Integrating Edge Computing with Internet of Things Systems for Smart Homes

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Abstract— The fast development of the Internet of Things (IoT) has dramatically transformed dwelling space, leading to the development of smart homes smart systems of connected devices that can perceive, compute and communicate. They enable automation, increase energy efficiency, safety and security, and improve user comfort etc. In the recent years, smart home systems were built upon centralized cloud computing architecture for data processing and decision-making. Even though the cloud brings in the ability of scalability and the centralized management of resources; but it also imposes some important challenges, including high end-to-end delay, high consumption, and an increase in vulnerability to data exposure since confidential information is moved to the other servers. Edge computing has been proposed as a promising paradigm to mitigate these issues by distributing computation and allowing data to be processed at, or near, the data source. This paper study the deployment of edge computing support for IoT systems in smart homes and perform a comparative study of two system architectures, the traditional cloud-based and the proposed edge-enabled architecture. The performance is evaluated through extensive simulations in OMNET++ using real smart home scenarios and traffic patterns. System efficiency is evaluated considering key performance parameters— end-to-end latency, bandwidth usage, CPU utilization and packet delivery ratio. It is shown that the edge-enabled architecture significantly reduces the latency, efficiently utilize the network resources, balance the processing load, and enhance the reliability of the packet delivery compared to cloud-only model.

Keywords— Internet of Things, Cloud computing, Edge computing, Smart homes, OMNET++ Simulator

I. INTRODUCTION

The exponential growth of digital and communication technologies during the last years has fuelled the development of the Internet of Things (IoT), a novel paradigm in which the real world is interconnected with the digital world [1]. IoT helps common objects such as home appliances, industrial machines, vehicles, and wearable devices to connect to each other and the internet, and interact on their own [2]. Such devices are equipped with the sensors, the actuators, microcontroller, and the communication interfaces that can enable them to perceive the surrounding, variety, and complexity, and to process their interactivity locally or remotely, and to communicate with other devices and/or cloud services. The IoT ecosystem enables real-time monitoring, automation, and intelligent decision making in several domains such as health, transportation, agriculture, smart cities etc. [3], [4].

An example of one of such application areas is smart home, a home environment facilitated by connected IoT devices [5]. These products are designed to make life and living in your home easy, comfortable, secure, efficient or just fun through intelligent automation and remote control. Examples are thermostats that automatically regulate for temperature and level of occupancy, light systems that are

adapted based on user preferences, surveillance cameras with motion sensing, door locks that are remotely unlocked, and appliances that are controllable or monitorable trough smartphones [6]. In a smart home, different subdomain systems (energy management [7], environmental monitoring [8], and security cooperate with each other to maximize resource utilization and use experience [9].

The conventional smart home systems heavily depend on cloud computing [10]. In cloud-centric architectures as depicted in Fig. 1, data accumulated by IoT devices is transferred over internet to centralized cloud servers for storage, processing, and analysis. The cloud infrastructure offers powerful computing capabilities, elastic storage, and centralized data management, making it suitable for large-scale data analytics and complex decision-making [11]. However, cloud computing also introduces significant limitations, especially in the context of real-time and privacy-sensitive smart home applications. First, end-to-end latency increases due to the round-trip time required for data transmission between devices and remote cloud servers. This delay can be detrimental to latency-critical applications such as fire alarms, intrusion detection, or emergency response systems. Second, the bandwidth consumption required to transmit large volumes of sensor data can strain

network resources, particularly in homes with multiple connected devices. Third, centralized data storage raises security and privacy concerns, as personal and sensitive information is exposed to potential breaches, unauthorized access, or misuse in remote data centers [12].
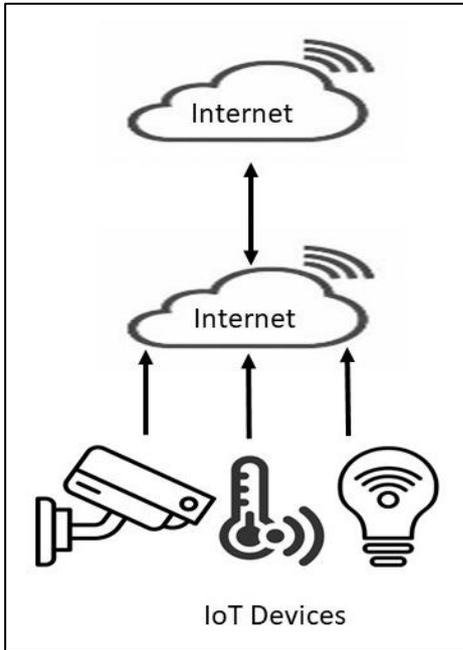

Fig. 1 Cloud-Based architecture

To address these challenges, the concept of edge computing has been introduced as a complementary or alternative computing paradigm. Edge computing, a strategy for computing on location where data is collected or used, allows IoT data to be gathered and processed at the edge, rather than sending the data back to a data center or cloud [13]. Fig. 2 illustrates the architecture of Edge computing in IoT, composed of three layers: IoT Devices Layer, which includes devices such as a security camera, a smart light bulb, and a motion sensor. These devices continuously collect environmental data and initiate communication within the smart home ecosystem. Edge Node Layer, which is represented by a wireless access point or gateway, the Edge Node is a localized processing unit—often a router, embedded system, or mini-server. It acts as a bridge between the IoT devices and the cloud for some data pre-processing, filtering, and sometimes real-time analytics. The edge node assists in moving computational burden from cloud, thereby speeding up the system and respond to high-priority events. Cloud Layer is still left as part of the architecture, where we perform deeper analytics, store huge amounts of data and train machine learning models. Data transmitted from edge to cloud is typically filtered or aggregated to avoid transmitting of redundant traffic and to offload the cloud onto only what is valuable [14]. In the

smart home scenario, this pertains to taking advantage of intelligent edge nodes such as IoT gateways, micro servers, or embedded systems that can locally process, analyze and decide about the data. By removing the need for cloud, edge computing is the next level of innovation than can improve latency, reduce bandwidth requirement by pre-processing data before sending it and strengthen your data security by ensuring that your data is not "in-flight" or indeed stored in a remote easily accessible place. In addition, edge-enabled applications are more tolerant to network outage, since they are able to work even over a short time of occasional connections to the cloud [15].

This study aims to explore and evaluate the integration of edge computing within IoT-based smart home environments. Specifically, it presents a comparative analysis of two architectural models: a conventional cloud-based smart home system and a smart home system integrated with edge computing. These models are implemented and simulated using OMNET++, an event-driven network simulation platform that provides a flexible and modular environment for modelling complex network behaviors, IoT protocols, and distributed systems.
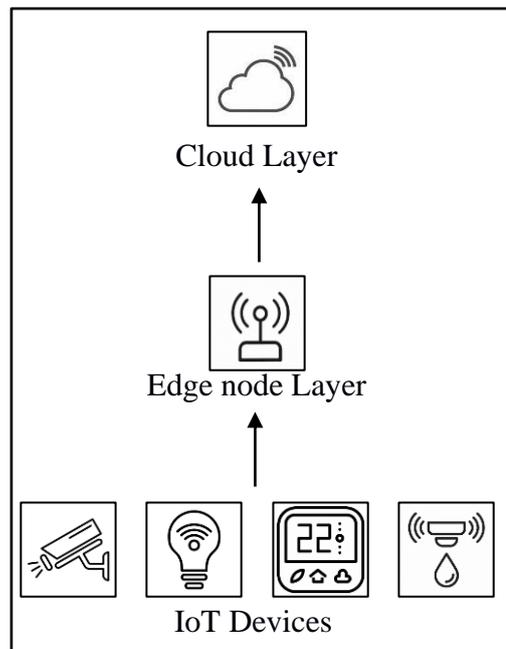

Fig. 2 Edge-Based architecture

II. RELATED WORKS

The proliferation of Internet of Things (IoT) in residential context has made possible the emergence of smart homes as intelligent environments, capable of providing comfort, safety, energy efficiency, and automation by means of interconnected devices. The devices collect and transmit data on an on-going basis; these data need to be processed in order to put them to good use. Historically, smart home

systems have been based on cloud-centric approaches though recent work has shown interest in edge-based or hybrid computing to address the drawbacks of centralized processing. This section is a detailed survey for both cloud enabled and edge empowered smart home models.

Hsiao T. et al designed a cloud-based platform for improving residential energy efficiency and user comfort in the smart homes' environment. The system combines IoTs with computing and cloud for efficient power management. It offers real-time power consumption information, appliances control and statistical analysis of the power usage data collected [16].

Albataineh and Bollampall [17] introduced a hybrid cloud-edge computing solution to increase the productivity of smart homes with the processing of IoT data. The research utilized a profound machine learning engine, in which a decision tree was utilized, to determine how the communication between the edge layer, failover between edges and the Cloud layer can be made. The result shows that the developed model has more throughput and more power consumption [17].

Jun L. presented a study that delves into the integration of cloud computing technology into smart home systems of the Internet of Things (IoT). The study had analysed cloud computing and Internet of Things integration, improved service quality in the smart home industry, and explored cloud computing applications in smart home systems [18].

Ma S. proposed a cloud computing-edge cooperation framework in the context of IoT applications. The proposed model enhanced the performance of real-time and data processing. It effectively reduced data transmission delay and network latency. In addition, I enhance resource utilization, task processing success rate, and bandwidth usage is significantly reduced in various IoT scenarios [19].

Saxena M. et al. introduced a resource allocation strategy for IoT Networks which maximizes the use of edge devices. The proposed strategy minimizes the end-to-end latency through an edge-to-edge device offload strategy, and the Queue delay is reduced by optimizing CPU frequency [20].

Sithiyopasakul J. et al. reported a detailed performance analysis of cloud computing and IoT, specifically on three large systems: Amazon Web Services (AWS), Google Cloud Platform (GCP) and Microsoft Azure. This study performed a comprehensive evaluation of the performance of cloud computing and IoT systems in terms of essential parameters, good performance with prospects to further improvement regarding response time, latency, and reliability were indicated in some cases. [21].

Kalra S., Mathur G, and Parashar A. presented a research on that about the wireless home automation system improvement using edge computing. The authors aimed to determine how introducing edge computing to home automation systems can overcome the main shortcomings of "classic" cloud-based architecture (high latency, security issues, ineffective real-time processing). It was based around creating a local edge-computing setup that consisted of hardware such as Raspberry Pi & OpenFaaS with a selection of sensors attached, and performing compare/contrasts between the only-cloud versus edge-configurations. Result depicted that edge computing is a more flexible, secure and power effective solution for the contemporary smart homes. But the experiments relied on a simple edge design based on Raspberry Pi and a limited number of sensors. Although this configuration is proof of concept, it is not scalable and does not resemble the real complexities of a bigger or mixed smart home ecosystem (dozens, hundreds or more than thousands of devices) [10].

Papcun P. et al. introduced an edge-enabled IoT gateway to lower data forwarding, cost, and underlined its capability. The role-edge within healthcare applications was underlined in this paper, which had defined four classes of IoT gateways: (1) normal gateway, (2) smart gateway, (3) intelligent gateway, and (4) edge gateway [22].

Pal T. et al. conducted a cooperative processing model based on cloud-edge computing and adopted the unified system deployment scheme in Kubernetes to implement cooperative processing. Experimental results show that the proposed approach provides better operational efficiency than systems firmly based on either the cloud or single-edge computing, so as to more adequately satisfy the real-time demands of smart homes [23].

III. METHODOLOGY

This section describes the detailed methodology used to simulate and evaluate the performance of cloud-based and edge-enabled smart home architectures.

A. The Proposed Framework

Fig. 3 illustrates the proposed edge computing framework for a smart home environment, organized into three primary layers: Device Layer, Edge Layer, and Cloud Layer. The Device Layer contains the IoT devices such as motion sensors, smart locks, and IP cameras which constantly generate sensor data depending on the context, which detect an environmental change and user interaction. This information is then sent to the Edge Layer who process the data: (1) in the Data Pre-processing Unit where it is filtered and the values are minimized; (2) in the Event Detection Engine, used to detect relevant information, such as an intrusion, a fire, etc.; and (3) Local Decision Module, which takes a quick action, like open a door. In order to study the performance of the considered architectures, we evaluate them against a selection of performance measures,

important to design and operate smart home systems. The Edge Node ensures low-latency responses while also communicating with the Cloud Layer. The Cloud Analytics Engine performs advanced tasks such as learning-based analytics, periodic summaries, and system-wide optimization. Arrows indicate the bidirectional flow of data: sensor inputs and control feedback travel vertically between layers, while pre-processed data and user commands are exchanged horizontally between the edge and cloud. This architecture supports a scalable, efficient, and responsive smart home ecosystem with minimal cloud dependency for critical operations.
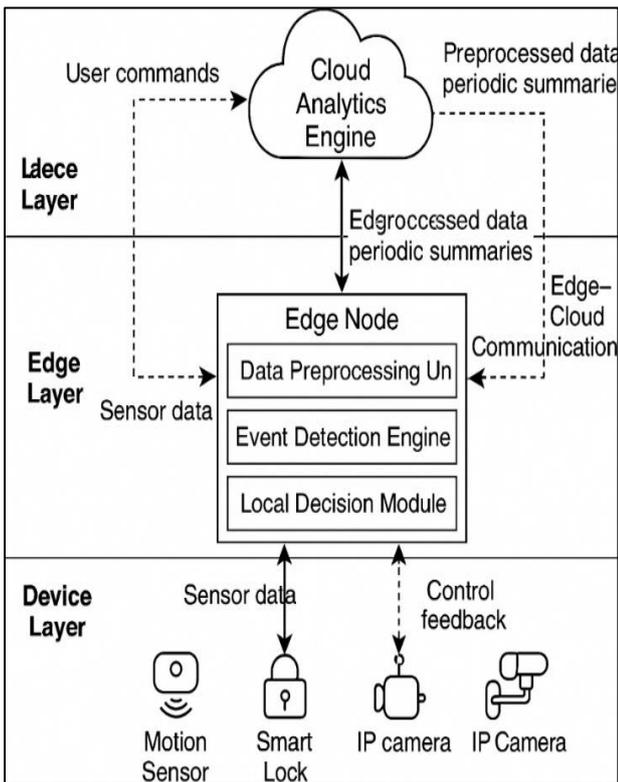

Fig. 3 The proposed Edge framework description

B. Simulation Environment

The selection of the research methodology and evaluation criteria was driven by the study's objective to assess the effectiveness of integrating edge computing into IoT-based smart home systems. A simulation-based approach using OMNET++ with the INET framework was adopted to create a controlled and realistic environment that models network topologies, IoT devices, and communication protocols without the complexity of large-scale physical deployment. The topology simulates a home setting with 20 IoT devices, connected either directly to the cloud or through a local edge node. Table I. presents the simulation parameters for the conducted scenarios.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Simulation Tool	OMNET++ (INET Framework)
Network Bandwidth	100 Mbps
Latency (Cloud Path)	50 ms
Latency (Edge Path)	5 ms
Packet Size	512 bytes
Number of IoT Devices	20
Simulation Duration	600 seconds
Traffic Model	Constant Bit Rate (CBR)
Edge Node Processing Time	2 ms
Cloud Server Processing Time	20 ms

C. Simulation Scenarios

Two scenarios are simulated using OMNET++ to evaluate the performance of smart home system.

1) Scenario 1 Traditional Cloud-Based Smart Home System: In this scenario, all IoT devices in the smart home, such as motion sensors, door locks, surveillance cameras, smart lights, and thermostats, are connected directly to the cloud via the internet. These devices transmit their data to remote cloud servers, where data aggregation, analytics, and decision-making are carried out. The cloud then sends control commands back to the devices based on the analysis. This approach centralizes processing but incurs communication latency, especially for time-sensitive actions like unlocking a door in response to an authorized facial recognition event or triggering an alarm in case of intrusion detection. The high volume of transmitted data also places significant demands on network bandwidth.

2) Scenario 2 Smart Home System with Integrated Edge Computing: In this scenario, IoT devices initially send data to a nearby edge node (e.g., home gateway or smart hub) with computing capabilities. The edge node performs in situ data processing and decision-making for real-time tasks at the local side. This distributed method can alleviate the effect of network congestion, improve real-time response, and minimize the dependence of the smart home system on an internet blockage.

D. Evaluation Metrics

To assess the effectiveness of the two architectures, we evaluate them using a set of key performance metrics that are critical to the design and operation of smart home systems:

1) End-to-End Latency: The time taken by a data packet to traverse from a sensing device to a control unit (in the cloud or at the edge) and for the response to be

executed. It is essential for real-time-oriented applications [24].

2) Bandwidth Usage: Bandwidth is the amount of information that can be delivered over a connection. Optimizing bandwidth usage is essential for scalability and for the sustenance of network performance in the presence of growing number of devices [25].

3) CPU Utilization: This measures the computational load on processing units, whether in edge nodes or cloud servers. It reflects the system's ability to handle processing tasks effectively without overloading hardware resources [26].

4) Packet Delivery Ratio (PDR): This represents the computationally loaded point in processing units on which in edge node or cloud server. It indicates the systems capacity to process the tasks efficiently without overloading the hardware resources [27], [28].

By simulating and analyzing these metrics, this paper provides empirical evidence on the advantages and trade-offs of integrating edge computing into smart home systems. The results contribute to the ongoing efforts in designing efficient, scalable, secure, and responsive residential IoT infrastructures that align with the growing demands of real-time intelligent automation.

IV. RESULTS AND DISCUSSION

A. End-to-End Latency

As observed in Fig. 4 the latency of edge-based is reduced far less than the Latency of the cloud-based. The cloud model averaged a latency of 225 msec, compared to 125 msec with the edge model, where this 44% acceleration is primarily associated with enabling the processing locally on the network edge, thus eliminating the necessity for the continuous round-trip communication with the remote cloud servers. This substantial improvement enables instant responses to time-sensitive events such as intrusion detection, fire alarms, and health monitoring, ensuring better automation performance and user experience. The lower latency also reduces the risk of failure in emergency scenarios and enhances the overall reliability and efficiency of smart home systems.
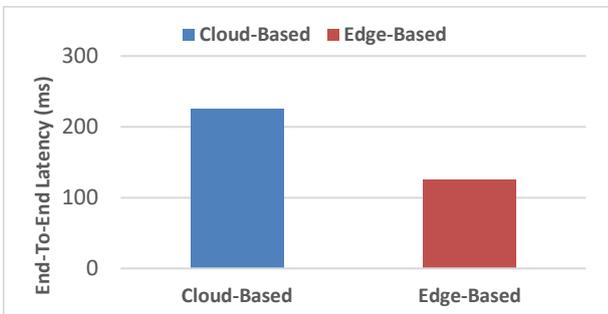

Fig.4 Average End-to-End Latency (ms) observed in cloud-based and edge-based smart home architectures

B. Bandwidth Usage

The total bandwidth usage in the two scenarios is shown in Fig. 5. The cloud-based model required more bandwidth to be used (about 90 MB) as opposed to the edge-based model (about 65 MB). This reduction of the bandwidth consumption around 28% is due to localized data aggregation and filtering at the edge devices which allows to avoid transmitting redundant and not essential data to the cloud. This increases network efficiency and lowers operating costs in bandwidth-constrained or per-byte/bandwidth-sensitive environments.
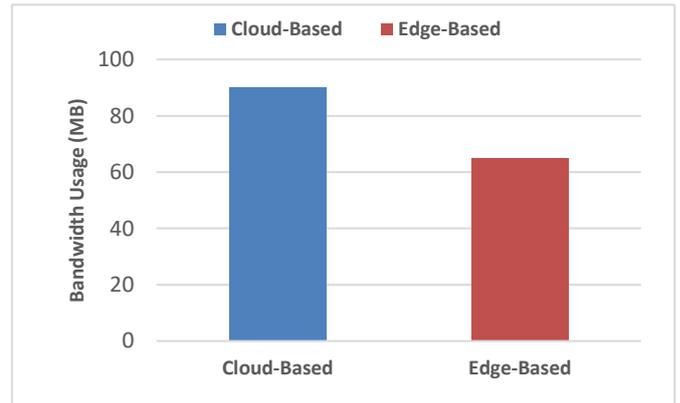

Fig. 5 Total Bandwidth Usage (MB) comparison between cloud and edge models

C. CPU Utilization

As illustrated in Fig. 6, the cloud-based system exhibited a higher average CPU load of approximately 42% than the edge-based model, which incurred a lower load of approximately 32%. This distinction indicates that edge computing indeed distributes computational tasks nondiscretely around the local resources and does not encounter bottlenecks as do centralized systems. Lower CPU usage also means better scalability and energy efficiency in the system by distributing processing between the edge and the cloud.
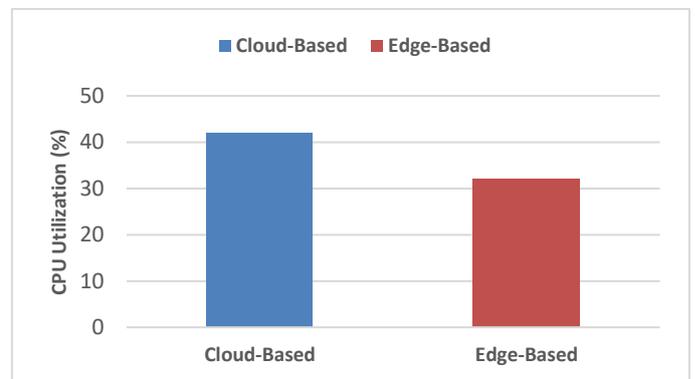

Fig. 6 Average CPU Utilization (%) for cloud vs. edge scenarios

D. Packet Delivery Ratio (PDR)

Packet Delivery Ratio in Fig. 7 results present enhanced communication reliability in edge-based model. The cloud-based one obtained PDR around 91%, and the edge-based one achieved PDR about 96%. This higher PDR observed is an evidence of better network performance, and of less congestion caused by shorter paths, which is a side effect of making decisions locally. A high end-to-end PDR is particularly important for smart home systems where the accurate and reliable delivery of control commands and sensor data is necessary for the correct operation of the system.
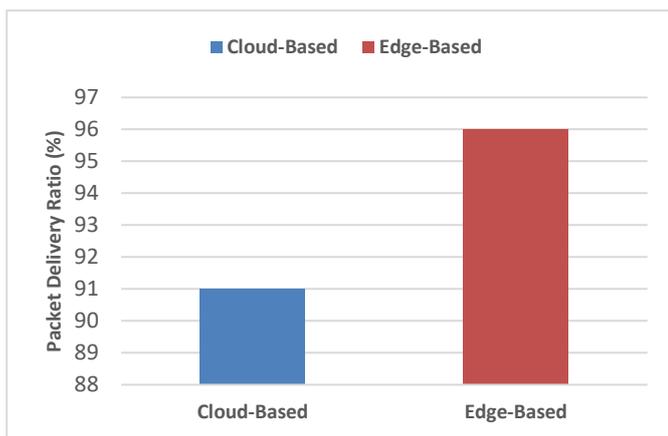

Fig. 7 Packet Delivery Ratio (%) comparison showing improved reliability with edge computing

V. Conclusion and Future Work

This study has shown that the combination of edge computing and IoT-based smart home systems can be benefited by performance advantages over the traditional cloud-based approaches. The study rigorously simulated in OMNET++ and found significant enhancements in the end-to-end latency, bandwidth efficiency, the CPU loading balancing and the packet delivery ratio. These improvements are particularly critical for applications requiring real-time responsiveness, data security, and uninterrupted connectivity. The study confirms that localizing computational tasks near the data source not only enhances system responsiveness but also reduces dependence on centralized cloud resources, ultimately leading to a more efficient and resilient smart home infrastructure. For future work, the author will focus on extending this research through the implementation of real-world prototypes that integrate edge devices with smart home platforms. Additionally, incorporating artificial intelligence and machine learning capabilities at the edge can further enable intelligent, context-aware decision-making. There is also a need to explore dynamic load balancing strategies for seamless edge-cloud coordination and to investigate the energy consumption implications of edge devices to ensure sustainable deployment. Finally, the scalability of edge-enabled smart homes across communities and urban environments will be studied to validate the approach in broader IoT ecosystems.

Conflict of Interest

The authors declare that there is no conflict of interest.

Author(s) Contribution Statement

The author contributed to the study conception and design, manuscript writing, and approval of the final version.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics Statement

This study did not require ethical approval

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