge computing has now gained potential research interest across the globe. In future, the increasing integration of internet in human lives will drive the growth of edge computing technologies in various industries. The main role of edge computing will be observed in the domains of smart transportation, smart home, gaming, digital industries, and more specifically in content delivery networks.

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