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A REVIEW ON HYBRID CLOUD-FOG-EDGE ARCHITECTURES FOR EFFICIENT AND SCALABLE SMART HOME IOT SYSTEMS

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Abstract

In the rapidly evolving field of Internet of Things (IOT), smart homes represent one of the most noticeable applications or devices, where multiple IOT devices interact with each other to enhance the convenience, security, and energy efficiency for users. The integration of these devices with cloud computing enables smooth data processing, remote control access, and automation of all devices. However, as the number of IOT devices in smart homes grows, cloud architectures faces increasing challenges in terms of scalability, latency, and resource management. Traditional cloud infrastructures are often overloaded by the vast amount of data generated by IOT devices which leads into performance jams and slow response times for real-time applications. The current state of smart home IOT systems is further complicated by issues such as latency in cloud communication, bandwidth limitations, and the lack of efficient data management across distributed devices. These challenges create an urgent need for more adaptable and efficient architectures that can handle the growing complexity of connected IOT devices while maintaining and solving problem of real-time processing and low-latency communication. To address these scalability concerns, we propose leveraging a cloud-fog-edge hybrid architecture, which distributes computational tasks across multiple layers which includes cloud, fog, and edge. This approach promises to improve system scalability, reduce latency, and optimize resource allocation by balancing the processing load between the cloud and local devices. The focus of this review is to analyze this architecture as a solution to the scalability problems in smart home IOT systems, exploring its advantages, challenges, and future research directions.

INTRODUCTION

The Internet of Things (IOT) has transformed the way everyday devices communicate and interact with each other. One of its most important applications lies within the empire of smart homes. Smart homes are rapidly becoming a foundation of modern living, where interconnected multiple IOT devices are used to automate tasks, which optimizes energy consumption, and provides enhanced security and convenience for users in their daily life tasks. These IOT devices starting from smart lighting systems and thermostats to voice assistants and security cameras, depend heavily on continuous data communication and processing to deliver real-time responses and efficient operations [1,14].

As these devices generates vast volume of data, traditional cloud-based architectures have been widely employed to handle data processing, storage, and management. [8] Cloud computing has played a crucial role in enabling the remote control and automation of IOT devices by providing vast computational power and storage capabilities. However, as the number of smart home IOT devices continues to grow, cloud architectures are becoming to show significant limitations. These limitations include scalability issues, increase in latency, and resource management challenges that delay the performance of real-time applications. The vast amount of data flowing between IOT devices and centralized cloud servers often leads to network congestion, longer response times, and, ultimately, performance bottlenecks.

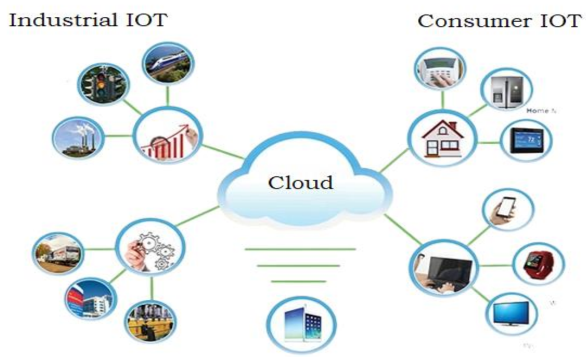

Figure 1: Cloud with IOT

Moreover, [11] as IOT systems within smart homes expand in complexity, additional issues arise, such as the inefficiency of bandwidth usage, lack of localized data processing, and delay in decision-making. Centralized cloud infrastructure struggles to meet the increasing demand for real-time responsiveness required by applications such as smart home security, energy management, and device automation, leading to potential system-wide inefficiencies.

In light of these challenges, it is becoming very clear that relying only on cloud computing is no longer a sustainable solution for large-scale IOT systems like smart homes. Instead, there is a demanding need for more decentralized architectures that can distribute computational and processing tasks more efficiently. One promising approach to overcoming these scalability barriers is the adoption of a cloud-fog-edge hybrid architecture. This layered architectural model distributes processing tasks across three interconnected layers which are edge computing for localized real-time processing directly on smart devices, secondly fog computing to handle intermediate tasks closer to the devices but still within the local network, and lastly cloud computing for heavy-duty processing and long-term storage.

This hybrid architecture not only mitigates latency problem by bringing computation closer to the source but also optimizes resource allocation by balancing the computational load across the cloud, fog, and edge. By offloading tasks from the centralized cloud to local and intermediate layers, this approach defines both scalability and performance concerns, making it a more adaptable and efficient solution for the expanding IOT-based smart home systems.

The focus of this review is to explore the cloud-fog-edge hybrid architecture as a practical solution to the scalability issues faced by smart home IOT systems. By analyzing its advantages, challenges, and real-world applications, this paper aims to provide understandings into how this architecture can enhance the performance, efficiency, and scalability of smart home environments.

1. Literature Review

In [1] paper, author address the need for secure and efficient system that automates the home appliances using IOT devices. The used IOT home devices were sensors, cameras and smart locks connected through Wi-Fi and Zigbee which was controlled by Raspberry Pi or Arduino for real-time monitoring and alerting through smartphone apps. The system successfully automates household tasks with enhance security through real-time surveillance and remote control access over all home appliances. They may face challenge of scalability when more and more devices added to the system.

Aldeen et al [2], takes the challenge of controlling charging stations for electrical vehicle using IOT devices and cloud computing. In these stations, IOT devices monitors activities and power consumption with the help of cloud. This system improves stations efficiency by allowing booking of stations, energy utilization and remote access for users to locate empty slots. The system may be costly and must requires permanent internet connectivity.

The problem addressed by [3], is the inefficiency of power distribution which was traditional and requires real-time monitoring, controlling energy management system. The framework is used to monitor and control the power distribution by using IOT devices which gather data and manages the power distribution with the help of cloud computing. This will enhances the efficiency of power distribution by enabling real-time monitoring and controlling.

In [4], the researcher takes the IOT devices of smart home where different communication protocols and platforms were used and make integration complex. Model-Driven Architecture (MDA) framework is suggested to simplify the complexity of various protocols. This abstracts the complexities by defining models to ease the communication between various IOT devices. This approach enhances the interoperability among smart home devices regardless of various used communication protocols. This requires standardization efforts to deal with highly customized IOT system that are resistant to standardization.

The paper [5], [7] examines the challenge of massive IOT networks energy consumption management. The author reveals energy efficient techniques which includes Dynamic Voltage and Frequency Scaling DVFS, Energy-Efficient Medium Access Control (MAC) protocols like S-MAC and T-MAC for minimizing communication energy costs and Sleep Mode Strategies where IOT devices periodically enter low-power states to conserve energy. It highlights a variety of methods that can reduces energy consumption for IOT devices which will result into more sustainable and long lasting IOT networks. Many energy-efficient techniques are still in the experimental phase. Additionally, balancing performance with energy efficiency remains difficult.

The impact of 5G wireless technologies in [6] explores the performance, scalability, and capabilities of Cloud Computing and IOT devices, with the main focus of how 5G takes existing limitations of connectivity, latency, and bandwidth for these technologies. Here author uses 5G technologies like enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), and Massive Machine-Type Communications (mMTC), which improves IOT and cloud computing by providing higher data rates, lower latency, and support for a massive number of connected devices. These capabilities enables faster data transfer, more reliable connections, and the ability to handle a larger number of devices. This results in improved performance for IOT applications, such as smart cities and autonomous vehicles. 5G infrastructure cost makes challenge in applying these technologies.

The integration of IOT devices with cloud, fog and edge computing is addressed in [8] paper which was used to resolve the problem of latency. Bandwidth, and processing limitations in old-fashioned cloud-based IOT systems. Cloud computing provides centralized data storage and processing for IOT but struggles with latency, then they added Fog Computing, which extends cloud capabilities by bringing processing closer to IOT devices, and after that Edge Computing was enabled to process data directly on IOT devices. These hybrid approaches enhances the system performances in the targeted areas to enables more efficient IOT applications in smart cities, healthcare, and autonomous vehicles. Complexity of managing distributed systems is the dare we may face.

Another difficult situation of managing vast amount of data generated by IOT devices was discussed [9]. Several key technologies that enhances the synergy between cloud and IOT includes Big Data Analytics, Machine Learning and Data security techniques. The integration of these technologies improves data management, processing capabilities, scalability of devices. The complexity of integrating diverse IOT devices with various protocols and standards, and the high costs of cloud services can be a barrier for small-scale IOT implementations.

Investigation done in [10] is associated with wireless technologies in Internet of Things (IOT) projects that utilize distributed computing, focusing on issues related to connectivity, scalability, and energy efficiency. Various wireless communication technologies for IOT, such as LoRaWAN, NB-IoT, Zigbee, and Wi-Fi, evaluating their capabilities in supporting distributed computing environments. Edge computing and fog computing approaches are also beneficial to process data closer to the source which will reduce latency issue and bandwidth usage. The integration of these technologies with distributed computing significantly enhances the performance and scalability of IOT projects. Limited range and data rates of some wireless technologies, opens security vulnerabilities in wireless communications. Additionally, the complexity of managing and integrating different wireless standards and protocols in one project can pose significant operational hurdle.

The papers [11], [12] addresses the significant security challenges associated with integrating the IOT with cloud computing due to the vast amounts of sensitive data generated by IOT devices which requires secure data transmission and storage. Authors analysis multiple risk factors, including data breaches, service outages, and vendor lock-in and suggests various mechanisms designed to protect IOT-cloud integration which includes encryption techniques for secure data transmission, authentication protocols to ensure only authorized devices access cloud resources, and access control mechanisms that manage user permissions, utilization of multi-cloud strategies to enhance redundancy, and establishing comprehensive service level agreements (SLAs). The integration of effective security measures improves the overall resilience of IOT-cloud integration and highlights successful implementations of these security techniques in real-world applications and maintaining data confidentiality, integrity, and availability.

Raza et al [13], examines the security implications of IOT with cloud computing which highlights vulnerabilities particularly in terms of data protection, user privacy, and overall system integrity. By analyzing various security challenges, importance of implementing robust authentication mechanisms, data encryption during transmission and storage, and secure API designs to protect against potential threats requires security frameworks and compliance standards that can help mitigating risks. The findings indicates that cloud computing can enhance the capabilities of IOT systems, it also illustrates successful security implementations that have effectively reduced risks and improved data security in IOT-cloud environments. The diverse range of devices makes challenging to maintain consistent security standards.

2. Proposed methodology

The problem in the literature review are of various types which includes latency due to cloud services because all the data have to transfer to cloud for processing which requires reasonable bandwidth. The solution to solve these problem is to introduce Cloud-Fog-Edge Hybrid Architecture. This architecture distributes all computational tasks across three layers which are cloud, fog, and edge. Cloud will handle large-scale data processing, long-term storage, and analytics of data. Fog acts as an intermediary layer that brings processing closer to the IOT devices, reducing latency issue using cloud while Edge handles local, real-time data processing directly on or near the IOT devices. This also Solves Scalability problem because this architecture reduces the load on the cloud by distributing tasks across fog and edge layers. It also lowers latency and bandwidth usage, making it easier to scale with additional devices.

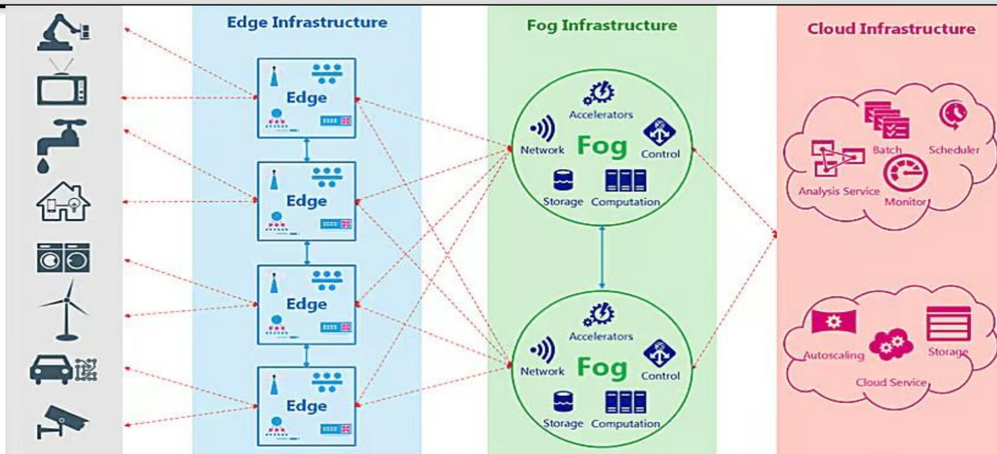

Figure 2: Hybrid Cloud-Fog-Edge Architectures

3. Result

The cloud-fog-edge hybrid architecture provides a great solution to the scalability challenges faced by smart home IOT systems. By distributing processing tasks across cloud, fog, and edge layers, this architecture minimizes the dependence on centralized cloud resources, which often suffer from latency and bandwidth limitations. The edge layer, consisting of smart home devices and local gateways, handles real-time data processing and decision-making which will reduce the need for constant communication with the cloud. This will not only improves response times but also reduces data transmission overhead. The fog layer acts as an intermediary layer to provide additional processing power and storage closer to the source, thus offloading tasks from both the cloud and the edge, further enhancing the system's scalability.

4. Conclusion

In this review paper, we have explored the cloud-fog-edge hybrid architecture as a solution to the scalability challenges faced by smart home IOT systems. As the implementation of IOT devices in smart homes continues to grow, traditional cloud-based architectures are proving poor performance due to issues related to latency, bandwidth constraints, and resource management. These challenges creates the real-time responsiveness and efficiency glitches that smart homes does not requires, particularly for applications such as security, energy management, and automation.

To address these problems, we examined the potential of decentralized architectures, particularly the cloud-fog-edge hybrid model, which distributes computational tasks across three layers, cloud, fog, and edge. By offloading tasks from the cloud to local edge devices and intermediate fog nodes, this architecture provides significant results which reduces latency, improves scalability, and optimizes resource usage. The hybrid approach provides a more adaptable and efficient solution for managing the growing complexity of smart home IOT systems.

Our analysis of existing literature has shown that while the cloud-fog-edge architecture offers several advantages, such as enhanced performance and responsiveness, it also presents challenges related to communication, security, and data synchronization across different layers. This hybrid model holds great opportunities for the future of smart home IOT systems, offering a robust framework for handling the increasing number of connected devices while maintaining low-latency communication and efficient resource management.

In conclusion to this review paper, the importance of adopting the cloud-fog-edge architecture to decreases or finishes the limitations of traditional cloud computing in smart homes. Future research should focus on addressing the integration challenges, improving security mechanisms, and optimizing data flow between the cloud, fog, and edge layers to fully recognize the potential of this architecture in large-scale IOT environments.

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