JOETSR-Journal of Emerging Trends in Scientific Research
Volume 1, Issue 1 | July-2023
e-ISSN: 2997-8718 Print ISSN: 2997-870X

Advanced Edge Computing Frameworks for Optimizing Data Processing and Latency in IoT Networks

Bhumeka Narra[1], Dheeraj Varun Kumar Reddy Buddula[2], Hari Hara Sudheer Patchipulusu[3], Achuthananda Reddy Polu[4], Navya Vattikonda[5], Anuj Kumar Gupta[6]
[1]Sr Software Developer, Statefarm.
[2]Software Engineer, Elevance Health Inc.
[3]Senior Software Engineer, Walmart.
[4]SDE3, Microsoft.,
[5]Business Intelligence Engineer, International Medical Group Inc.
[6]Oracle ERP Senior Business Analyst ,Genesis Alkali

Received: 17-05-2023; Revised: 14-06-2023; Accepted: 24-06-2023; Published: 08-07-2023

Abstract: ***The advent of edge computing has been revolutionary in improving data processing efficiency and reducing latency in IoT networks. By decentralizing computational tasks, edge computing enables real-time analytics and scalability while reducing reliance on centralized cloud infrastructures. This paper explores advanced frameworks, including hierarchical and decentralized architectures, that integrate AI and machine learning to enhance predictive optimization and resource management. It also addresses challenges such as protocol compatibility, energy efficiency, and operational complexities. The review provides insights into current advancements and identifies future opportunities for improving IoT network performance and supporting latency-sensitive applications like smart cities and industrial automation.***

Keywords*:* ***Edge Computing, IoT Networks, Latency Optimization, Data Processing Optimization, Hierarchical Frameworks, Smart Cities, Decentralized Computing, Network Connectivity Protocols (MQTT, CoAP, LoRaWAN, 5G.***

1.Introduction

The various devices carrying out distinct activities for certain shared goals compose the internet of things, a kind of network. These devices (sensors) may take many forms, including cameras placed strategically throughout the city to record traffic, the metrological department, municipal agencies, banks, a variety of sensors, individuals, phones, traffic police, and so on. A widespread and ubiquitous computing function is carried out by these gadgets. Yet, the IoT defies easy categorization. Definitions have been provided by several organizations. The IoT is characterised by a number of attributes, including a comprehensive perception, dependable transmission, and intelligent processing, as well as by its heterogeneity, scalability, mobile nature, diversity, intimacy, interdependence myriad, unattunedness, and limited resource power (1).

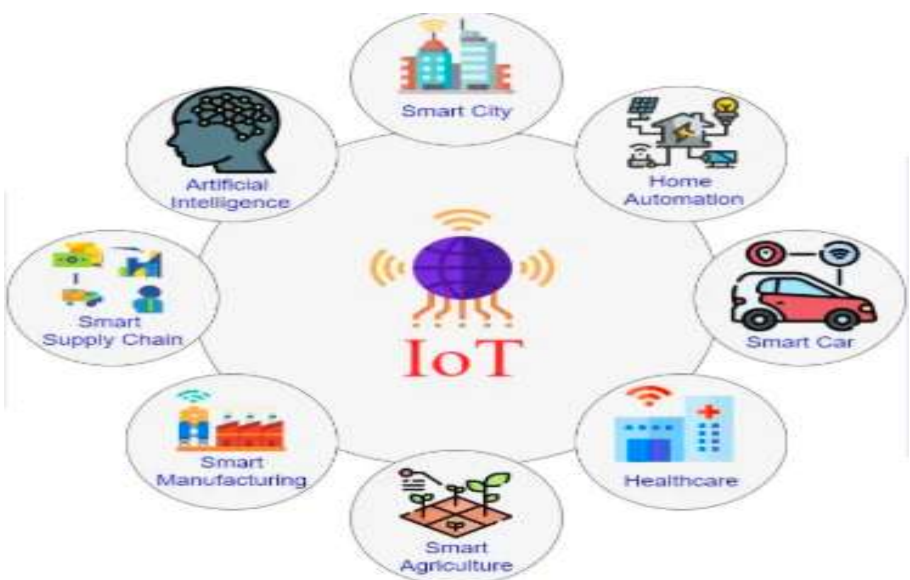

Figure 1 Overview of IoT

The IoT primarily does the following: object detection, object sensing, object identification, and action triggers (2).
Edge computing has become more prevalent thanks to the widespread adoption of internet of things data processing at network edges. The advanced edge computing frameworks optimize system performance through data source proximity while reducing processing delays. Edge computing frameworks integrate decentralized-hierarchical system designs which support real-time analysis capabilities and scalable distributions together with minimal cloud infrastructure dependency. The implementation utilizes lightweight AI/ML predictive optimization in addition to effective resource management along with strong network protocols. The improved infrastructure of edge computing frameworks provides optimized operations for latency-focused systems such as smart cities along with industrial IoT technologies and autonomous applications (3).
Researchers investigated existing edge computing frameworks that handle IoT data processing needs and network latency problems throughout 2019. This research evaluates various edge computing architectural patterns beginning with centralized and decentralized structures and hierarchical models by explaining both their benefits and weaknesses. Real-time analytics and AI-driven predictive optimization emerged as key techniques while optimization methods received further examination throughout the paper. The objective of this analysis is to deliver the current status of edge computing advancements during 2019 so future optimization strategies can improve data processing and latency performance in IoT systems.

2.Overview of IOT Networks and Challenges

The interconnection of billions of devices for data collection, processing, and analysis has revolutionised many sectors, thanks to the fast growth of IoT networks. A wide variety of uses, from healthcare and smart cities to industrial automation, are made possible by these networks. However, there are several difficulties in controlling IoT networks. To enable real-time decision-making, the vast amount of structured and unstructured data produced by IoT devices necessitates the use of effective processing frameworks. Latency issues, bandwidth constraints, and the limited computational power of IoT devices further complicate operations. Resolving these issues is crucial to maximising IoT networks' potential in contemporary applications (4).

A. Growth and Applications of IoT

Radio Frequency Identification (RFID) technology is an electronic labelling system that facilitates the assignment of a digital identity to any object. It was initially employed during the Second World War to distinguish friendly aircraft. In the early phases of production, for a little fee, an RFID tag is affixed to the product. This tag then follows the goods through the supply chain, from the factory to the store, and eventually into the customer's hands.

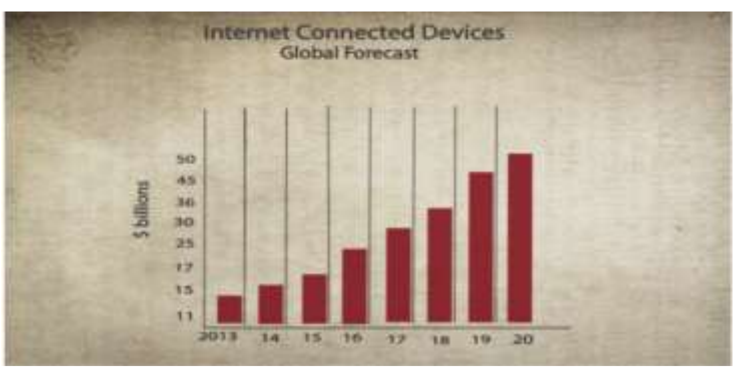

Figure 2 Internet Connected Devices - Global Forecast

A distinct evolution in digital technology called IoT stands apart from the Internet of People (IoP). IoT emerged from wireless technology fusion with micro-electromechanical systems, electrical infrastructure development, and network interconnection to become a vital business competition factor which delivers operational improvements and cost efficiencies seen in figure 2. Since its initial emergence during the 1970s IoT has experienced explosive growth which pushed connected devices numbers from 11 billion in 2013 to reach more than 50 billion by 2020. Research indicates that the global IoT market will experience exponential expansion from $157 billion in 2016 to $661 billion by 2021 which will generate substantial economic value and add trillions to global GDP through the upcoming decades (5).

1. Applications of IOT:

Smart cities: The concept of a "smart city" is getting people all around the globe excited about the IoT. Incorporating IoT into smart city planning includes automating transportation, water distribution, improved energy management systems, environmental monitoring, and smarter surveillance. Major issues encountered by city dwellers will be resolved via the IoT. Time, energy, and money may all be saved with smart home technologies (6).

Security & Emergencies: Perimeter Access Control: Identification and management of individuals who are not authorised or restricted. Liquid Presence: Detecting liquids in warehouses, critical areas of buildings, and data centres to avoid corrosion and malfunctions. Radiation Levels: To detect radiation leaks in the areas around nuclear power plants, a system of dispersed detectors is used (7).

Home: It is widely anticipated that smart houses will reach the kind of ubiquitousness seen in smartphones, making them the revolutionary rung on the success ladder in residential environments. Whenever they think of IoT systems, Smart Home consistently ranks as the top IoT application across all channels, making it the most essential and efficient application. Companies are developing devices to make your life easier and more convenient, so don't be shocked by how the IoT is developing.

Smart Farming: Smart agriculture leverages IoT and advanced technologies to optimize farming practices and enhance productivity. It monitors soil nutrition, light, humidity, and temperature, enabling automated adjustments to improve greenhouse conditions and maximize yields. Real-time data collection and processing enable precise strategies for plant health monitoring, yield prediction, and drainage mapping (8).

B. Challenges in Data Processing and Latency

There are some challenges they phase in data processing steps and their latency:

1. Challenges in Data Processing in IoT Networks

- Resource Limitations: Edge devices in IoT systems often face computational and storage constraints, impacting their ability to process large datasets locally and necessitating reliance on centralized or cloud-based processing for resource-intensive.
- Tasks a Quality Assurance: The heterogeneous and unstructured nature of IoT data introduces issues such as noise, incompleteness, and inconsistencies. Real-time systems require robust mechanisms for data cleaning and validation to ensure accurate decision-making (9).
- **Service Risks:** Physical manipulation, illegal entry, and theft are threats to IoT edge devices. To protect data and system integrity, robust authentication, encryption, and access restrictions are required.
- Data Synchrotributed: Datasets across numerous edge devices presents synchronization challenges. Ensuring all devices have access to updated, consistent data is critical to prevent errors in real-time decision-making.
- Operational Complexity: Large effective management tools to ensure devices are functional, coordinated, and capable of handling distributed processing tasks efficiently (10).

2. Latency Challenges in IoT Networks:

High Latency in Wide-Area Networks: IoT focuses on things where it has wide area and remote control where transitional nodes, back haul, core or cloud infrastructure building, etc., contribute in degrading the latency (11).

Energy Constraints: The IoT devices for meeting the latency requirements unsparingly use power which leads to destroy the device life.

Packet Transmission Issues: Wasted bandwidth and increased latency due to packet retransmissions as a result of decoding or channel impairments, particularly in time sensitive situations.

Scheduling Delays: The development of the system is challenging issue is to manage the resources in shared environment efficiently by scheduling the unexpected data packets in any resource set, as task scheduling delays affect the overall latency.

Mobility-Related Delays: The handover in mobile networks can introduce delays that increase clock times for real-time IoT operations like, self-driving cars or industrial automation (12).

3.Edge Computing Frameworks: A Technical Perspective

A key answer to the constraints of centralised cloud systems in IoT networks has been the emergence of edge computing frameworks. By processing data closer to the source, these frameworks minimize latency, reduce bandwidth consumption, and enable real-time analytics. Architectures such as centralized, decentralized, and hierarchical frameworks provide varying approaches to resource distribution and scalability. Ensuring flawless data flow and effective processing is made possible by a number of important components, including edge devices, gateways, network protocols, and cloud connectivity. These frameworks empower IoT applications like smart cities, industrial automation, and healthcare by offering localized, scalable, and latency-optimized solutions, making edge computing an essential enabler of next-generation IoT systems.

A. Defining Edge Computing

E Edge computing enables IoT data analysis at the network's periphery prior to transmission to the cloud or data centre. Information may be efficiently sent via a system by a single device, but problems arise when several devices communicate information at once. Idleness will not only degrade quality, but it may also result in enormous data transmission capacity costs.

- Cutting-edge computing infrastructure and services alleviate this problem by acting as a regional hub for handling and archiving a large number of these frameworks.
- For example, to reduce transmission capacity demands, an edge gateway may parse data received from an edge device and then just transmit the meaningful data back over the cloud.
- An IoT sensor, a worker's scratch pad PC, their most current mobile phone, the security camera, or even the web-connected microwave in the break room are all examples of edge devices.
- In an edge-computing architecture, edge gateways are considered edge devices (13).

B. Architectural Models for Edge Computing

Edge computing architectures address the limitations of traditional centralized cloud models by decentralizing computational resources. These architectures include centralized models, which rely on core cloud infrastructure but suffer from high latency and bandwidth constraints, and decentralized models, which distribute computational tasks closer to users, reducing delays and enhancing real-time data processing. Additionally, hierarchical frameworks combine both approaches, leveraging layered architectures to optimize resource allocation, scalability, and performance. Such models enable IoT networks to support latency-sensitive applications while maintaining efficiency (14).

1. Centralized Model

In centralized computing, all company information and software applications are located in one central computing center or server. This architecture means that data can flow efficiently, that the replies are immediate, and work can be improved through the use of control and scaling (15).

a. Traditional Use Cases

Mainstream models include those practiced in health care systems in which EHRs are centralized for assimilation into a single system that can capture information from various organizations for purposes of shared access and analysis. This is useful for application where users are in real demand large set of data and operational aspect of system.

b. Limitations

High Latency: The response time is expected to be slow where the users are located far from the central server.

Bandwidth Costs: A number of transactions to and from the central server adds a high bandwidth consumption cost.

Single Point of Failure: A failure at this layer leads to unavailability of services with poor data access and operation time.

Scalability Challenges: Although centralized structures make it easier to scale up, logistics constraints can quickly become an issue during bursts of usage.

2. Decentralized Model

In decentralized edge computing, data and computational functions are different from one another, and they are processed at a local level. This architecture minimizes reliance on central servers, and can give the edge devices or a small data center some processing roles nearby the data source (16).

Advantages:

- Localized Processing: It means that tasks within the layer are carried out nearer to the data source so that response times are faster.
- Reduced Network Traffic: Decentralized systems reduce the quantity of data that needs to be sent across networks, therefore, decreasing bandwidth use when data processing occurs locally.
- Fault Tolerance: It is important for all the nodes to have redundant data to avoid system failure that would halt operations.
- Flexibility and Scalability: A distinctive feature of distributed systems is that they are extendable – they can add new nodes as necessary (17).

e-ISSN: 2997-8718 Print ISSN: 2997-870X

Examples

Smart Cities: As decentralized models, the platforms are responsible of handling real time information for traffic and environmental conditions and public safety systems.

Industrial IoT (IIoT): Manufacture industries adopt the decentralized approach in the use of various alarm systems for predictive maintenance and machine to machine communication in a bid to reduce on time delays and even downtime.

3. Hierarchical Frameworks

The design of Hierarchical Edge Computing is shown in Figure 3. The Hierarchical Edge Computing (HEC) idea focuses on the organizational level to achieve the highest efficiency and avoid delays. On the lower hierarchy stands the device layer, through which IoT devices and sensors collect data in its purest form from the physical environment, and data is mildly pre-processed to filter out undesirable background influence. The processed data is then channelled to the edge layer, which are to be implemented as micro or mini data centers serving near the entry or exit of the ISPs or gateways.

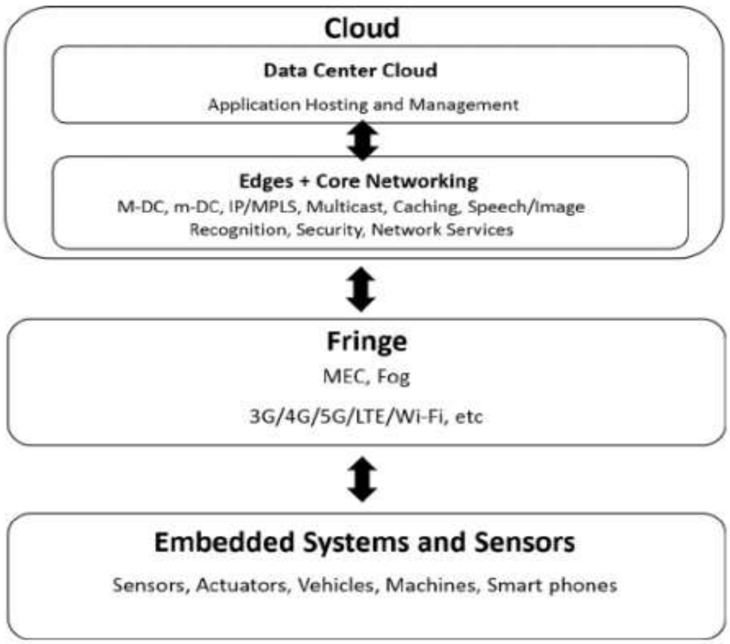

Figure 3 The architecture of Hierarchical Edge Computing

These edge nodes perform more advanced operations such as data acquisition, filtering, three message compression and real-time data analysis. Finally, tasks that cannot be further processed in the network are transferred to the next layer – the cloud layer which has special computational power for computation and sturdy computing and storage.

It is this organization that makes a hierarchical structure feasible, and to optimize it, they place, for example, real-time signal processing nearer the interface with the end-users as a delay constraint may be crucial.

Use case: HEC framework is effective mostly for the latency-critical and high throughput applications.

For instance, in full autonomous vehicles, the edge nodes are used in processing and making decisions, such as detecting obstacles and planning the best routes to follow, while other data that are not so crucial are processed in the cloud.

Likewise, smart factories leverage the framework where real-time control of machines depends on local computations from sensor data while the cloud side is applied for large-scale analytics and predictive maintenance (18).

c. Key Components of Edge Computing Frameworks

There are some key components in their edge computing framework:

1.Edge Devices and Gateways

IoT infrastructure utilizes edge devices such as sensors and actuators for initial data harvesting efforts by extracting physical domain information. Plants and sensors function as IoT entry points because they process baseline data

 https://doi.org/10.5281/zenodo.15209364

before they reach the network gateway. IoT Gateway serve as the first connection to IoT devices and the rest of the network. They also perform data consolidation, format translation and data transmission to the edge computer framework. Edge devices and IoT Gateways serve as the building blocks in building edge computing systems. That support on-site data processing, lower response times, and maintain connectivity with cloud and network resources (19).

2. Network Connectivity Protocols

- The connectivity protocols used by edge computing execute data and communication tasks between connected devices and gateways and cloud systems.
- Short-Range Protocols: Short-range protocols WIFI, Bluetooth and ZigBee provide local connectivity networks that connect edge devices with their neighboring gateways.
- Wide-Area Protocols: The communication protocols LTE and 5G and LoRaWAN operate for extensive data exchange purposes across large expanses with quick response times.
- Multipath TCP (MPTCP): This approach stands out because it establishes parallel network paths for simultaneous utilization that enhances reliability along with bandwidth management capability.
- Protocol Optimization: Network traffic optimization along with dynamic resource allocation techniques enable the reduction of delays through protocol implementations (20).

4.Latency and Data Processing Optimization Techniques

Latency and efficient data processing are critical challenges in IoT networks, especially for applications requiring real-time decision-making. Edge computing addresses these issues by processing data locally, reducing delays caused by transmitting data to centralized cloud servers. Techniques such as real-time data analytics, predictive optimization using AI and machine learning, and distributed data processing enhance system responsiveness (21). Additionally, resource management strategies like load balancing, task scheduling, and energy-efficient operations optimize processing efficiency. By employing these techniques, IoT networks can achieve faster data processing, lower latency, and improved scalability, ensuring seamless performance for latency-sensitive applications like autonomous vehicles, smart cities, and industrial IoT.

A.Real-Time Data Analytics at the Edge

Data collected in real-time with the help of edge computing are processed near the data source region mitigating the latency issues. As a result, dependency on central servers is minimized. This increases the decision-making speed for crucial IoT applications. To illustrate, edge devices with event stream processing engines can now disaggregate sensor data in real-time to identify anomalies and trigger applicable acts. Fast response time is guaranteed by eliminating unnecessary information exchange which saves bandwidth and storage. This system is ideal for industries IoT systems utilizing predictive maintenance and real-time monitoring for their critical devices (22).

B.Load Balancing and Resource Allocation

Load balancing in IoT systems distributes workload across resources to optimize performance. It uses algorithms to allocate tasks, implements balancers at various layers, and impacts system performance by improving resource utilization, scalability, reliability, and energy efficiency. Resource allocation in IoT involves designing load balancing strategies and optimizing resource distribution. This includes identifying critical components, choosing algorithms, defining policies, and implementing monitoring mechanisms. Optimization techniques like dynamic allocation and containerization further enhance efficiency.

1.Load Balancing in IoT Systems

- Resource Management: Resource management requirements become fundamental for IoT and edge computing to work together effectively. Through load balancing methods IoT networks become optimized as computational and storage requirements are allocated evenly across edge nodes to minimize congestion.
- Storage Balancing: Load balancing is key to spreading data storage across multiple edge nodes. This reduces storage time, less network traffic and managing multiple IoT devices that generate different data streams.
- Task Scheduling: At edge/cloudlet servers, task scheduling is about allocating the right resources while meeting certain constraints. This is to minimize compute and transmission delay, energy consumption and bandwidth usage and balance the workload across nodes.
- Failure Recovery: Load balancing also includes failure recovery mechanisms to keep edge storage and computing systems up and running (23).

2.Resource Allocation in IoT Systems

Identify critical components and services requiring load balancing, such as data ingestion and processing pipelines, data storage and retrieval services, and application servers and microservices. Determine appropriate load balancing algorithms based on system requirements, considering factors like resource heterogeneity, workload patterns, and scalability needs. Define load balancing policies and configurations, specifying criteria for workload distribution and configuring the load balancer with appropriate settings (24). Implement monitoring and auto-scaling mechanisms to detect performance bottlenecks and automatically adjust the number of resources based on workload demands.

C.AI and Machine Learning for Predictive Optimization

AI and ML are used efficiently in this process and are most effective in minimizing the latency in edge computing environments. In replenishing a networked-embedded smart environment with differing datasets, systems can process these data in a more real-time manner without having to involve centralized cloud servers that would increase latency tremendously. Predictive optimization techniques are especially useful where low latency is critical as in driverless cars, plants and factories, and health care. Key Techniques for Predictive Optimization:

Pruning: Contributes to successful AI model by thinning down unnecessary weights; improves efficiency of computations without the loss of performance.

Quantization: Translates precise information into less precise formats thus permitting a higher rate of inference and lesser memory utilization.

Knowledge Distillation: Teach smaller, easy-to-deploy models to mimic the behavior of large, complex models, which makes them a good fit for edge placement.

Real-Time Data Processing: In the collected stream, data from the field are managed locally through the help of AI/ML models to allow fast detection of data anomalies, to predict maintenance requirements, and to dynamically adjust network load (25).

Federated Learning: It is a way in which training of the ML models can be done across multiple edge devices and at the same time the raw data is not transferred hence increasing the privacy, as well as decreasing transfer latency. Especially when the data is personal as is the case in health and financial applications.

Energy-Efficient AI: Moreover, methods like energy-aware scheduling and approximate computing help to optimize the usage of predefined amounts of resources on edge devices, decreasing latency but not affecting performance (26).

5.Literature Review

In this section, provides the previous research on Advanced Edge Computing Frameworks for Optimizing Data Processing and Latency in IoT Networks. This table I organizes the key aspects of the reviewed studies and highlights their contributions, challenges, and limitations.

Mogi, Nakayama and Asaka (2018) provide a strategy for handling traffic jams and guerilla rainstorms that uses multi-access edge computing to distribute the workload across edge servers in an IoT sensor network. Smartphones and other tiny terminals with built-in sensors have proliferated in recent years, and research into edge computing and wireless sensor networks is making strides thanks to cutting-edge tools like the IoT and smart transportation systems. Furthermore, there has been little investigation on load balancing across edge servers or offloading in the face of dynamically fluctuating demand circumstances (27).

Bhuvaneswari and Porkodi (2014) shows a variety of applications that have used smart technology so far are covered in the first fold. An outline of the sensors and their specifications is provided on the second fold of this document. The most exciting new frontier that combines the best of pervasive computing with wireless sensor and actuator networks is the Internet of Things (IoT). The IoT has many potential uses, and its proponents have laid out its advantages, disadvantages, possibilities, and obstacles, as well as the technological standards that underpin it (e.g., mobile phones, RFID tags, sensors, actuators, etc(7).

Middha (2018) analyses of resource distribution and its many processes, as seen through the eyes of diverse researchers. The IoT is the newest and most advanced computer level. Because of its rapid growth and the growing number of linking devices, it is now the most interesting field to study. With such a broad reach, it has many uses across several industries and also confronts certain difficulties. The distribution of available resources is a significant obstacle. Allocating resources is essential for the effective operation of the whole IoT ecosystem, as each network node has its own set of priorities and demands (24).

Parmar and Desai (2016) explores the unusual combination of wireless personal area networks, such as 6LowPAN and ZigBee, with the IEEE 802.15.4 protocol, which operates the physical layer and handles medium access control

for 6LoW-PAN and ZigBee connection. This offers insight into how IoT networking works. Furthermore, this study delves into topics like wireless local area network protocol (Wi-Fi) and mobile communication technology (LTE) that facilitate internet and wide area network access. For the IoT to function, this article primarily discusses the interdependencies between various technologies. Highlighted are significant obstacles to study in that field (28).
Symeonides et al. (2019) provides an overview of their goal for an abstract query model that is both rich and declarative, with a focus on how Edge Computing works, and showcases a framework prototype that makes this goal a reality. This is achieved by means of the declarative query model, which lets users articulate descriptive and high-level analytical insights, and by means of their framework, which builds, optimises, and executes the query plan independently of the programming paradigm of the underpinning data processing engine. They then demonstrate some use cases that might gain from edge computing query-driven descriptive analytics (29).

Table 1 Summary of Reviewed Studies on Edge Computing Frameworks for Data Processing and Latency in IOT Networks

Reference	Study On	Approach	Key Findings	Challenges	Limitations
[27]	Load balancing in IoT sensor systems using MEC	Multi-access edge computing to equalize load during events like traffic congestion	Load balancing methods improve edge server efficiency in dynamic situations	Cooperation between edge and cloud, dynamic offloading, and orchestration issues	Limited research on dynamic load conditions and edge server balancing
[7]	Application s of IoT and sensor standards	Overview of smart technology applications and sensor standards	Identifies IoT opportunities, challenges, and technology standards (e.g., RFID, sensors, actuators)	Managing diverse sensor and IoT standards	Limited focus on optimization and real-time applications
[24]	Resource allocation mechanisms in IoT	Review of various resource allocation mechanisms	Efficient resource allocation is critical for IoT ecosystem functionality	Managing device priorities and demand in IoT networks	Lack of concrete solutions for large-scale IoT resource management
[28]	IoT networking technologies	Analysis of WPANs (6LowPAN, ZigBee), Wi-Fi, and LTE technologies for IoT	Collaboration of multiple network protocols is essential for IoT connectivity	Interoperability between different networking technologies	Limited focus on practical implementations and scalability
[29]	Query-driven analytics for edge computing	Declarative query model and prototype framework for edge computing	High-level analytics can optimize edge data processing	Query model integration with edge programming environments	Open challenges in implementing advanced analytics frameworks
[30]	Secure and efficient MEC for IoT applications	Framework for secure MEC in IoT devices with limited mobility	Ensures mutual authentication between IoT devices and edge providers	Addressing mobility challenges in IoT devices	Security threats in mobile IoT devices remain unresolved

6.Conclusion and Future Work

Edge computing frameworks offer significant potential for addressing the latency and data processing challenges inherent in IoT networks. Through decentralized and hierarchical models, these frameworks enable real-time analytics and efficient resource allocation, reducing the dependency on cloud systems. Protocols like MQTT and CoAP facilitate seamless communication, while AI and machine learning enhance predictive optimization and energy efficiency. Despite these advancements, challenges such as interconnectivity, security vulnerabilities, and resource constraints remain. The continued evolution of edge computing frameworks is vital for unlocking their full potential in enabling scalable, latency-optimized, and reliable IoT solutions across various domains.

Future research on edge computing should focus on addressing interconnectivity challenges by standardizing protocols and improving interoperability across IoT systems. Advancements in AI and machine learning, particularly in federated learning, will be critical for enhancing real-time analytics on resource-constrained edge devices. Energy-efficient strategies, such as low-power hardware and adaptive scheduling, must be prioritized to support sustainable operations. Hybrid edge-cloud architectures also hold promise for balancing computational loads and improving scalability. Additionally, robust security measures, including advanced cryptography and privacy-preserving techniques, are essential to safeguard decentralized systems. By targeting these areas, edge computing can achieve its maximum potential in IoT networks.

Acknowledgement: Nil

Conflicts of interest

The authors have no conflicts of interest to declare

References

1. Farooq MU, Waseem M, Mazhar S, Khairi A, Kamal T. A Review on Internet of Things (IoT). Int J Comput Appl. 2015;113(1):1–7.
2. Khan R, Khan SU, Zaheer R, Khan S. Future internet: The internet of things architecture, possible applications and key challenges. Proc Int Conf Front Inf Technol. 2012;:1–5.
3. Varghese B, Wang N, Barbhuiya S, Kilpatrick P, Nikolopoulos D. Challenges and Opportunities in Edge Computing. 2016;:1–6.
4. Rose K, Eldridge S, Chapin L. The Internet of Things (IoT): An Overview. Internet Things An Overv. 2015;5(12):71–82.
5. Attaran M. The Internet of Things: Limitless Opportunities for Business and Society. J Strateg Innov Sustain. 2017;12(1):1–9.
6. Abomhara M, Køien GM. Cyber security and the internet of things: Vulnerabilities, threats, intruders and attacks. J Cyber Secur Mobil. 2015;4(1):65–88.
7. Bhuvaneswari V, Porkodi R. The internet of things (IOT) applications and communication enabling technology standards: An overview. Proc Int Conf Intell Comput Appl. 2014;:324–329.
8. Dawood M. Review on Applications of Internet of Things (IoT). 2018;:1–5.
9. Atlam HF, Walters RJ, Wills GB. Fog computing and the internet of things: A review. Big Data Cogn Comput. 2018;2(2):10.
10. Sperber M, Neubig G, Niehues J, Stüker S, Waibel A. Lightly supervised quality estimation. Proc COLING. 2016;3190(6):3103–3113.
11. Muthanna A, et al. Secure and reliable IoT networks using fog computing with software-defined networking and blockchain. J Sens Actuator Netw. 2019;8(1):15.
12. Siddiqi MA, Yu H, Joung J. 5G ultra-reliable low-latency communication implementation challenges and operational issues with IoT devices. Electronics (Switzerland). 2019;8(9):981.
13. Dalan D. An Overview of Edge Computing. Int J Eng Res Technol. 2019;7(5):1–4.
14. Mach P, Becvar Z. Mobile Edge Computing: A Survey on Architecture and Computation Offloading. IEEE Commun Surv Tutor. 2017;19(3):1628–1656.
15. Ling MH, Yau KLA, Qadir J, Poh GS, Ni Q. Application of reinforcement learning for security enhancement in cognitive radio networks. Appl Soft Comput J. 2015;37:809–821.
16. Taherizadeh S, Jones AC, Taylor I, Zhao Z, Stankovski V. Monitoring self-adaptive applications within edge computing frameworks: A state-of-the-art review. J Syst Softw. 2018;136:19–38.
17. van der Meulen R. What Edge Computing Means for Infrastructure and Operations Leaders. Gartner. 2018;:1–6.
18. Smeliansky R. Hierarchical Edge Computing. 2018;:1–11.
19. Xu R, Jin W, Kim D. Microservice security agent based on API gateway in edge computing. Sensors (Switzerland). 2019;19(22):4905.
20. Mohan N. Edge Computing Platforms and Protocols. 2019;:1–9.

21. Qin C, Eichelberger H, Schmid K. Enactment of adaptation in data stream processing with latency implications—A systematic literature review. Inf Softw Technol. 2019;113:1–25.
22. Gillespie R, Gupta S. Real-time Analytics at the Edge: Identifying Abnormal Equipment Behavior and Filtering Data near the Edge for Internet of Things Applications. 2017;:1–5.
23. Yu W, et al. A Survey on the Edge Computing for the Internet of Things. IEEE Access. 2017;6:6900–6919.
24. Middha K. Resource Allocation in IoT – A Review. Int J Manag IT Eng. 2018;8(8):315–321.
25. Syafrudin M, Fitriyani NL, Li D, Alfian G, Rhee J, Kang YS. An open source-based real-time data processing architecture framework for manufacturing sustainability. Sustain. 2017;9(11):2139.
26. Sittón-Candanedo I, Alonso RS, García Ó, Muñoz L, Rodríguez-González S. Edge computing, IoT and social computing in smart energy scenarios. Sensors (Switzerland). 2019;19(15):3353.
27. Mogi R, Nakayama T, Asaka T. Load balancing method for IoT sensor system using multi-access edge computing. Proc Int Symp Comput Netw Worksh. 2018;:1–5.
28. Parmar J, Desai A. IoT: Networking Technologies and Research Challenges. Int J Computing Appl. 2016;154(5):1–6.
29. Symeonides M, Trihinas D, Georgiou Z, Pallis G, Dikaiakos M. Query-driven descriptive analytics for IoT and edge computing. Proc IEEE Int Conf Cloud Eng. 2019;:65–72.
30. S. Almajali, H. B. Salameh, M. Ayyash, and H. Elgala, "A framework for efficient and secured mobility of IoT devices in mobile edge computing," in 2018 3rd International Conference on Fog and Mobile Edge Computing, FMEC 2018, 2018. doi: 10.1109/FMEC.2018.8364045.
31. Routhu, K., Bodepudi, V., Jha, K. M., & Chinta, P. C. R. (2020). A Deep Learning Architectures for Enhancing Cyber Security Protocols in Big Data Integrated ERP Systems. *Available at SSRN 5102662*.
32. Chinta, P. C. R., & Katnapally, N. (2021). Neural Network-Based Risk Assessment for Cybersecurity in Big Data-Oriented ERP Infrastructures. *Neural Network-Based Risk Assessment for Cybersecurity in Big Data-Oriented ERP Infrastructures*.
33. Katnapally, N., Chinta, P. C. R., Routhu, K. K., Velaga, V., Bodepudi, V., & Karaka, L. M. (2021). Leveraging Big Data Analytics and Machine Learning Techniques for Sentiment Analysis of Amazon Product Reviews in Business Insights. *American Journal of Computing and Engineering*, *4*(2), 35-51.
34. Karaka, L. M. (2021). Optimising Product Enhancements Strategic Approaches to Managing Complexity. *Available at SSRN 5147875*.
35. Chinta, P. C. R., & Karaka, L. M. AGENTIC AI AND REINFORCEMENT LEARNING: TOWARDS MORE AUTONOMOUS AND ADAPTIVE AI SYSTEMS.
36. Boppana, S. B., Moore, C. S., Bodepudi, V., Jha, K. M., Maka, S. R., & Sadaram, G. AI And ML Applications In Big Data Analytics: Transforming ERP Security Models For Modern Enterprises.
37. Chinta, P. C. R., Katnapally, N., Ja, K., Bodepudi, V., Babu, S., & Boppana, M. S. (2022). Exploring the role of neural networks in big data-driven ERP systems for proactive cybersecurity management. *Kurdish Studies*.
38. Chinta, P. C. R. (2022). Enhancing Supply Chain Efficiency and Performance Through ERP Optimisation Strategies. *Journal of Artificial Intelligence & Cloud Computing*, *1*(4), 10-47363.
39. Sadaram, G., Sakuru, M., Karaka, L. M., Reddy, M. S., Bodepudi, V., Boppana, S. B., & Maka, S. R. (2022). Internet of Things (IoT) Cybersecurity Enhancement through Artificial Intelligence: A Study on Intrusion Detection Systems. *Universal Library of Engineering Technology*, (2022).