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Abstract
The Internet of Things (IoT) interconnects billions of physical objects to amass and transmit data, catering to a wide array of applications, including industrial contexts. Nevertheless, certain applications face infeasibility due to limitations in IoT sensors, especially within industrial IoT (IIoT). To tackle these constraints, cloud computing (CC) has emerged as a solution; however, it brings forth its own set of challenges. This study offers a comprehensive comparison of IoT, cloud computing, and fog computing (FC), delving into parameters, operations, scheduling algorithms, and challenges. Notably, cloud computing's drawback lies in the geographical gap between data centres and end devices, leading to elevated communication costs and security vulnerabilities, particularly for latency-sensitive applications. FC, alongside emerging edge computing (EC), presents an alternative by placing resources near end devices, mitigating costs, and enhancing security. However, fog nodes confront limitations in processing, storage, and memory, compounded by resource disparities and uncertainties. On the other hand, the edge computing concept is still in its developmental phase and requires further research in strategic scheduling of tasks for optimizing resource utilization. This paper introduces various work scheduling algorithms and explores associated tools and challenges. It identifies pending issues in task scheduling for cloud-FC integration and offers recommendations for future research to harness the potential of this approach for IoT applications

Keywords: Fog Computing, Cloud Computing, Edge Computing, Task Scheduling, resource management, energy efficiency

1. Introduction

With the growing invention, various technologies came into existence and one of them which revolutionizes the whole world is Internet of Things (IOT). The datacentres are also expanding according to the data generation and gathering. Figure 1 shows the concept of data centres for huge storage [1]. However, with the expansion of it in various application areas, several issues evolved such as latency, bandwidth utilization, maintenance, mobility, security, sensor deployment strategies tec are not addressed well. On the other side, industry gearing itself to increase its production capacity with the current resources by deploying IoT under the ambit of Cyber Physical System (CPS). The idea of IoT introduced in industry enabled by industry 4.0 (I4.0) goals and known as industrial internet of things (IIoT). While IoT was facing issues concerned mentioned above and now similarly every aspect of IoT is not equally applicable to industrial applications.

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Figure 1: Datacentre for storing the large data [1,2]

The concept of latency in delivery of data is recently deals with the introduction of fog computing, however some industrial applications such as chemical reactors and chemical formation requires hard time bound data delivery. Figure 2 show the kind of data generated and stored at various layers of Cloud, Fog, and Edge environment along with IoT and sensors for the data collection. It is evident that cloud layer stores, analyses and process the data with the help of datacentres. On the other hand, the fog layer advances in local data analytics, processing and storing the same on the fog nodes. The edge layer stores the data in real time, visualizes it and stores the data in micro storage devices. Beside storing the data, various tasks execute in parallel mode, which requires efficient and optimized task scheduling to achieve low latency, less energy consumption, efficient resource utilization and in time data processing. To keep in view concerns encountered in fog and cloud computing (CC) such as latency, reliability, security etc. the concept of edge computing (EC) is introduced. The table mentioned below will address to differentiate the requirements of IoT and IIoT.

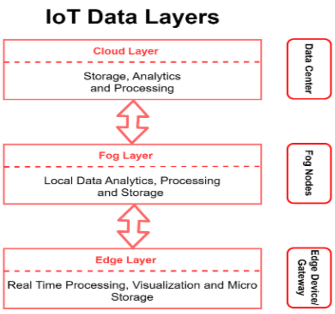

Figure 2: Data generation by Cloud, Fog and Edge layers with IoT and related data collection

TABLE 1: Characteristics Examination of IoT and IIoT in various computing paradigms

	IoT	IIOT
Objective	consumption based luxurious and comfort life	CPS based production enabled by industry 4.0
Sensor Deployment	varies as per application	Varies as per industry requirement
Latency	soft latency schemes can be used	very low latency schemes required
Reliability	Comparative low	promising reliability required
Security	high	very high
Data Volumes	intensive to extensive	extensive to very extensive
Application Environment	indoor, outdoor	indoor, outdoor

Proximity of sensors	close to distant	installation of sensors near industrial units	installation of sensors near industrial units
Operation Completion Time	Soft time bound	hard time bound	hard time bound

1.1 **Motivation**

To provide a comprehensive comparison survey among fog, cloud, and edge computing; this article focuses on contribution of every in development of industrial application to fulfil the requirements of industry 4.0. CLOUD, FOG, and ECare three popular paradigms used in the realm of the Internet of Things (IoT). Each of these paradigms has its own unique characteristics and capabilities, making them suitable for different use cases. A parametric analysis of these paradigms can help in identifying the strengths and weaknesses of each approach, and assist in selecting the appropriate one for a specific application.

TABLE 2: Comparison of Cloud, Fog, and EC parameters

Parameter	Cloud Computing	Fog Computing	Edge Computing
Latency	Highest	Medium	Lowest
Scalability	High and easily scalable	Scalable within network	Hard to scale
Distance	Far free from Edge	Network close to the edge	At the edge
Data Analytics	Less time sensitive data processing, Permanent storage	Real time, decides to process locally or send to cloud	Real time, instant decision Making
Computing Power	High	Limited	Limited
Interoperability	High	High	Low
Latency	Highest	Medium	Lowest
Scalability	High and easily scalable	Scalable within network	Hard to scale

This article systematically compares IoT, cloud computing, and fog computing in the context of IoT and IIoT applications. It begins with the rise of IoT and the challenges of data centres, introduces cloud computing, and outlines its limitations. The focus then shifts to FC and EC solutions, with a specific emphasis on IIoT's requirements for timely data delivery. The distinctive attributes of each computing paradigm are examined, along with their motivations and research gaps, highlighting the need for careful paradigm selection based on application needs and resources.

2. COMPARISON OF CLOUD ,EDGE, AND FOG COMPUTING

2.1 Cloud Computing

CC is a centralized computing infrastructure that provides access to shared computing resources over the internet. CC is highly scalable, cost-effective, and provides flexible resource management. It is suitable for applications with high resource requirements, such as big data analytics and machine learning. However, CC has higher latency than edge and fog computing (FC) and can be more expensive for applications with high data transmission requirements

2.2 Fog Computing

FC is a decentralized computing infrastructure that brings computing resources closer to the edge of the network, where data is generated. In FOG computing, computation and storage are distributed across multiple nodes and devices, and data processing is done locally on the edge devices. FC provides low latency, high bandwidth, and reduced data transmission costs. However, it requires more hardware and infrastructure than EC and may not be suitable for applications with limited resources

2.3 Edge Computing

EC is a distributed computing paradigm that processes data closer to the source, where it is generated. EC reduces latency and improves network performance by processing data locally on edge devices, rather than sending it to a centralized cloud server. EC(EC) is suitable for applications with limited resources and is often used in real-time applications such as smart homes and industrial automation. However, EC has limited scalability and can be more challenging to manage than cloud computing.

3.Enhancing Efficiency and Reliability: The Role of Edge Computing in Transforming Critical Sectors.

Devices near the edge, collect the data from sensors and then further transfer it through some mode of communication to the application layer to fulfil the requests received from the end users. This process is a little time-consuming due to the centralised mechanism used to handle the data through cloud computing. To troubleshoot such problems, Cisco introduced concept named FC introduces a fog layer between edge devices (perception layer) and the cloud layer. This layer was responsible for collecting data from the edge layer, analysing it, storing it, and further transferring it to the cloud for storage if necessary. However, this layer decreased the latency due to the local availability of data nearer the edge. The data available at the fog layer becomes useful to provide real-time streaming of data in various applications such as weather forecasting, HD videos, live monitoring of patients under critical health conditions etc. The advantages of FC are extended further to reduce the latency in delivery of data, make it more secure, reduce bandwidth costs and consequently increase the output in terms of speed and efficiency. However, some time-critical services like smart grid, live monitoring of the oil and gas sector, health monitoring, gaming, delivery of content, autonomous driving vehicles, etc. are the sectors that are going to get a big impact through EC due to its high-speed delivery of information and secure and reliable data as well. The data collected at the edge is further stored at the edge and analysed at the edge layer itself.

The concept of EC is introduced by Akamai while introducing concept of content delivery network (CDN) in 1990s. The idea was to place the nodes geographically nearer to end user for delivery of real-time information. EC is new and quite different from CC in terms of computing received information at the edge itself. Its main objective is to bring the computing and analysis of data closer to the edge devices. The edge devices, such as various sensors, are used to collect the information. This information is computed, analysed, and processed at an edge device in an autonomous mode. Due to its powerful features, it is known as edge computing. Figure 3 represents the data transfer from EC to FC and CC whenever required at the lowest layer, after that FC environment transfers the data to CC and stored in the respective devices for storage and visualization.

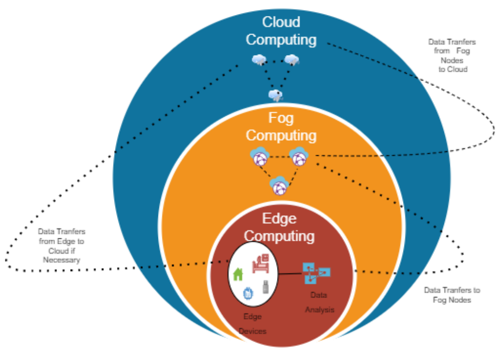

Figure 3: Data transfer from Edge to Fog and Fog to CC environment

3.Exploring the Competitive Edge of EC Over CC and FC

It is a new computing concept that executes computing at the edge of the network. The idea is to decrease the latency and to increase the computing output by reducing data delivery and decision-making time. Academicians and researchers have various definitions of edge computing. EC brings services closer to the devices provided by CC with the aim of responding to application users in no time. Real-time data streaming in entertainment, research, healthcare, virtual reality, and other emerging applications requires instant processing and low latency. It has been shown that end users operate applications on constrained devices while the high-end services are provided by cloud computing. Mobile devices leverage the services provided by the cloud, which results in latency and demands high bandwidth too, which consequently drains mobile devices' power supplies as well. To overcome these issues, the concept of EC was introduced to bring the processing closer to edge devices and provide more security as well. Satyanarayanan et al. establish the cloudlets concept to troubleshoot the issue of latency while accessing the cloud and, in the same way, mobile edge nodes pave the way to offload processing, storage, and application services close to users.

4.DISTINCTIVE ATTRIBUTES OF EDGE COMPUTING

EC seems to be the most promising paradigm for future technology, and it is very important to consider those advantages which make it so popular among researchers. The following are the characteristics of edge computing:

- ✓ Mobility
- ✓ Location Awareness
- ✓ Ultra-low latency
- ✓ vicinity to the user
- ✓ enhanced network bandwidth
- ✓ better operational efficiency
- ✓ improved security and privacy

To transfer the services of CC such as computing, analysis, storage to the edge of the network which provide hard time bound operational efficiency in industrial applications, security, privacy, real-time monitoring of industrial units etc. Some decisions in industry need to be performed in time which provides the low latency and high bandwidth due to its closeness to the network. Figure 4 shows the final storage at datacentres when data generation devices increase invariably at various layers of Computing.

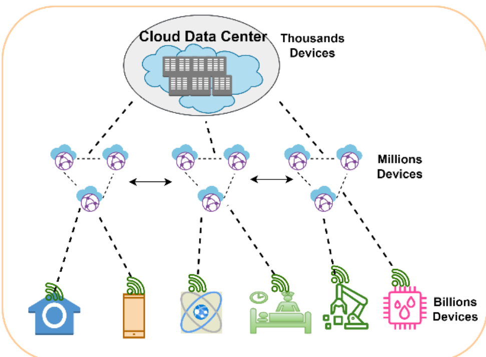

Figure 4: Storage at Datacentres when devices increase invariably

The concept below in Figure 5 explains how the devices at various levels and layers of computing are increasing day by day resulting in the generation of data as most of the smart devices are sensors based and the apps based on machine learning employed for analytics are also resulting in huge amount of data. So, there is a need to keep an eye of the data storage at various levels starting from edge to fog-cloud or cloud storage devices.

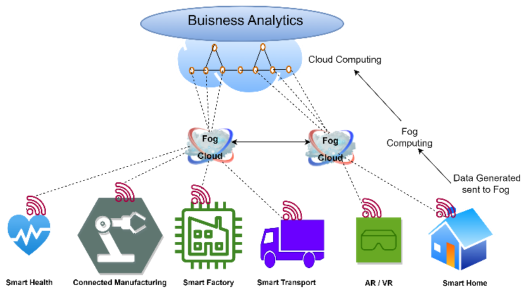

Figure 5: Data Generation and Analytics in terms of Edge, Fog, and Cloud computing

One more parametric analysis can be done when the computing environments are implemented with the help of various devices, locations, software's architecture, context awareness, function proximity, various access mechanisms, communication between internode.

5.Task Scheduling Challenges

The task scheduling was always critical while dealing with large storage mechanisms such as cloud computing. To find the best solution for task scheduling was always been a challenge because of its NP compete natured problem. Consequently, it became difficult to find solution for large sized problems. However, the task scheduling can be optimized by reducing the make span of various virtual machines [3]. The edge of the network in FC is in constrained nature which requires assignment and scheduling of tasks. On the other side and efficient task scheduling can saves significant amount of energy consumption as well as response time to an applicant too [4]. On the other side, to schedule tasks in EC environment is also challengeable due to the installation of various heterogeneous computational devices. On the other side the dynamic environment of EC(EC), availability and reliability of resources makes it more challengeable. EC environment consists of huge number of devices and the EC offers a high scalability in over a large geographic region, which in turn demands scalable task scheduling algorithms [5]. In continuation of task challenges in various environments, next section will be discussing various challenges in task scheduling.

Table3: Comparison of different Computing Implementations

Implementation Parameters	Fog Computing	Mobile-Edge Computing	Cloudlet Computing
Node devices	Routers, Switches, Access Points, Gateways	Servers running in base stations	Data Center in a box
Node location	Varying between End Devices and Cloud	Radio Network Controller/Macro Base Station	Local/Outdoor installation
Software Architecture	Abstraction Layer based	Mobile Orchestrator based	Cloudlet Agent based
Context awareness	Medium	High	Low
Proximity	One or Multiple Hops	One Hop	One Hop
Access Mechanisms	Bluetooth, Wi-Fi, Mobile Networks	Mobile Networks	Wi-Fi
Internode Communication	Supported	Partial	Partial

6.Scheduling Problems

Based on literature survey and review a range of comprehensive answers cropped up for analysing the scheduling problems. The task scheduling algorithms can be also categorized into four general groups:

- static scheduling algorithms
- dynamic scheduling algorithms
- heuristic scheduling algorithms

- hybrid scheduling algorithms

Now the question arises that if following questions can be answered properly that will be helpful in researching this area more wisely and effectively.

1. Which type of scheduling method is gaining more attention comparative to existing ones?
2. For which kind of environments is well suited for the scheduling algorithms?
3. Which efficient metrics for scheduling will be well suited and can be used by scheduling algorithms?
4. What challenges and which areas need more severe investigation in future works

7.Research Gaps and Findings

- The real time scheduling in dynamic environment is a major challenge. The arrival of tasks can be highly dynamic in real time, however various existing algorithms are static with respect to task arrival rates [**MR Alizadeh**].
- To manage the heterogeneous resources with varying capacity in CC is still an open research issue [**M Sohani**].
- To conserve energy consumption in CC while scheduling the tasks in dynamic environment is highly challengeable.
- CC environments are highly prone to power failure, network congestion etc. The task scheduling algorithms should be capable to manage with such failures [**N Mansouri**].
- The exploration of multi objective task scheduling mechanism and inspects trade-offs between multi objects, holds impactable research directions in FC environments [**R Thakkar**].
- Due to the distributed nature of fog computing, it highly demands security and privacy requirements such as secure task placement is a big trouble [**P Hosseinioun**].
- The task identification on edge devices is difficult due to heterogeneity of resources and varying conditions, where as efficient migration of task among devices if necessary to reduce network load and resource utilization [**N Kaur, A Kumar, R Kumar**].
- The limited energy of edge devices makes task scheduling more challengeable. The energy consumption awareness-based algorithms are required to allocate tasks [**Alizadeh**].

8.CONCLUSIONS

In summary, the advent of technologies like the Internet of Things (IoT) has reshaped industries and data management practices. This article underscores the expansion of data centers to accommodate escalating data volumes. While IoT holds immense potential, challenges persist in latency, security, and deployment strategies. The integration of IoT into Industry 4.0 (I4.0) has led to Industrial Internet of Things (IIoT), transforming manufacturing and processes. Fog computing has emerged as a solution to latency issues, especially in industries with stringent time-bound data needs. The comparison of Cloud Computing (CC), Fog Computing (FC), and Edge Computing (EC) highlights their distinct attributes, aiding in paradigm selection based on application requirements. Edge computing's real-time processing and low latency make it especially relevant. The challenges of task scheduling across these paradigms are highlighted, calling for innovative solutions in energy efficiency, real-time adaptability, and heterogeneous device management. In conclusion, this article navigates the complex landscape of IoT, IIoT, and various computing paradigms, emphasizing the need for tailored solutions. The integration of fog and edge computing is critical for industries requiring timely data delivery. As technology evolves, strategic choices in computing paradigms will drive efficiency, security, and operational success across various sectors.

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