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Professional paper

EDGE COMPUTING FOR INTERNET OF THINGS: ARCHITECTURES, CHALLENGES AND OPPORTUNITIES

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Abstract

The Internet of Things (IoT) connects diverse devices to provide digital services globally. Edge computing, a new model, processes data at the network edge for faster responses. This paper discusses IoT architecture, protocols, computing models, and the benefits and challenges they pose. It highlights the need for high-performance IoT applications, especially in critical scenarios, and suggests that Edge computing can enhance efficiency and privacy by processing data where it's produced. Environmental impacts of cloud-based data management and the sustainability of Edge computing are also explored.

Keywords: IoT, Edge, Fog, Cloud, Efficiency and Privacy

1. Introduction

The Internet of Things (IoT) is rapidly growing and being used in many aspects of daily life. Modern technologies provide globally connected wireless services [1]. IoT applications require critical developments that meet network demands, such as security and timely process execution [2]. IoT is the convergence of connections between people, things, data, and processes that impact people's lives and businesses.
According to Cisco, the number of connected devices will reach 55 billion by the end of 2023, generating 85% of data traffic [3]. However, the traditional cloud approach is not suitable for many IoT applications due to issues like high latency, bandwidth usage, and data security. These challenges have inspired the development of new computing models like edge and fog computing [5].
Cloud serves as the primary location for IoT data processing, management, and storage. However, there is a need to shift the model to address these challenges and consider edge and fog computing. These models offer benefits in terms of latency, geographic distribution, mobile applications, and large-scale control.
IoT applications can benefit from using edge and fog computing to address challenges related to latency, security, and infrastructure. Improvements in decentralized data processing and management at the source can enhance IoT efficiency and security. Fog computing integrates with the edge network and provides solutions for applications requiring low latency, geographic distribution, and large-scale control [4].

2. What Is IoT Architecture?

The perception layer, the network layer, and the application layer are the three essential layers that make up the Internet of Things network.
The sensitive layer that includes endpoints like sensors and cell phones is known as the perception layer. Before transmitting the data to the network layer, it interprets and collects environmental data (such as pressure, temperature, and humidity) using sensors and actuators [6].

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Data distribution and final destination routing are ensured by the network layer. Devices like switches and routers are part of this intermediary layer in the Internet of Things architecture.
Based on data and information gathered from the layers above, the application layer provides different services and applications. This is the uppermost layer of the Internet of Things architecture, which includes the data model algorithm, user interface, and all other necessary components [7].

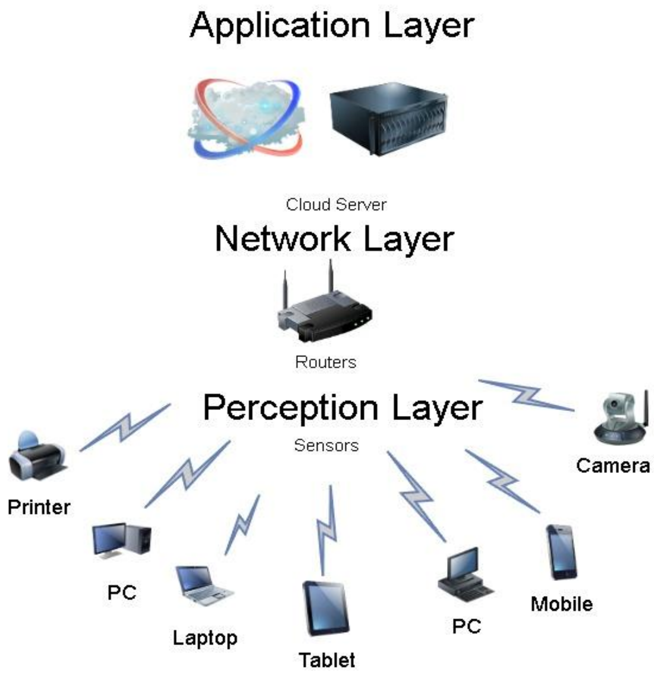

Figure 1. Three-layer IoT Architecture

3. Challenges of IoT

IoT has advantages for the economy and for people's convenience, but it also has significant issues that require attention [8].

3.1 Big Data: The output of raw data is increasing due to the rapid growth of IoT devices. The method is complicated since it requires the processing and storage of this data in real-time in dynamic environments.
Cloud computing has limits when it comes to managing the sheer amount of Internet of Things data, even while it offers plenty of resources for data processing and long-term storage. Data integrity is a major difficulty since application performance is essential for quality of service and privacy concerns [9].

3.2 Privacy and Security: A private, secure infrastructure is necessary for the successful implementation of IoT. Sensitive data is collected by IoT devices, therefore developing a strong security architecture is essential [10]. Since most Internet of Things (IoT) devices use wireless networks, they are susceptible to "man-in-the-middle" and "data sniffing" attacks. These devices' large volume and complexity increase the area that hackers can target [11][12].

3.3 Networking: To communicate as quickly as possible, IoT devices employ a variety of protocols. It's not easy to design a new protocol that satisfies requirements for usability, quality of service (QoS), cost, and system performance. One of the biggest challenges in creating an appropriate network topology is dealing with IoT devices [13][14].

3.4 HetIoT: One of the main challenges is the heterogeneity of IoT platforms, devices, operating systems, and services. It is a challenging and complex procedure to connect and perform jobs across IoT system devices made by different manufacturers [15][16].

3.5 Maintenance: With so many IoT devices on the internet, there are a lot of maintenance difficulties to deal with. The majority of IoT devices are made by various firms that pay insufficient attention to security, privacy, updates, and other concerns, leaving them vulnerable to hacker assaults and negatively affecting the functionality of the IoT network in its entirety [15]

4. Cloud Computing

4.1. Definition of Cloud Computing: The foundation of Internet of Things applications, cloud computing is a quickly expanding idea that makes data processing, storing, and worldwide access possible. It facilitates complex service creation and deployment by providing resources and services through the internet. Location independence is promoted by cloud data centers, which offer management services, including processing and storage resources, that are globally available from any internet-connected device.

Furthermore, because different systems and protocols exist, combining various data is difficult. Traditional cloud solutions handle the data processing and storage requirements of IoT. Prominent cloud service providers comprise Amazon, Microsoft, IBM, and Google. The multi-tenant characteristic of cloud computing facilitates resource sharing across users across time and place, resulting in encouraging the convergence of IoT and cloud.

IoT's main objective is to connect people, things, and devices; this generates a lot of raw data. Additionally, multi-tenant characteristics offered by cloud computing enable the distribution of storage space and the long-term combination of resources for many entities [17].

4.2 Cloud Service Models: Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS) are the three service models that cloud computing provides.

Distributed digital infrastructure is provided by Infrastructure as a Service (IaaS), which gives customers the ability to set up virtual computers and manage resources like processing and storage capacity. GoGrid, Amazon EC2, Microsoft Azure, and Rackspace are a few examples.

The cloud-based environment provided by Platform as a Service (PaaS) allows developers to design, test, and launch applications. Examples include OpenShift, SAP, Force, Google App Engine, and Windows Azure [18][19].

Software as a Service (SaaS) eliminates the need for maintenance by enabling customers to access cloud-hosted programs using web browsers or graphical user interfaces. Google Docs, Office 365, Zoho, and Adobe Creative Cloud are some of the examples.

These cloud-hosted applications, development environments, and infrastructure types (IaaS, PaaS, and SaaS) accommodate different user preferences and demands [20]. These service models are illustrated in Figure 2.

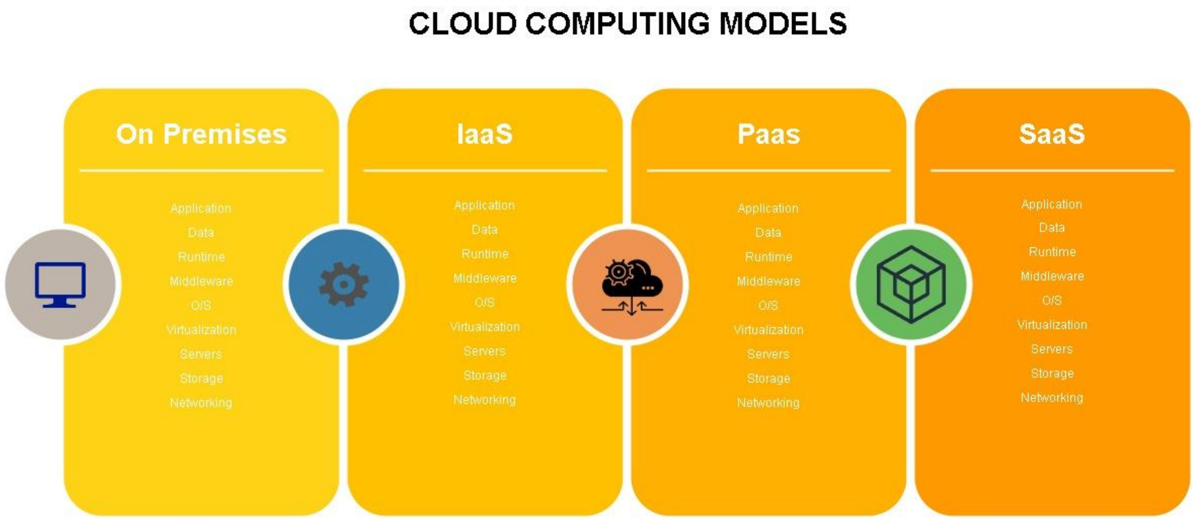

Figure 2. Cloud Computing Models

4.3 Cloud Computing Types: Public, private, and hybrid cloud computing are the three varieties available.

Public clouds are open to all users and give free usage for apps that are supplied; infrastructure expenses are covered by service providers. It might not, however, be able to satisfy the security requirements of businesses managing sensitive data [22].

With complete control over scalability and adaptability, private clouds provide a specialized setting for businesses to safely handle sensitive data [21].

With a hybrid cloud, enterprises can access both private and public clouds for different purposes. For example, private clouds are ideal for storing sensitive data, while public clouds are better suited for managing less important data [19]

4.4 The benefits of cloud computing: The benefits of cloud computing include:

Scalability: The ability to quickly scale up or down, pay for only the amount of processing power and storage used, and use it as required.

High availability: To ensure high uptime, cloud companies provide various worldwide regions with multiple availability zones.

Cost-effectiveness: Considering high availability, pay for only the resources you require, which is frequently less expensive than internal solutions.

5. Edge Models Overview

Conceptual presentations of fog computing and edge computing have been performed, together with information on their definitions, architectures, advantages, and difficulties.

Fog Computing makes advantage of network edge devices' capacity for computation. The potential of edge computing to improve IoT more effectively is being investigated by researchers. Services are split between cloud data centers and edge devices that generate data according to Cisco's fog computing architecture.

With capabilities to distribute, organize, manage, and protect resources over the network and edge devices, fog computing serves applications that cannot wait. It ensures the security and privacy of sensitive data by putting an extra layer between end devices and the main cloud [23].

Similar to a core cloud, fog nodes on network devices carry out calculations and data storage.

An increasingly attractive solution for IoT data processing issues is fog computing. By integrating specialized software platforms and making use of nearby device assets to lower

latency and network congestion, it enables the development of Internet of Things applications [24].
The decreased communication latency between nearby devices employing edge resources is one of the main advantages of Fog computing.

5.1 Characteristics of Fog Computing: Fog nodes provide a number of important advantages for IoT data processing and communication. The primary benefits consist of:
Low Latency and Location Sensitivity: By bringing computation closer to end points, fog nodes minimize the physical gap between data sources and the fog server. By caching localized data, this reduces latency and aids in the provision of location-based services [25].
Large-Scale Sensor Network: A large sensor network that communicates with fog nodes is part of the fog computing concept. As a result, requests may now be sent from sensors to fog nodes rather than cloud centers. Fog nodes might handle the request internally or forward it to other nodes in the area for additional processing [26].
IoT Device Mobility: End-device interaction mobility is essential for scattered IoT devices. End-device identities are independent of their physical location and IP address, and fog nodes are dynamic. Fog nodes can act as platforms for resources that are static or movable [27].
Real-time Interaction: Rather than processing input in batches, fog nodes provide real-time interaction. This lowers internet data traffic while providing high-speed services that meet the needs of low-latency Internet of Things applications.
Reduced Bandwidth: By analyzing, storing, and processing data from end devices, fog nodes at the network edge can eliminate the need to send all data to the cloud over the internet.
Interoperability: Video streaming and resource virtualization are only two examples of the smooth communication that fog nodes could enable between various IoT devices and service providers.
Geographic Distribution: IoT devices are mobile and distributed geographically. In order to handle this data, fog computing is required. Fog nodes execute local calculations closer to the devices, which lowers network traffic and latency.
By utilizing resources available in local devices, fog computing leverages dedicated fog computing and IoT platforms to deliver considerable benefits to Internet of Things applications. By leveraging edge resources, this lowers communication latency between nearby devices.

5.2 Fog System Architecture: The fog, edge, and cloud layers are components of fog computing architectures.
Smartphones, cars, sensors, actuators, and other Internet of Things devices are examples of end-device layer hardware. These devices perceive and send data to the fog layer for processing and storing.
Fog nodes, such as routers, switches, gateways, and servers with higher processing and storage capacity, make up the fog layer. These nodes provide services by connecting end devices to the cloud.
Fog nodes in transportation can communicate with end devices and be either fixed or mobile.
For intense computation and large data storage, the cloud layer offers strong servers and storage.
In mobile situations, fog computing is more energy-efficient and performs better than cloud processing. The effective data processing and storage provided by the fog architecture might be advantageous for IoT and mobile internet [27].

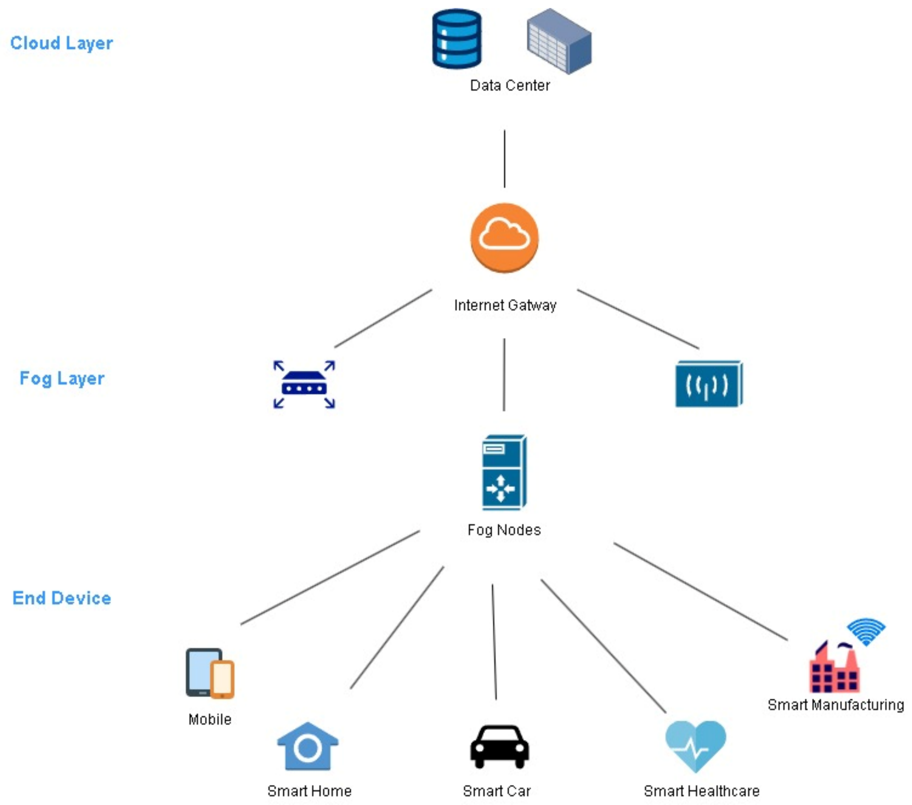

Figure 3. Fog Computing System Architecture

5.3 Fog Computing Platforms for Internet of Things Applications: Compared to cloud computing, fog computing offers a wide range of interesting applications.

Video analytics: Traditional video surveillance is unable to handle the dynamic analysis of events from several cameras as the number of devices increases. By reducing latency and enabling near-end device video stream processing, fog computing offers distributed real-time video analysis.

Smart Grid: To enable intelligent energy management, smart grids integrate communications and electrical grids. Efficiency may be increased by localizing computing and data processing close to the smart grid network as opposed to depending only on the cloud [28].

E-health: Reliable, low-latency data links are necessary for remote patient monitoring. When it comes to real-time diagnostics and patient-health infrastructure interaction, fog computing is a better fit than cloud computing.

Smart Cities/Homes: To manage data from many IoT devices, distributed intelligence is required. Fog computing can minimize reaction times through local data processing and mitigation.

Connected Vehicles: Using edge computing, roadside equipment offers real-time car communication. Applications for intelligent transportation, such as mobility awareness and self-driving automobiles, are made possible by the fog model.

5.4 Understanding Edge Locations: In the edge computing model, data created by end devices is calculated at or close to the network edge. The analog of core networks, where data is generated directly by end devices, is this edge network [29].

A new layer of communication is added by Edge Computing (EC) between end devices and the centralized cloud. EC effectively expands cloud services to nearby Internet of Things devices, such as WiFi access points, allowing for fast data speeds, low latency, real-time communication, and management over personal user information [30]

Multi-access Edge Computing (MEC) has been proposed by the European Telecommunication Standard Institute (ETSI) as a standard solution for 5G networks. Rather of transferring every piece of data to centralized clouds, MEC uses mobile and IoT devices to offload fundamental network data processing and storage.

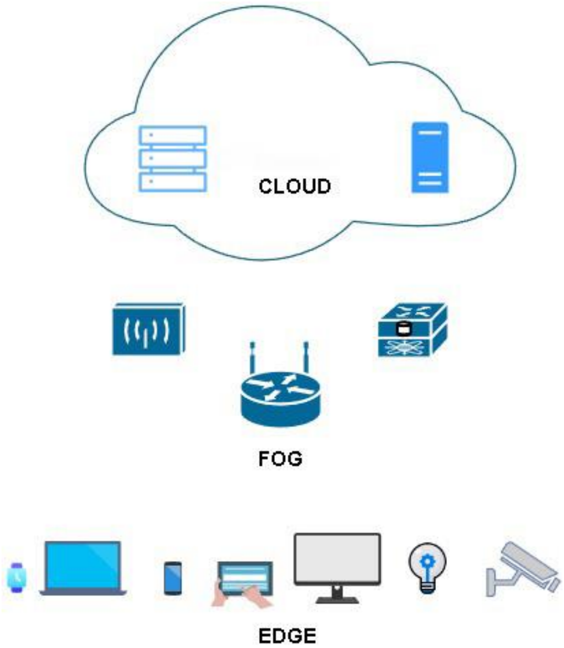

Figure 4. Edge/Fog devices in the network system

Mobile Cloud Computing, or MCC, enhances the management, storage, and calculation of data created by end-devices while offloading the capabilities of mobile devices in comparison to edge computing. Through cloud services installed on IoT devices and cloud integration, the edge model provides pre-processing of IoT data [31].

5.5 Benefits of Edge Computing: Edge computing is used to reduce the main network load and is a new layer in the network system for processing, not to eliminate cloud computing.
Among the principal advantages are:

- Trust: Edge computing makes data easier to manage and control at a lower layer while guaranteeing the privacy of local user data [32]
- Proximity: Using local nodes for communication and information sharing is more efficient than relying on distant cloud servers.
- Intelligence: Edge devices may enable distributed applications for crowd recognition and automated decision-making due to their increased processing capabilities [33]
- Control: Tasks can be assigned or delegated to other cloud peers by edge devices, which are responsible for managing and controlling applications [34]
- Latency: Edge computing offers millisecond-fast reaction times, making intelligent applications conceivable for ubiquitous computing and real-time system interaction for improved user experience [35]
- Bandwidth and Scalability: Edge reduces energy consumption and bandwidth utilization for MANET applications by reducing data in upper network layers. Additionally, it offers low latency for vital applications like VANET and IoV that require quick responses.
- Cost-effective: When it comes to outsourcing data extraction, edge computing is more affordable than cloud servers.

6. Discussions and Conclusion

This paper has reviewed the technologies and applications enabling IoT currently. There is a need for edge computing and shifting the model where the role of edge devices will change from data consumers to data producers. Edge provides faster response times, better bandwidth utilization, guaranteed reliability, and handling data at the edge instead of uploading to the cloud. While some core operations still require the Cloud, Edge Computing is unlikely to fully replace the Cloud. However, investments in Edge are important.

There are two central debates in Edge development, focused on the efficiency and privacy of data processing at the edge. If devices began acting as micro data centers, the efficiency benefits for IoT would be manifold: fast processing, use of small tools, and latency reduction. Shifting data management away from Cloud devices and onto IoT devices can bring visible benefits for environmental sustainability, along with efficiency and privacy.

The Cloud is known as a large data center, but also as many small data centers. In this sense, Fog is a network intermediary connecting millions of remote servers to transfer big data between billions of IoT edge network devices and thousands of Cloud data centers. A key Fog characteristic is low latency and location-awareness, geographic distribution, and a large number of nodes.

Edge has the potential to address concerns around the need for fast responses, short battery life, costs and bandwidth, data security and privacy. Based on the analysis, the benefits of our three-tier Edge IoT model are undisputed. This model enables optimization by considering the benefits of the three available computing tiers, and provides optimized solutions for performance, efficiency, and reliability, based on known application requirements and system resources.

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