Toward Open Edge Networks: A Survey of Community-Driven and Distributed Computing Architectures

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***Abstract*—The creation of future intelligent applications relies on distributed, community-driven, and decentralized resource sharing, made possible by open edge networks, a new paradigm in computing. With edge computing, resources like processing, storage, and networking are brought closer to end devices. This improves scalability, real-time responsiveness, and decreases latency and bandwidth usage, all while decreasing reliance on centralized cloud infrastructures. With an emphasis on their function in constructing collaborative, open, and resilient edge ecosystems, this survey offers a thorough evaluation of community-driven and distributed computing designs. Architectural models and enabling technologies such as artificial intelligence, the Internet of Things, software-defined networking, network function virtualization, and multi-access edge computing are covered in the article, which serves as an introduction to the basics of edge computing. Open edge networks are further investigated in the study by looking at their uses in smart cities, healthcare, transportation, robotics, smart homes, robots in agriculture, smart roads, and disaster management. In addition, it reviews key security, privacy, and trust mechanisms required for secure distributed environments and highlights challenges related to interoperability, heterogeneous resource management, scalability, and cyber resilience. The study concludes by outlining future objectives and identifying existing research needs in the pursuit of intelligent, autonomous, secure, and sustainable open edge network architectures. These designs should be able to serve varied real-time applications across heterogeneous computing environments.**

Keywords— Open Edge Networks, Distributed Computing Architectures, Artificial Intelligence (AI), Internet of Things (IoT).

I. Introduction

Edge computing (EC) offers hope as a potential solution to these issues. One distributed computing strategy that facilitates the relocation of data processing and storage closer to its original sources is known as "edge computing." [1]. Some have proposed using edge computing technologies to reduce bandwidth consumption and satisfy the requirements for low latency. Companies with an emphasis on real-time responses through their internet of things (IoT) networks likely reap the most benefits from this innovation in the years to come [2]. In addition, V2I and I2V applications have unique latency and reliability issues due to the constant data extraction and pushing from/to the deployed IoT devices [3]. The massive surge in data congestion brought on by the geographically dispersed network of IoT sensors is only one of many pressing problems that several practical applications have found solutions for by leveraging edge computing [4].

"Edge computing" is a decentralized paradigm that moves data storage and processing closer to the end users, away from centralized data centers [5][6]. By allowing for localized processing, this architectural upgrade greatly decreases end-to-end latency, alleviates congestion in backbone networks, and improves data availability and privacy. The significance of edge infrastructures in supporting mission-critical services with ultra-low latency and high bandwidth has been further underscored by the proliferation of Mobile Edge Computing (MEC) platforms, which are expected to be implemented by Sixth-Generation (6G) and Fifth-Generation (5G) technologies, respectively [7][8]. The increased operational complications brought forth by this architectural decentralization are really worth noting [9]. Edge environments are dynamic and contain nodes with varying computational capacity, energy profiles, connection, and geographical dispersion; they are subject to frequent change as a result of unexpected workloads, user movement, and environmental conditions.

The widespread use of online services, together with the democratization of access to high-speed networks and powerful computers, is revolutionizing the way compute. The scientific computing community has relied on distributed

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computing for many years now [10]. The steps in it all work together to accomplish a single objective. The impact of information and communication technologies (ICTs) on daily life has been evident to everybody. An ongoing trend in the manipulation of culture and information through the Internet has social networks as a stepping stone [11]. The majority of social media websites run on the principle of massively distributed computer systems [12]. The IoT and edge computing serve distinct purposes within the system, but they share the objective of enabling seamless computing at any time and at any location. If looking for near-field computation, go no farther than edge computing; the IoT is all about endpoint sensing. Consequently, integrating these two technologies into EC Driven-IoT systems has great promise. Smart cities, smart grids, smart homes, virtual reality, augmented reality, and autonomous driving are just a few of the complex contexts where the IoT has recently found significant usage.

A. *Structure of the paper*

The structure of the paper: **Section II** presents the fundamentals of open edge networks. **Section III** discusses community-driven and distributed computing architectures. Integration of aided IoT and edge computing is reviewed in **Section IV**. The literature review is emphasized in **Section V**. **Section VI** offers a summary and recommendations for further study.

II. FUNDAMENTALS OF OPEN EDGE NETWORKS

The goal of opening edge networks, which are decentralized computer systems, is to move computing, storage, and networking resources closer to users and data sources. Delays, bandwidth consumption, and dependence on centralized cloud infrastructures are all reduced as a result [13]. They pave the way for heterogeneous device processing of data in real-time, distributed intelligence, and community-driven resource sharing [14]. To better support next-gen distributed applications, open edge networks integrate technologies like the IoT, AI, SDN, NFV, and MEC. This leads to improved scalability, reliability, interoperability, and efficient service delivery.

A. *Edge computing*

The objective of compute at the network's periphery, as opposed to the cloud, is known as edge computing. Developers of both content and apps may be able to move their services closer to where their users are using edge computing platforms [15]. The characteristics of edge computing include a large amount of available bandwidth, extremely low latency, and the ability for several applications to access network information in real-time [16].

1) *Concepts*

The idea behind edge computing is to move data processing away from centralized cloud servers and closer to the point of origin. "Edge computing" is a new distributed computing paradigm that stores and processes data locally, rather than in a centralized cloud, using devices like sensors and IoT nodes [17][18]. believe that the basic motivation behind edge computing is handling data "near the source of its generation," thus reducing the need to transfer it to distant cloud data centers. This proximity to origin data enhances processing efficiency, reduces latency, and diminishes bandwidth use, making it well-suited for real-time applications where fast decisions are critical.

2) *Architecture*

The edge computing architecture has layers that have control over data at different points in the network. Figure 1 displays the network architecture at the network's perimeter [19].

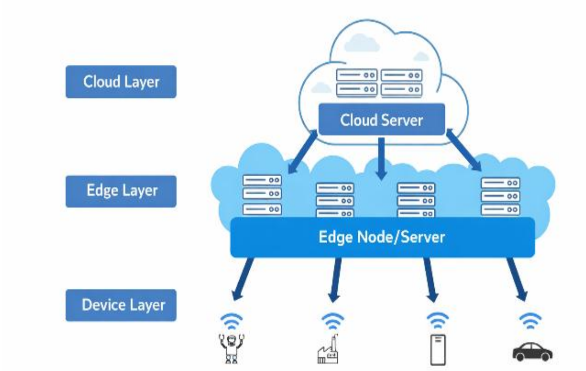

Fig. 1. Edge Computing Architecture

- Cloud Layer: A cloud layer in an edge computing architecture is only practical for tasks that need substantial processing power or for data storage in the cloud with an expected lifetime of several years; otherwise, its utility is much diminished [20].
- Edge Layer: The edge layer includes nodes such as routers, gateways, and small data centers that act as intermediaries between the source of the data and the user . These edge nodes do more complex processing and provide greater computational power than is available at the edge device[21].
- Device Layer: They are basically data sources including sensors, actuators, and IoT. They have constrained computing power so they can only perform the most basic processing operations that include only filtering anomalies or normal data .

B. *Applications of Edge Computing*

There are many uses for edge computing because it has many benefits. Businesses need to know these uses in order to stay competitive in the digital world. The following are some of the areas:

1) *Industrial Automation and IoT*

Edge computing significantly changes predictive maintenance and real-time control of robotics in industrial tasks. mentioned that it is applied to alleviate network congestion in industrial video surveillance systems. Emphasizes how important it is to properly design AI processes for PdM in industrial uses at the edge [22].

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suggested a hybrid cloud-edge computing architecture and developed a suite of smart air-quality monitoring tools. developed an approach to managing energy resources for industrial IoT that is based on software-defined networks [23]. Industrial wireless networks (IWNs) benefit more from SDN-based IIoT architectures with EC than from more conventional approaches when it comes to adaptive computation, efficient resource management, and latency.

2) Smart Cities

The domain of smart cities has gained advantages from edge computing in traffic regulation, environmental surveillance, and energy optimization illustrated real-time optimization of urban traffic and infrastructure. Explored its function in relation to smart city planning and traffic control. Brought attention to the ways in which smart city transit may utilize edge computing [24][25]. developed an IoT-based smart traffic management system using Edge Cloud technology to optimize traffic flow and enhance safety at urban intersections. proposed utilizing edge computing to alleviate stop-and-go traffic patterns and their negative effects on urban transportation systems.

3) Healthcare

Edge computing is revolutionizing patient care in the healthcare sector by facilitating remote monitoring and real-time data analytics. Highlighted some of its uses, such as in real-time analytics, industrial automation, and healthcare. Discussed real-time data processing for wearable medical devices. addressed improvements related to latency for telemedicine applications through fog and edge computing[26][27]. Explored the advantages of healthcare analytics in real-time and remote patient monitoring. They also highlighted the influence of latency reduction on remote patient monitoring with edge computing. They also took note of diagnostics and real-time monitoring by highlighting the approach of edge computing[28].

4) Agriculture

Edge computing enables precision agriculture's automation and real-time data processing. Addressing flaws in centralized databases that might cause information breaches and product quality difficulties, smart agricultural systems are integrating edge computing with blockchain technology to improve data security and integrity [29]. There has to be more affordable infrastructure and improved internet access to encourage agricultural development, but integrating smart sensors with edge computing can help underdeveloped countries enhance precision agriculture.

5) Smart Homes

Edge computing functions, including device automation, help benefit the smart home environment in aspects of privacy protection[30]. Discuss smart home energy management systems in IoT networks for green city demands and services. Edge computing for smart parking automation and device coordination.

6) Virtual Reality

Edge computing mitigates the high computational requirements in these technologies. discussed how edge computing facilitates immersive experiences. They identified edge intelligence in virtual reality (VR) and augmented reality applications. further discussed edge computing for immersive VR applications[31]. A research roadmap for future efforts and basic ideas were outlined, and edge intelligence was separated into two branches: AI for the edge and AI powered by the edge. While AI on edge is concerned with training and inferring models at the edge, AI for edge leverages AI technologies to improve edge computing solutions.

7) Telecommunications

The telecom industry is able to improve the efficiency and scalability of 5G networks with the aid of edge computing. placed an emphasis on scalability through edge computing to enhance data and connection management. discussed how mobile edge computing accelerates services through reduced network congestion and decreased latency[32]. Moreover, they addressed every angle of mobile edge computing studies, including combined radio and computational resource management, privacy, green practices, mobility, application scenarios, deployment, caching, and recent standardization efforts.

8) Smart Grids

In smart grids, edge computing manages energy resources and ensures scalability. outlined how it enables efficient scaling. They discussed enhancing smart grids for energy management.[33] emphasized improving smart grid infrastructure through edge computing.

9) Robotics

Edge computing with low-latency control and real-time decision-making is made possible by AI [34][35]. Looked at the potential advantages of edge computing and LDM platforms for autonomous driving robot systems, particularly with regards to real-time decision-making and low-latency processing.

10) Disaster Management

In disaster management, edge computing is essential because it allows for quick decision-making and real-time analytics. This is particularly vital during.large-scale disasters when traditional communication networks may be compromised or congested. For instance, mobile edge computing can facilitate smart traffic offloading, improving system throughput and reducing delays for relief workers in disaster areas[36].

III. COMMUNITY-DRIVEN AND DISTRIBUTED COMPUTING ARCHITECTURES

Computing, storage, and networking resources may be shared collaboratively among decentralized edge devices using community-driven and distributed computing architectures. They reduce latency, improve scalability, and

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enhance system reliability through intelligent resource coordination[37]. By integrating AI, IoT, SDN, NFV, and MEC, these architectures support secure, efficient, and real-time services for smart cities, healthcare, industrial IoT, and transportation applications.

1) MEC-IoT Integration

This section examines the problems with the IoT and demonstrates how MEC-based IoT might solve them. Focusing on the IoT, the main advantages of MEC are emphasized. Also included are the anticipated difficulties of MEC-IoT integration [38]. Without a question, the IoT is maturing as a technology thanks to the fast improvements in it. The proliferation of IoT devices and applications, as well as the demand for adaptable connection alternatives, have all contributed to the emergence of new challenges in areas such as scalability, mobility, latency, power consumption, availability, security, and privacy [39]. As a whole, the IoT relies on cloud computing, which can have issues including reachability, high WAN latency, lack of location awareness, and single-point-of-failure. Here, MEC is prepared to provide a helping hand by offering several mutually beneficial aspects.

2) Software-Defined Networking (SDN)

The goal of SDN, a new paradigm in networking, is to partition a physical networking resource's data plane and control plane activities. Data plane commodity switches are advocated for, rather than vendor-specific black-box hardware, according to the document [40]. The benefits of centralizing network control functionalities are several [41]. Still, critical IoT apps necessitate the SDN controller's physical proximity to the data plane to fulfill the low-latency criterion. The use of MEC can thus provide a practical means of meeting the latency criterion. By turning mobile networks into software networks and guaranteeing very effective network management and service delivery, MEC supplements the achievements made by SDN.

3) Network Function Virtualization(NFV)

The ability to physically separate network hardware from the applications that operate on it is achieved through the use of virtualization technologies in NFV technology [42]. Thus, NFV enables the installation of several VNFs as software on one or more conventional servers inside the company. This eliminates the need to buy and install new hardware every time a VNF has to be moved or instantiated at a different physical network location. One of the main reasons why 5G-IoT networks may use MEC is because of NFV.

IV. I NTEGRATION OF EDGE COMPUTING AND ASSISTED IOT

This section lays forth the groundwork for understanding the integrated IoT and EC paradigm, including its core principles, practical applications, and architectural framework. There also be citations for related studies. There has been fast development in both the IoT and EC on their own [43]. The features of the two models are, however, very similar. The most important IoT applications rely on improved QoS, hence specialists in the field are trying to get EC and IoT paradigms to work together.

1) Advantages of EC-Assisted IoT

There are three primary benefits of using EC to support the IoT, the most notable of which are:

- **Communication:** IoT networks that use EC have shown improvements in several aspects, including as compute and communication latency, bandwidth utilization, device power consumption, and packet data overhead. This allows them to enhance the network's communication throughput significantly while still meeting the QoS requirements of time-sensitive IoT applications and services.
- **Computation:** A huge burden was lifted off centralized cloud servers when data processing and computation in EC-assisted IoT networks were shifted to edge servers. Because of this, the network's ability to handle priorities and allocate resources efficiently enhanced.
- **Storage:** End-user devices connected to the IoT often have limited storage capacity, so EC servers step in to fill that need. The devices do this by transferring all of their data to storage servers [44]. The quality of service has improved as a result of the easier management of load balancing and failure recovery.

2) Challenges of EC-assisted IoT

There are still many significant obstacles to overcome, despite the fact that EC-assisted IoT design has numerous benefits.:

- **Security and Privacy:** Emerging concerns around user privacy and security challenge for EC. The network becomes more susceptible to possible hostile operations due to the movement of services required for IoT capability, which occurs on both local and global dimensions. The fact that the EC servers receive and store users' personally identifiable information further highlights the importance of security and privacy concerns in this kind of decentralized system.
- **Network Heterogeneity:** There is a great deal of variety in the topologies, physical platforms, and servers that make up EC-assisted IoT networks. The ability of IoT devices to function flawlessly in such a complex and technologically advanced environment is, however, another major obstacle. It would be very difficult, for instance, to manage resources in applications that are executing on disparate, dispersed, and physically separate platforms.
- **Resource Management:** Decentralized EC-assisted IoT networks rely on three main resources—communication, computation, and storage—so figuring out how to control, manage, and optimize these three areas is a top priority [45]. This problem

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manifests itself due to the exorbitant diversity of service providers, IoT edge devices, applications, etc.

- **Smart System Support:** IIoT devices provide new possibilities for data collecting, sharing, optimization of resources, and system administration. Optimal and rapid management decision-making depends on a system that can store, assess, and transfer data flow from various multi-platform devices across geographical regions utilizing several EC servers/nodes [46].

V. Literature Review

Recent studies on open edge networks emphasize community-driven and distributed computing architectures for enabling scalable, low-latency, and resilient services. However, challenges such as interoperability, security, privacy, dynamic resource allocation, energy efficiency, and large-scale deployment remain significant research concerns.

S. D. A. Shah et al.(2026) explore an identified O-RAN architecture that integrates embodied AI agents directly within disaggregated network components. The examined architecture takes an embodied AI stance, rather than seeing intelligence as an independent optimization module; this allows agents to integrate visual sense with RF telemetry, leading to enhanced physical world situational awareness [47].

A. Cárdenas et al. (2026) propose a novel NFV/SDN-based 3-Dimensional (3D) Infrastructure Management framework for integrated terrestrial and non-terrestrial networks, extending the ETSI NFV Management and Orchestration and 3GPP management architectures with a hierarchical Infrastructure Mobility Management model. The model introduces three dedicated functions: a Global Mobility Management Function for geospatial-aware cross-domain coordination, a Domain Mobility Management Function for segment-level topology and policy management, and a Local Mobility Management Function for trajectory-aware resource lifecycle control[48].

Y. Ye et al. (2026) An architecture for multi-tiered UAV edge computing that uses a robust backup server and a fleet of tiny, lightweight L-UAVs to provide users in the vehicles with access to cloud services. The objective, regardless of the system's future states, is to minimize job execution delays while ensuring the L-UAVs' long-term energy stability. The combined optimization problem of task assignment, computing resource allocation, and trajectory control of L-UAVs and H-UAVs is tackled using a BCD algorithm after an efficient technique to match vehicles with L-UAVs has been designed [49].

A. Moustafa, et al., (2025) suggested CEP, or the Community Edge Platform. To decrease recruiting costs and protect anonymity in EED-enabled environments, CEP is the only platform that builds communities of requesters and EEDs by using corporate, institutional, and social interactions. CORA is a proposal that might help with this problem. While maintaining an acceptable scheduler runtime, CORA aims to minimize execution time and make span while accounting for community limits [50].

A. Aimi, et al. (2025) present substantial operational and technological challenges that have impeded the technology's capillary adoption up until this point. To overcome these restrictions, suggest a novel bottom-up deployment paradigm that lessens operational and managerial hurdles while decentralizing ownership of data and networks. The LoRa network is being used for urban sensing by the community. Empowered by Smart Homes is a project that encourages a participatory and decentralized sensor network through the integration of smart gateways into people's smart homes [51].

R. Jadhav, et al. (2025) include the recent research on edge computing, covering architectures, applications, security challenges, and future trends. This article delves into the topic of edge computing, specifically looking at how it relates to 6G networks, multi-access edge computing, and neural networks. Computing overheads, attack vulnerabilities, and scalability in distributed edge networks are some of the important topics covered [52]. L. Kong, et al. (2023) discuss how edge computing has impacted the development of the IoT and how it excels in comparison to other computing paradigms as they pertain to the IoT. Then, determine whether or not a comprehensive study of the IoT powered by edge computing is required (ECDriven-IoT) [53].

VI. Research Gap

A number of knowledge gaps persist in distributed edge computing and community-driven systems, despite the fact that both areas have seen substantial advancements in recent years. The majority of current methods are architecture-specific, making them inapplicable in heterogeneous edge settings. These include O-RAN, NFV/SDN, UAV-assisted edge computing, community platforms, and IoT-based frameworks. Challenges related to interoperability, cross-domain resource orchestration, security, privacy, trust management, and energy-efficient operation are still inadequately addressed. Furthermore, current solutions provide limited support for real-time adaptive resource allocation, autonomous AI-driven decision-making, and large-scale deployment.

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TABLE I. SUMMARY OF KEY STUDIES ON THREAT DETECTION AND SECURITY IN SAAS AND CLOUD ENVIRONMENTS

Reference	Study Focus	Approach/Technology	Key Findings	Limitations / Future Scope
S. D. A. Shah et al. (2026)	Agentified Open Radio Access Network (O-RAN)	Embodied AI agents, RF telemetry, visual sensing, Brain-Reflex control loop, communication-compute slicing	Improved situational awareness and unified management of communication and computing resources.	Requires scalable deployment, interoperability, and real-time coordination across heterogeneous O-RAN environments.
A. Cárdenas et al. (2026)	Integrated terrestrial and non-terrestrial infrastructure management	NFV/SDN, ETSI NFV MANO, 3GPP architecture, hierarchical Infrastructure Mobility Management	Efficient mobility management through global, domain, and local management functions.	Cross-domain interoperability, security, and dynamic orchestration remain challenging.
Y. Ye et al. (2026)	Multi-tier UAV edge computing	Lyapunov optimization, Block Coordinate Descent (BCD), UAV trajectory optimization, resource allocation	Reduced task execution delay while maintaining long-term UAV energy stability.	Limited validation under large-scale, highly dynamic, and heterogeneous edge scenarios.
A. Moustafa et al. (2025)	Community Edge Platform (CEP)	Community-driven edge computing, CORA scheduling, hierarchical control	Preserved privacy, reduced recruitment cost, and improved community resource allocation.	Workload balancing, scalability, and heterogeneous community participation require further investigation.
A. Aimi et al. (2025)	Community-driven LoRa Networks (CLUES)	Decentralized deployment, smart gateways, participatory sensing	Reduced deployment barriers and enabled decentralized urban sensing through smart homes.	Large-scale deployment, interoperability, and long-term network sustainability remain open issues.
R. Jadhav et al. (2025)	Edge Computing Survey	AI, MEC, 6G, distributed edge architectures	Reviewed architectures, applications, security challenges, and future trends in edge computing.	Computational overhead, cyber threats, scalability, and efficient resource management require further research.

VII. CONCLUSION AND FUTURE WORK

This survey offered a thorough analysis of open edge networks, highlighting how distributed computing architectures driven by communities are crucial for enabling next-gen decentralized applications. It examined the fundamentals of edge computing and discussed how technologies such as AI, IoT, SDN, NFV, and MEC enhance resource sharing, intelligent orchestration, and real-time data processing. Open edge networks were also emphasized in the study as having a significant impact on several application areas, such as smart cities, healthcare, transportation, smart homes, agriculture, and disaster management. Furthermore, it reviewed key security, privacy, and trust mechanisms required to ensure reliable and resilient distributed services. Overall, community-driven open edge networks provide a scalable, flexible, and low-latency computing environment that reduces dependence on centralized cloud infrastructures while improving service quality, interoperability, and efficient resource utilization for future distributed computing ecosystems.

Future research should focus on AI-native edge intelligence, federated learning, blockchain-based trust, digital twins, and 6G-enabled communication to improve scalability, security, and interoperability. Developing standardized, energy-efficient, and autonomous resource orchestration frameworks will enable sustainable, resilient, and intelligent open edge networks for emerging real-time distributed applications.

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