Deep Science Publishing, 2025
https://doi.org/10.70593/978-93-7185-625-6_9

Chapter 9: Edge Intelligence and Fog Computing for Decentralized Smart Environments

9.1. Introduction

Smart environments are ecosystems that use sensors and actuators to perform environmental actuations. Although these systems have been widely deployed in many domains, several difficulties remain, such as complexity, heterogeneity, rapid mobility, and connectedness of devices with a large amount of data. A new technology that integrates Edge Intelligence (EI) and Fog Computing (FC) is advocated for solving these problems. EI brings the intelligence capacity generated by deep learning models to the edge of the network. On the other hand, the FC paradigm provides computing resources, storage, and services closer not only to the edge devices but to the user or application sources.

The advances of EI and FC, and their combination for synthesizing new smart environments, have been successful. Integrating a deep learning model into a Fog Computing infrastructure can be understood as a contribution of the fusion for solving specific problems. These technologies have been advancing fast, and the challenges and new opportunities emerging demand a detailed, structured analysis of these challenges and solutions. EI–FC-DevOps presents a Developer Operations methodology for handling the intelligent model life cycle and the infrastructure supporting the smart environments. Different implementation options are presented for these methodologies. The integration of both methodologies and their implementation is developing and is illustrated by the domain of Smart Agriculture. The creation and evaluation of mechanisms for generic EF-service management systems that provide services for any smart domain are still under development.

9.1.1. Purpose and Scope of the Study

Introduction. A key challenge faced by the world is the development of smart environments able to address and improve specific aspects of well-being and health, while providing awareness of and protection against threatening scenarios of any type. Recent advances have occurred in the health domain, particularly during the recent pandemic, due to the rapid development of new procedures for the monitoring of patients and COVID-19 carriers, reducing face-to-face interaction. Lately, some challenging issues, such as the integration of mobile device ecologies with the support of micro-mobility services, have become an area of interest in both futurology and mobility domains. Smart environments can be efficiently realized through the integration of IoT and IA services. However, connecting a new generation of objects to the Internet that can exchange information with minimal human interaction presents several challenges, especially when focusing on effective intelligence in the network and fog computing models for managing all data and providing support to the decision-making process.

Smart environments represent a key concept in the realization of smart cities, smart healthcare, smart homes, smart cars, and smart shopping centers. All these ecosystems require ubiquitous coexistence of humans, agents, and things, which operate seamlessly together to achieve common goals and to offer rich services tailored to the environment, humans and agents. Nevertheless, smartly designing smart environments, especially when focusing on services, objects of interaction, and underlying technologies, can be considered a difficult task. The research community poses two important and interrelated questions: how can smart environments become smarter? And how can the smartness of smart environments be evaluated? In particular, it is important to build highly functional and usable smart environments. Centers for the integration of things that are used in daily life in one system can provide better support for users in real-life activities.

9.2. Background and Motivation

Artificial intelligence (AI) and IoT technologies are at the core of modern approaches for the design and development of smart environments and are perceived as key enablers facilitating a multitude of applications in several domains, including transport, healthcare, energy, agriculture, and industry [1-3]. The rapid growth of IoT has caused what is now described as a data deluge, leading to the emergence of a new type of data termed Big Data (BD). In parallel, the advances of AI, machine learning, and data analysis techniques can transform BD into Smart Data (SD) capable of supporting the decision-making process. Naturally, the enormous volume generated by the vast number of IoT devices is expected to be uploaded and processed in the Cloud, giving rise to Cloud IoT. However, the QoS of Cloud IoT is questioned in terms of response time and network load since millions of devices are requesting services from the Cloud at the same time. Nevertheless, Cloud IoT still holds a key position in supporting BD and SD analytics.

9.2.1. Significance and Rationale for the Research

The combined contributions of edge intelligence and fog computing toward decentralizing smart environments represent a valuable framework for next-generation services. Decentralization enables services to achieve enhanced real-time response, privacy, security, availability, reliability, energy efficiency, and cost reduction. It also tackles several challenges and limitations of centralized cloud services. The challenge lies in determining how intelligence should be distributed and where it should be located to best serve the diverse requirements of decentralized applications.

Edge intelligence, a recent concept derived from distributed and on-device artificial intelligence, offers promising developments for decentralizing smart environments. It distributes the capabilities of artificial intelligence alongside the data on which services are built. Emerging edge artificial intelligence chips provide services with greater advantages. Conversely, fog computing provides the necessary computing infrastructure to enable scalability, computing power, and an increased number of services. Together, the computing infrastructure and AI technologies define the requirements of decentralized services. Numerous applications—such as smart cities, smart homes, smart grids, smart health, Augmented Reality (AR)/Virtual Reality (VR), and Industry 4.0− leverage the synergies of edge intelligence and fog computing to establish a more efficient architecture in terms of latency, throughput, privacy, security, and availability.

Fig 9 . 1 : Edge Intelligence and Fog Computing for Decentralized Smart Environments

9.3. Overview of Edge Intelligence

Edge Intelligence (EI) represents a distributed architectural framework for training and inference at the edge of smart environments. Its feasibility is augmented by the relatively higher computational capabilities of modern edge devices compared to Cloud nodes. Current trends in Edge Intelligence support the training of deep learning models outside centralized Cloud infrastructures either entirely or incrementally. While conventional training mechanisms utilize the centralized and powerful infrastructures of Cloud Data Centers (DCs), centralized training is also feasible in Fog nodes equipped with high computing power.

Notably, model training can be performed solely in the Cloud or centrally by aggregating local models trained at the Fog or Edge levels. In this context, Federated Learning emerges as a distributed training architecture. Additionally, Edge Intelligence facilitates multiple training techniques based on Reinforcement Learning (RL), including Self-learning and Transfer Learning. From a decentralization perspective, Self-learning RL supports fully distributed training, whereas Transfer Learning is applied to partly distributed training environments.

9.3.1. Definition and Key Concepts

Remote areas suffer from information isolation, poor communication, and a lack of emergency relief. Deals with Complex 3C problems: Communication, Computation, Content. Contribution: Standalone edge server with two-level resolution. When the community network cannot connect to the Internet, the edge server provides on-demand content response via Wi-Fi networks, which can be used for the three 3Cs. Scenarios like wildfire in rural areas, and flood in the city. If the community network is connected, it can provide 3C services with one-level resolution. Existing techniques focus on a single element of 3C, so a new method is needed to jointly deal with 3C problems. The framework can build a communication channel in the absence of the Internet, provide computing on local information, and use available information content in a community to respond to users' requests, so the main difficulty lies in effectively realizing stand-alone edge servers.

9.3.2. Role in Smart Environments

Many smart environments rely on RT services to provide a suitable user experience during an interactive session for a task. Tasks with strict RT requirements rely heavily on low-latency communication between the user and the computing infrastructure, making cloud data centers unsuitable [3-5]. For example, the acceptable latency for a real-time interactive computer game is just a few milliseconds. HT computing makes the distinction between DT and HT tasks considering the RDC's dynamic information about the placement of HT tasks inside it. Flexible resources allow the RDC to first place DT tasks with strict low-latency requirements at the most suitable device for processing in the location, and later place HT tasks seeking the highest throughput in the platform.

The IoT is growing exponentially. For highly complex applications, such as smart cities or health monitoring, intensive computations and large-volume transformations of the data generated by the IoT need to be performed. Commercial IoT clouds currently operate in the field to store and process sensory data. These infrastructures consist of thousands of high-uptime data centers distributed globally and designed to provide high-bandwidth connections to the Internet. Processing IoT Big Data by using only the IoT clouds leads to the overload of both networks and clouds and decreased application QoS. The lack of always-on resources turns out to be a restricting factor in many computing scenarios. Given the fact that IT infrastructure is present in nearly every company and industry, a new distributed computing model is proposed that allows the system to take advantage of available resources at the edge of the network.

9.4. Fog Computing Fundamentals

Fog computing shifts the center of computation from a centralized cloud infrastructure toward the network edge, leveraging IoT gateways or dedicated nodes for early-stage processing of recorded data. This approach confers notable advantages in terms of latency, bandwidth conservation, and data security and privacy. Due to varying definitions provided by organizations, fog is best understood as an overarching concept, residing between the cloud and edge devices, on the edge-to-cloud continuum. It balances computation, communication, and storage resources among different layers of a distributed system.

Much like cloud systems, fog computing integrates communication, computation, control, and storage resources between Internet-of-Things (IoT) devices and traditional cloud data centers. Emerging standards produced by the OpenFog Consortium and the European Telecommunications Standards Institute (ETSI) also advocate a multi-tier hierarchy of smaller-scale data centers distributed across the edge–cloud continuum. Subsequently adopted by the National Institute of Standards and Technology (NIST), fog computing enhances vertical and horizontal integration and orchestration across computing, networking, storage, and control resources, facilitating the establishment of diverse vertical industry applications.

9.4.1. Architecture and Components

Proposes an architectural framework for EI based on five layers: resource management, AI models, fog computing, smart core, and social awareness. «Resource management» provides the computing capabilities required to execute the EI-based models. «AI models» are in charge of developing AI models from training datasets. «Fog computing» locates the intelligence at the edge of the network. «Smart core» is a zone that concentrates a set of services. «Social awareness» assesses how those services influence society.

Daniela et al. propose a four-layered Fog-based framework. The first layer is responsible for functionality, operation, and communication. The second manages the virtual machine instances, network infrastructures, and resource pools. The third allocates resources on demand and manages task scheduling. The fourth monitors the task status, execution times, resource allocation, and virtual machines. Machrouhi et al. propose that EI applications analyze data on machine failures, plant status, and logistics facilities to reduce toxic emissions and improve working conditions. The same authors consider Fog resources to be a subset of the Edge (Edge Intelligence and Fog Computing for Decentralized Smart Environments { id=urn:uuid:51d87abf-e4bc-4b0f-86d1-d446bfb2e992 parent-set=[urn:uuid:f9a9cc41-3fe5-4dec-8a8a-c068f1d9deae] }

Zootlexia Talks Inconsistency { id=urn:uuid:f9a9cc41-3fe5-4dec-8a8a-c068f1d9deae }); in both terms, the main principle is to bring the processes closer to the data sources without going into a detailed decomposition.

9.4.2. Differences from Cloud Computing

When compared to cloud computing, fog computing exhibits some differences. Data in fog computing remains proximate to the edge of the network and closer to the end users; these flows not only come from IoT devices but may also define the download activity of the edge devices. Proximity to the edge enables support for low latency and, consequently, real-time application ecosystems. The greater number of fog nodes and their allocation close to the edge of the network reduces the number of hops—i.e., intermediate nodes—that packets of information have to traverse, consequently reducing network bandwidth consumption and saving costs. The reduced information flow in the network and the greater number of nodes also increase the security and privacy of the system. The capability of providing centralized information and data may be a negative aspect in this context, since it creates a rich and valuable data heap that attracts cyber attacks. Protocols and rules related to fog computing and cloud computing systems are different and should be carefully designed, taking into account specific issues.

In the architecture, the cloud layer is positioned beneath the fog layer because the cloud acts as a data storage repository. When compared to the cloud, fog computing provides better support for low, uniform, and high distributed control functions of the system. Similar to cloud computing, fog computing also provides privacy, freshness, real-time analytics, and control and management comparable to the cloud. Although fog computing offers real-time analytics, the data retrieval and storage are poor when compared to the cloud. No cloud service provider completely removes the need for specialized networking and software skills for the users, although it does help to reduce IT infrastructure management. Even cloud providers have only tried processing at the edge but not fully shifting their data centers to the edge.

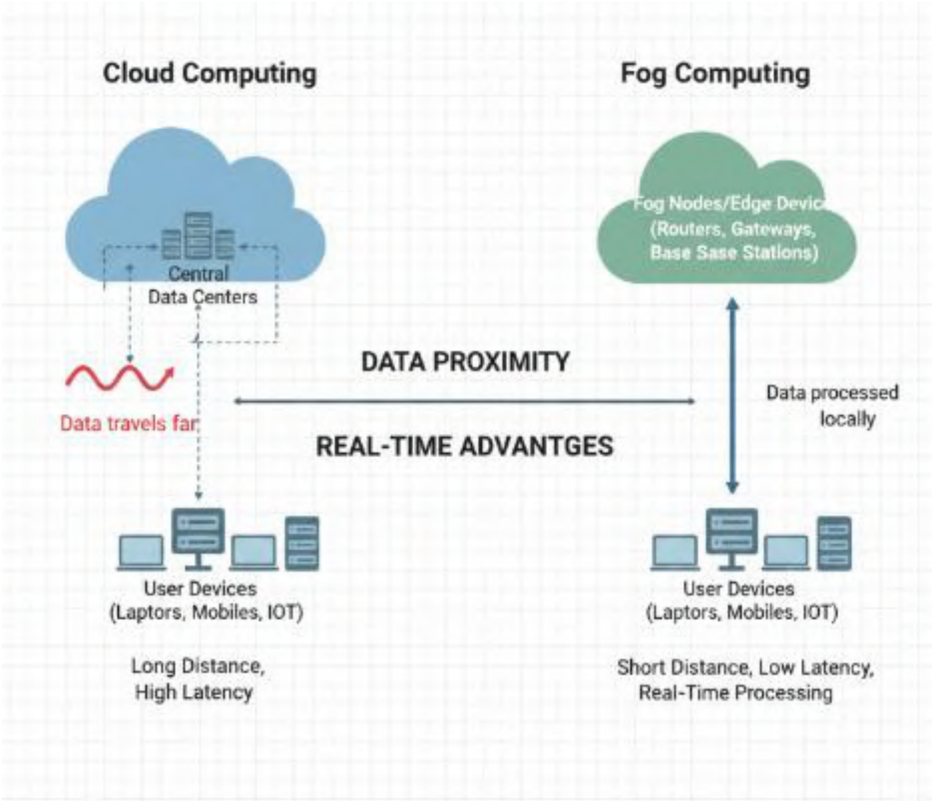

Fig 9 . 2 : Fog Computing vs. Cloud Computing: Data Proximity and Real-Time Advantages

9.5. Decentralized Smart Environments

Nowadays, the so-called smart environments (SEs) generate a vast amount of data, mainly because of the growing number of distributed sensors. However, the traditional approach to handling such data is by storing it in a dedicated cloud platform for subsequent processing. This poses two problems:

1. When an application demands real-time response (e.g., a vision system that processes data from cameras detecting an accident to take the corresponding preventive measures);

2. In cases where sensors are geographically distributed and the amounts of generated data are very large (e.g., cameras deployed all over the country for surveillance).

The main problem with the first scenario lies in the fact that managed applications are not typically offered by a cloud platform in proximity to the end user, which takes action on detected events before sending notifications. The problem in the second scenario stems from the requirement of sending all the data to a cloud, resulting in high bandwidth consumption for transmitted data, which is often not useful. To solve these issues, some proposals add computing capabilities both in the proximity to the sensor, thus creating the so-called fog computing layer, and in the sensor, resulting in edge intelligence (EI) [6-8].

9.5.1. Characteristics and Benefits

Edge intelligence introduces significant improvements in 5G/Web 3.0 architectures regarding privacy, security, latency, and energy consumption. In smart environments, Fog Computing represents a natural bridge toward the Web 3.0 and 6G paradigm. Interest in the Fog Computing paradigm relates to the deployment scenario, which is characterized by highly dynamic environments and fragmented, widely distributed node positions. Nodes are often resource-limited; in some cases, they are even mobile, making the Fog deployment extendible and migration possible in several situations. Such features have led to the definition of the Fog environment as a “nano–data center” that is pervasive, localized, and distributed. Moreover, supporting mobility at all levels may benefit new cyber layers, such as the Metaverse.

This section shows the layer structure proposed for Fog–Edge Intelligence and the benefits related to the considered layered organization of infrastructure and applications. It analyzed the roles that take place at the Edge and in the Fog. Such consideration also regards other useful classification criteria, including the time of application–level deployment, geographical distribution, and type of services, which categorize the deployed applications within the Fog Computing environment. Finally, an overview of the Edge–Fog role in Greener AI is presented.

9.5.2. Challenges and Limitations

The IoT paradigm introduces an overwhelming amount of data for Information and Communication Technology (ICT) infrastructures to collect, filter, analyze, and store, creating a demand for more computing resources. This overtaxing highlights the need for the short-term processing of some data close to the edge of the network, near the place where information is generated—an approach provided by edge intelligence—thus avoiding the longer delay of performing analysis in the cloud or fog. Nevertheless, whenever the limitations of edge devices present a problem, the requested tasks are then offloaded to the fog layer. Similarly, the fog offers higher-level capabilities closer to the edge than the cloud to provide services such as routing and filtering for optimization reasons, together with decision-making algorithms. Although some of these tasks require a lower capacity at the edge or a centralized view of the environment, and therefore should remain in the fog, in general, this division aims to maximize service triggers and responses near the source and the edge.

Three application scenarios for edge intelligence are defined according to the natural placement of devices in the network. The first group corresponds to the edge cloud scenario of IoT-landmark landmarks, where the network-generated data is processed in computers with an architecture like cloud computers and capable of supporting the execution of a hypervisor and virtual machines, deep-learning-based model training, or machine learning. The second group consists of the client-edge scenario of Deep Decision, where an application deployed on a machine uses an artificial intelligence inference model for decision-making. Finally, the third group includes the far-edge scenario of DeepDelegate, where a device generally labeled as restricted offers its support in the performance of an application on another device.

9.6. Integration of Edge Intelligence and Fog Computing

Edge intelligence and AI are boosted with the introduction of fog computing, a computing paradigm that supplies virtualized computing, storage, and networking services oriented at the edge of the network [1,3,5]. Fog computing extends cloud services and capabilities to the edge of the network, nearer to devices. As a result, time-critical applications benefit from computational and storage resources that exist near their data sources and users. This new surrogate layer of computing resources mitigates the inherent limitations of the edge, such as unbalanced resource provisioning, to enable the deployment of a new wealth of applications requiring low latency for the data created at the edge. Additionally, cloud–edge synergies introduced by fog computing present promising possibilities for applications involving the Internet of Things (IoT). These applications often depend on IoT data streams, generated continuously by devices without any break, and require a scalable processing infrastructure during redirection from the edge to the cloud.

Using fog computing, an IoT application will have the ability to deploy services on fog nodes, where they will be located closer to the IoT devices themselves. Fog nodes become an exceptional way of hosting services that require minimal latency in order to offer added value. Fog computing platforms provide an optimal answer for qualified demand from industries that require a scalable environment to host services near a large number of IoT sensors. Such platforms should be designed to present generic characteristics, such as rapid fault tolerance, scalability, cost reduction, improved performance, minimized latency, and increased data security and privacy. Furthermore, to meet future application requirements, fog computing platforms have to address an increasing number of services, mobile devices with different implementations, and user mobility.

9.6.1. Synergistic Benefits

Smart environments are supported by connecting different IoT components and sensing nodes hierarchically. The proposed systems for smart environments leverage fog computing at the manager nodes, thus achieving the full deployment of edge intelligence required in smart environments. IoT gateways can utilize fog computing services to fulfill the characteristics of very low latency (local data processing) and location awareness (services provided in different geographical areas). Additionally, multilayer hierarchies can be established by incorporating different queues at the fog nodes, and the quality of service (QoS) can be improved with optimal queue management and scheduling.

Sensitive IoT applications depend on location awareness to fulfill a specific visit purpose. If the support of location awareness is not feasible in a specific environment, such applications become complicated. In addition, context awareness is a prime factor that provides information related to time, place, and communication with other intelligent objects. If IoT nodes can be integrated following the context awareness philosophies, the environment will efficiently deliver the required services. Furthermore, the needed foresight for network devices, specifically in smart networks, can be captured through location and context awareness.

9.6.2. Use Cases and Applications

Edge Intelligence and Fog Computing for Decentralized Smart Environments. Following the general discussion of induction forests, the applicability to edge intelligence and fog computing is addressed through the presentation and discussion of related use cases and applications.

Cloud computing centres have reported exponential growth in the volume of data that they receive, with most of this data being generated at IoT-connected devices at the edge of the network. Consequently, cloud computing centres that host the necessary infrastructure for processing and storage are reaching their limits. This affects the ability of future systems to make use of emerging technologies such as Edge Intelligence that require enormous storage and computational power for processing and analysing data. The resulting reliance on several centralized cloud computing centres may lead to a host of issues. These include spikes in power consumption due to over-utilization of data centres, which increases greenhouse emissions and has an adverse social impact on society; network latency and condensed network bandwidth utilization, which restricts real-time decision-making for time-sensitive applications and deployments; and data security and privacy concerns, which restrict data sharing.

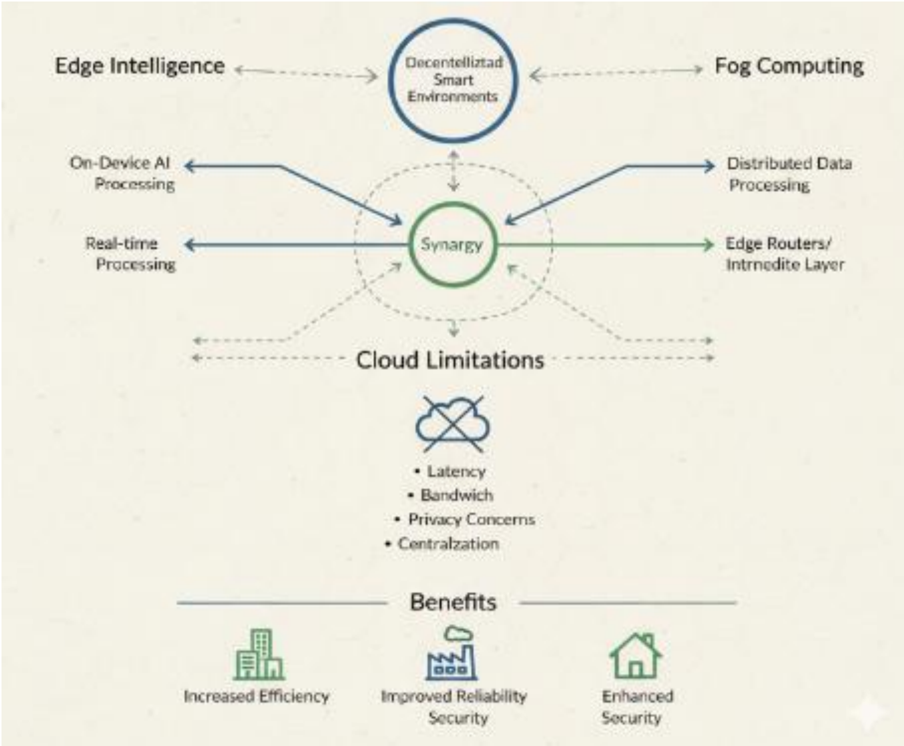

Fig 9 . 3 : Edge Intelligence and Fog Computing for Decentralized Smart Environments: Addressing Cloud Limitations

9.7. Future Trends and Directions

Edge intelligence stands as a key building block of the future Internet of Things, forging a path for distributed decentralized artificial intelligence where data-driven models must be deployed close to their learning environment. It is at the core of a novel generation of self-adaptive systems that enable advanced capabilities at the edge of the network. Additionally, Fog computing synergizes by extending the Cloud to the network edge, supplying compute and storage resources among end devices, users, and data sources. Together, edge intelligence and Fog computing allow for products and services that acquire and process data while in movement or operating unattended, granting virtually unlimited scalability and enhancing user experience.

Interest in a wide range of applications benefiting from decentralization mobilizes the whole system and the software engineering research community. Even core management tasks such as deployment, self-adaptation, and monitoring require novel approaches due to the decentralization and scalability enabled by Fog-oriented technologies. Highly interactive applications incorporating analytics and machine learning increasingly confront privacy, trust, or data sovereignty issues. These challenges demand movement away from central Cloud data centers and towards the Edge. This section explores future trends and directions for decentralized engineering of distributed intelligent systems.

9.7.1. Emerging Technologies

Emerging Technologies

Edge Computing. Edge computing represents the evolution of cloud computing, where data processing capabilities are extended beyond data centers. In this paradigm, the intelligence of the cloud is implemented closer to the data source or destination of the data flow. By locating computing resources at a closer proximity to the terminal nodes, edge computing facilitates quick decisions and supports services that rely on real-time response at the edge of the network. These services can be implemented near end devices, thereby conserving valuable network resources. The expected outcome includes reduced latency and quicker decision-making capabilities, thereby enhancing Quality of Service (QoS). Moreover, it has the potential to enhance privacy, given that personal data remains confined within local domains and is less exposed to threats. The intelligence and decision-making processes occurring at the edge of the network support not only the data center but also edge services. Additionally, edge computing can be employed to address resource scarcity of devices, ensuring high availability of services by distributing computing resources during traffic congestion periods.

Fog Computing. Recent technological advances in the Internet of Things (IoT) have set the stage for a massive deployment of interconnected smart objects. These smart objects generate exhaustive records of events and transactions, which are relayed to the cloud for further processing and analysis. Although the cloud offers an ideal infrastructure for centralizing services and enabling business continuity regardless of location, it is important to highlight that the cloud model was not designed for the specific scenario presented by the IoT model—particularly due to the heavy traffic volumes generated by an enormous number of users demanding stricter Quality of Service (QoS) requirements [7,9-10]. Moreover, the IoT also demands cooperation between services within the same client domain or between domains.

9.7.2. Research Opportunities

An overview of the existing elements related to the decentralization of the Internet of Things enables identification of specific research challenges, opening relevant directions for addressing them. The integration of edge intelligence (EI) and fog computing (FC) may help to advance towards decentralized smart environments with greater robustness, privacy, diversity, and reduced latency. The following aspects require further research in pursuit of truly decentralized multilayer environments that combine edge intelligence and fog computing.

With the introduction and analysis of multilayer environments, it becomes apparent that each layer has its requirements. It is therefore necessary to define or identify specific needs and restrictions, depending on the nature of the processed data and the hardware requirements, for designing a multilayer environment that combines fog computing and edge intelligence. Consequently, not only hardware needs must be taken into account; the type of data and the real-time constraints inherent to it must also be considered. In this sense, the devices of the lower layer, which process only local data, will have much stricter real-time requirements than those of the upper layers. Other parameters, whether related to networking, power consumption, or others, may also influence the design of a combined fog-computing/edge-intelligence environment.

9.8. Conclusion

IoT technology is becoming increasingly popular in modern homes, offices, and industrial scenarios to facilitate our daily activities by making them more automated and smart. Technology providers try to automate several tasks to improve the quality of life of users, resulting in substantial day-to-day time savings. To address these challenges, IoT devices borrow processing and storage power from the cloud by sending data to be mined and analyzed remotely. However, as the number of IoT devices grows exponentially, cloud solutions show limitations in terms of bandwidth, latency, security, and privacy. Fog computing pushes the processing and storage of sensitive and real-time data closer to IoT devices, acting as an intermediate layer between the cloud and IoT devices. Similarly, edge intelligence assigns decision-making capabilities to IoT devices, since the presence of embedded sensors also makes them capable of controlling and triggering actions under certain circumstances. These distributed features of fog computing and edge intelligence make IoT-driven applications more scalable and reliable.

Smart environments are usually created by integrating IoT devices that enhance people's quality of life through automation and intelligence. However, when considering aspects such as scalability, latency, and privacy, these smart environments present limitations that are addressed by the features of fog computing and edge intelligence to support smart and interactive applications. The integration of smart environments with fog computing and edge intelligence plays a crucial role in enabling decentralized applications that require real-time and intelligence-aware services. Similarly, edge-enabled smart walking environments help visually impaired users by enhancing their situation-awareness. The same has also been achieved by combining edge intelligence and decentralized smart environments with smart homes that learn human behavior and provide intelligent support to inhabitants. These advantages of combining edge intelligence, fog computing, and decentralized smart environments form the solid foundation for people and environment-aware smart applications.

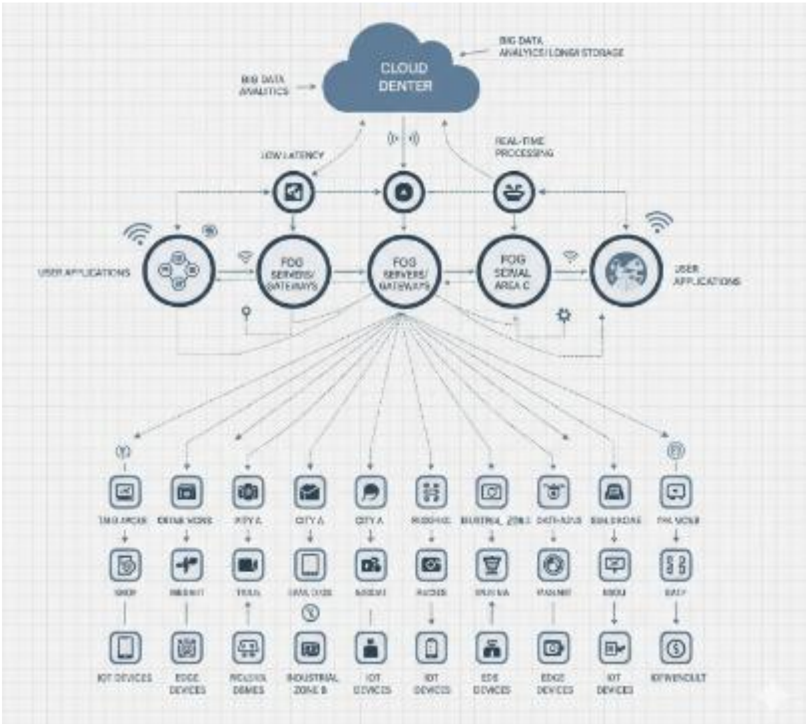

Fig 9 . 4 : Fog Computing Integration

9.8.1. Summary of Key Findings and Implications

Smart devices together with their supporting infrastructures generate unprecedented volumes of data. The Fog and Smart Edge Computing paradigms have emerged as new concepts for distributing computational work closer to the data producers and users. Data are filtered, aggregated, preprocessed and analyzed in Fog and Edge Smart nodes, located between the Cloud and things and within or nearby end-users, thus distributing processing. This enables advanced intelligent actions that are automated, context-aware, in real-time, or with other requirements that the formal centralized Cloud model cannot provide. Looking at the Fog and Edge Clouds, the question arises of the optimal placement of intelligence (computation, network resources, storage, decision, etc.). Considering that IoT nodes are frequently resource-constraint, knots with higher resource capabilities—gateways, smartphones, routers, network nodes, micro-data centers—will host the necessary decision-making entities. For highly demanding or specialized intelligence, the Cloud usually enters into action; however, for advanced operations closer to things and end-users, required by the support of context awareness and Quality of Services and Experience guarantees, "Edge Intelligence," which emerges from the joining of Artificial Intelligence and Edge Computing, is an emerging concept in modern Cyber-Physical Systems.

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References

[1] Tuli S, Mirhakimi F, Pallewatta S, et al. (2023). AI-Augmented Edge and Fog Computing: Trends and Challenges. Journal of Network and Computer Applications, 216, 103648. https://doi.org/10.1016/j.jnca.2023.103648

[2] Integrated Genomic and Neurobiological Pathway Mapping for Early Detection of Alzheimer’s Disease. (2023). IJARCCE, 12(12).

[3] Zhou Z, Chen X, Li E, Zeng L, Luo K, Zhang J. (2019). Edge Intelligence: Paving the Last Mile of Artificial Intelligence with Edge Computing. arXiv preprint. https://doi.org/10.48550/arXiv.1905.10083

[4] Kurdish Studies. (n.d.). Green Publication. https://doi.org/10.53555/ks.v10i2.3854

[5] Kuchuk H, Malokhvii E. (2024). Integration of IoT with Cloud, Fog, and Edge Computing: A Review. Advanced Information Systems, 8(2), 65–78.

[6] Implementing Scalable Identity and Access Management Frameworks in Digital Insurance Platforms. (2020). IJARCCE, 9(12). https://doi.org/10.17148/ijarcce.2020.91224

[7] Iftikhar S, Gill SS, Song C, et al. (2022). AI-based Fog and Edge Computing: A Systematic Review, Taxonomy and Future Directions. arXiv preprint.

[8] Designing Secure Data Pipelines for Regulatory Compliance in Cross-Border Tax Consulting. (2020). IJIREEICE, 8(12). https://doi.org/10.17148/ijireeice.2020.81208
[9] Vaquero LM, et al. (2019). Edge Computing: A Survey. Future Generation Computer Systems, 97, 219–235. https://doi.org/10.1016/j.future.2019.02.050
[10] Munnangi, A. S. M., Koppolu, H. krishna R., Nayeem, S. M., Prathipati, S., & Munnangi, S. R. (2025). Integrating experimental data, molecular dynamics, and machine learning for physicochemical insights into γ-butyrolactone and isopropyl acetate binary system. Journal of Molecular Liquids, 434, 127983. https://doi.org/10.1016/j.molliq.2025.127983