Chapter 1

Introduction

The rapid growth of the Internet of Things (IoT) has marked a transformative shift in how devices interact, communicate, and contribute to intelligent environments. From smart homes and healthcare systems to industrial automation and urban infrastructure, IoT networks are rapidly becoming foundational to modern technological ecosystems. This chapter provides an overview of IoT networks, describing their key components, communication mechanisms, and applications across various fields. It discusses data transmission methods, highlighting the trade-offs between direct transmission and multi-hop routing [3, 4] in terms of energy efficiency and network performance. The challenges of faulty nodes [5, 6] and dynamic network topology were identified as critical issues affecting IoT reliability and efficiency. Faulty nodes can disrupt data transmission, while time-varying networks introduce complexities in maintaining stable connections. Building upon this foundational understanding, the following section presents an overview of the thesis, outlining its motivation and key research areas. Finally, it discusses the scope of the research and concludes with the organization of the thesis.

1.1 Background

An IoT network refers to a complex system of interconnected smart devices that are capable of communicating and exchanging data over the internet or other communication infrastructures, often without the need for direct human involvement [7]. These networks are composed of a wide variety of devices embedded with essential components such as sensors, actuators, data storage units, processors, transceivers, and communication modules. Together, these components empower the devices to autonomously collect environmental or contextual data, process it locally or remotely, and transmit it to other devices or centralized systems for further analysis. This functionality supports real-time monitoring, intelligent decision-making, and automated control in diverse application domains. The term ‘Things’ in “Internet of Things” encompasses a broad spectrum of physical objects and devices that have been enhanced with computational and communication capabilities. These include, but are not limited to, human health monitoring devices [8, 9] (such as fitness trackers and remote patient monitoring systems), home security cameras, unmanned aerial vehicles (UAVs), industrial machinery, baby monitors [10], smart thermostats, security alarms, and a wide range of wearable technologies [11]. Each of these “Things” contributes to the formation of an intelli-

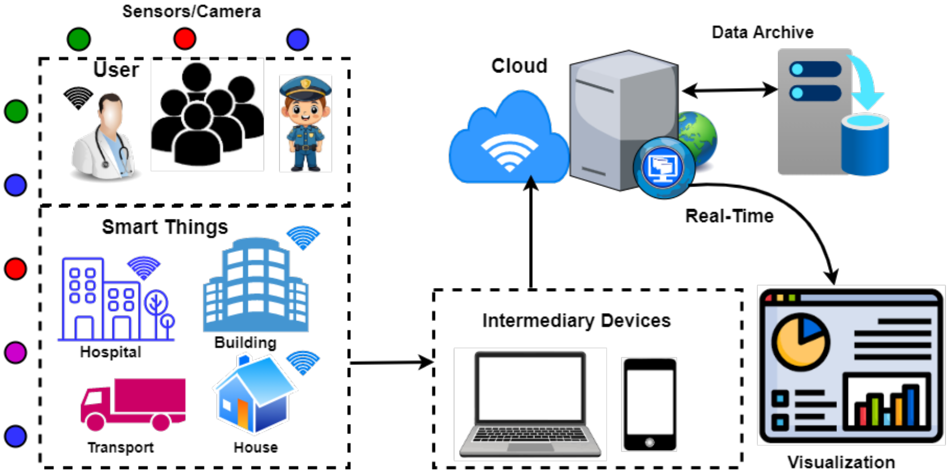


Figure 1.1: An illustration of IoT ecosystem [1]

gent ecosystem capable of enhancing efficiency, convenience, and functionality in both personal and industrial contexts. As the number and diversity of connected devices continue to grow, IoT networks are becoming increasingly integral to modern digital infrastructure across sectors such as healthcare [12], transportation [13], manufacturing [14], agriculture [15, 16], and smart cities.

As shown in Figure 1.1 [1], a typical IoT network comprises multiple components, including IoT devices (IoDs) that gather environmental or operational data, gateways and edge computing nodes that preprocess information before sending it to centralized cloud servers, and cloud platforms where large-scale data storage and analytics occur. To facilitate human interaction with the system, user interfaces such as mobile applications, desktop software, or web-based dashboards are integrated into the IoT architecture. These interfaces provide users with visual insights into the network's operational status, real-time alerts, performance metrics, and control options. Users can remotely configure devices, manage system settings, or make informed decisions based on visualized data outputs. Recently, IoT has been growing rapidly across both

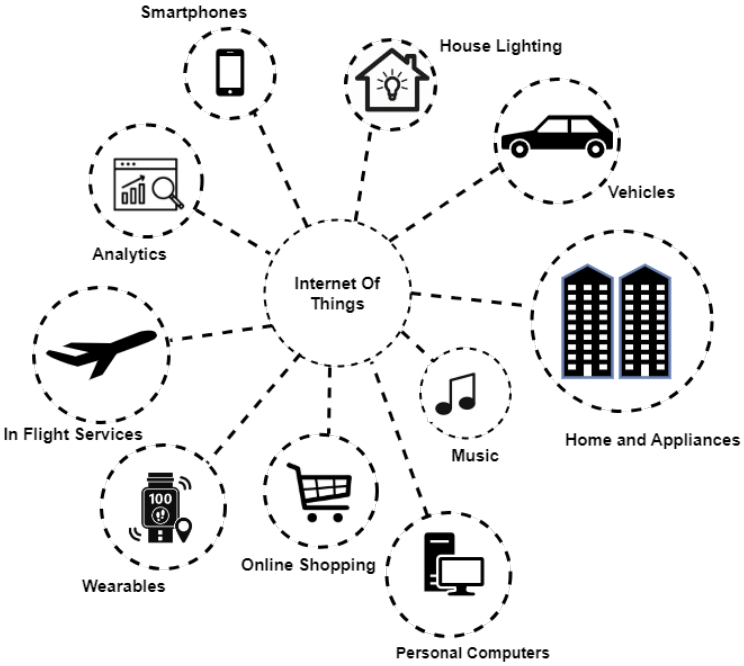


Figure 1.2: Applications of IoT

social and commercial sectors [17, 18], playing an important role in a wide range of applications such as smart homes, logistics, industrial automation, healthcare, smart cities, manufacturing, and agriculture [9], as illustrated in Figure 1.2. This technological advancement has significantly transformed various industries by enabling the seamless integration of devices and systems, thereby supporting efficient data collection and exchange to enhance decision-making and automation. IoT networks have become essential across multiple sectors, improving operational efficiency, increasing productivity, and offering user convenience. The following sections outline some of the key real-world applications of IoT networks

- **Smart Homes:** IoDs such as smart thermostats, lighting systems, and security cameras enable homeowners to automate and remotely control various aspects of their homes [19, 20]. Moreover, IoT-enabled security systems, including smart locks, doorbell cameras, and motion sensors [21], enhance home security by allowing users to monitor and control access to their homes from anywhere.
- **Healthcare:** Wearable health monitoring devices are increasingly used to track vital signs such as heart rate, blood pressure, and glucose levels [11, 12]. These smart devices transmit data in real time to healthcare professionals, enabling continuous remote monitoring and timely medical intervention. In clinical settings, IoT technology supports hospital operations by tracking the location of critical medical equipment, streamlining patient movement, and continuously monitoring patient conditions. By automating routine tasks and enhancing data accuracy, IoT reduces the potential for human error and contributes to higher standards of patient care and operational efficiency.
- **Smart Cities:** IoT-enabled traffic lights and smart sensors can optimize traffic flow by adjusting signals based on real-time traffic conditions. This reduces congestion and enhances mobility in urban areas [22, 23, 24]. Moreover, IoT-enabled waste bins can notify local authorities when they are full, allowing for more ef-

ficient waste collection and reducing unnecessary pickups. Apart from this, IoT sensors deployed throughout a city can monitor air quality, temperature, humidity, and other environmental factors, providing valuable data for public health initiatives and urban planning.

- **Industrial Automation (Industry 4.0):** IoT sensors, installed in industrial machinery, monitor the health of equipment, detecting potential failures before they occur. This enables predictive maintenance, reducing downtime and increasing operational efficiency. IoDs such as RFID tags and GPS trackers are used to track the movement of goods throughout the supply chain [25, 26]. This allows companies to improve inventory management, reduce theft, and ensure timely deliveries.
- **Agriculture:** Real-time monitoring of soil moisture, temperature, and nutrient content is made possible through IoT-based sensors deployed in agricultural fields [9]. The data collected by these sensors enables farmers to make informed decisions regarding irrigation schedules, fertilizer application, and pest management strategies. This precision-driven approach leads to optimized resource utilization [15, 16] and contributes to improved crop productivity and sustainability.
- **Logistics and Supply Chain:** IoDs, such as GPS trackers and telematics systems, are used to monitor the location, speed, and condition of vehicles in real-time. This enables fleet managers to optimize routes, improve fuel efficiency, and ensure the timely delivery of goods [27, 28]. IoT-enabled sensors and RFID tags allow for real-time tracking of inventory levels. This reduces the risk of stockouts or overstocking and ensures that products are available when needed.
- **Retail Customer Experience:** IoDs in retail stores can track customer movement and purchasing behavior, allowing businesses to personalize their marketing efforts and improve the overall shopping experience [29, 30]. Further, in smart shelves, IoT-enabled shelves can monitor stock levels and automatically reorder

products when inventory runs low, ensuring that shelves are always stocked and reducing out-of-stock situations.

- **Transportation and Mobility:** IoT enables vehicles to communicate with each other, as well as with traffic infrastructure, to improve road safety and traffic efficiency [13, 31]. For instance, vehicles can warn each other about hazards or accidents ahead, reducing the risk of collisions. IoT sensors, cameras, and data analytics power the development of autonomous vehicles, enabling them to navigate, detect obstacles, and make real-time decisions without human intervention.
- **Environmental Conservation:** IoT-enabled tracking devices monitor the movement and behavior of wildlife, helping conservationists track endangered species [32] and study their habits in their natural habitat. Moreover, IoT sensors are deployed in water bodies [33] to monitor parameters such as pH levels, temperature, and contamination. This real-time data helps ensure safe water quality and supports environmental protection efforts.

The diverse applications of IoT across various sectors such as smart cities, healthcare, agriculture, and industrial automation demonstrate the immense potential of IoT networks to transform industries and improve everyday life. However, the effectiveness of the IoT systems depends on the network's ability to reliably transmit data while managing constrained resources such as energy and bandwidth. As IoT networks continue to expand in scale and complexity, several technical challenges emerge that hinder their optimal performance and reliability. These challenges include energy-efficient data routing, managing node faults, coping with the dynamic nature of network topology, and maintaining low-latency communication. Addressing these issues is critical for ensuring that IoT systems deliver the expected benefits in real-world environments. The following section explores these core issues in depth, emphasizing their significance and providing the foundation for the research undertaken in this thesis.

1.2 Challenges

A fundamental aspect of IoT communication is data transmission, which can be achieved through direct or multi-hop routing. Direct transmission allows IoDs to send data directly to a central hub or cloud server, ensuring low latency and faster processing. However, this method consumes significant energy, making it unsuitable for battery-powered or resource-constrained devices. On the other hand, multi-hop routing enables data to be relayed through intermediate nodes before reaching the destination, effectively reducing energy consumption [34, 35, 36] while leading to poor quality of service (QoS), such as higher data latency, more data interference, low data throughput, inefficient bandwidth utilization, and reduced network lifetime due to non-uniform energy consumption over the network [37, 38]. These trade-offs highlight the need for optimized communication strategies in IoT environments. Apart from this, several critical challenges are associated with IoT networks. These include node faults, energy-efficient and QoS-aware data routing, dynamic network topologies, and the necessity for maintaining low path length with high clustering. The discussion below offers a deeper insight into these challenges, highlighting their impact on system performance and the motivation behind the solutions proposed in this thesis.

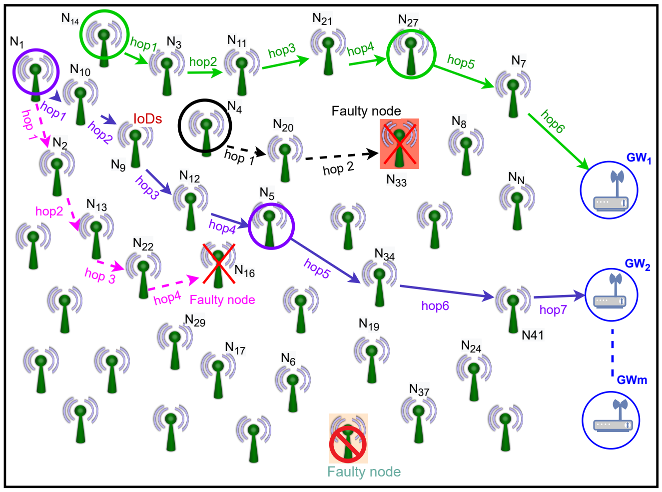


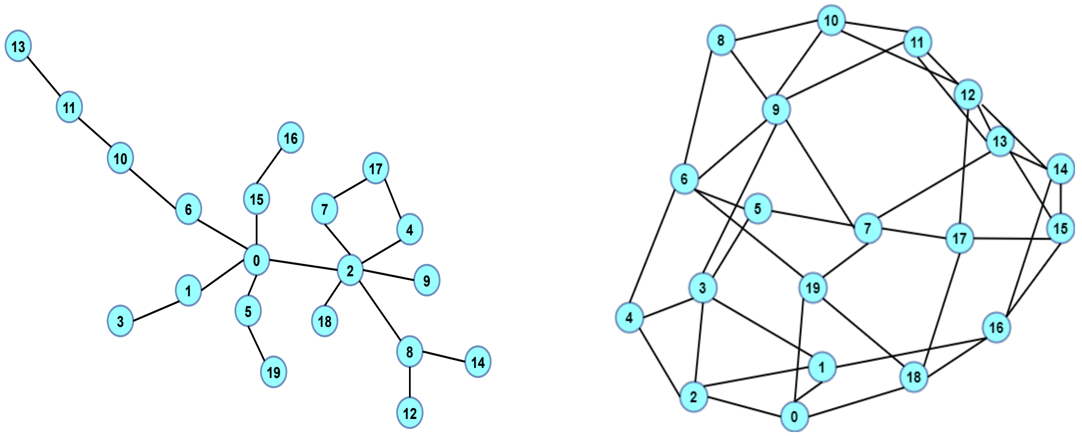
Figure 1.3: Illustration of multi-hop data routing in IoT networks with faulty nodes [2]

- **Node Faults in IoT Networks:** IoT networks rely heavily on sensor and actuator nodes that are often deployed in large numbers and in remote or harsh environments. These nodes are typically resource-constrained, with limited energy, processing power, and storage capacity. Over time, nodes may experience faults due to battery depletion, hardware failure, environmental interference, or software bugs. Faulty nodes can lead to inaccurate or missing data, broken communication paths, increased packet loss and retransmissions, and unnecessary energy consumption due to route rediscovery. As shown in Figure 1.3 [2], in large-scale IoT networks, data transmission often depends on multi-hop routing, where packets travel through multiple intermediate nodes before reaching their destination. Faulty devices can disrupt the network, causing congestion or packet collisions. This disruption not only affects the network's reliability but can also strain its available resources, including bandwidth and processing power. Detecting these faults early is essential to maintain network reliability and ensure that data reaches its intended destination without degradation in quality or delay.
- **Efficient Data Routing:** Routing data from sensor nodes to gateways or central servers is a fundamental operation in any IoT network. This process ensures that the information collected by distributed sensors reaches processing centers where it can be analyzed and acted upon. However, routing in IoT networks presents several significant challenges due to the unique characteristics and constraints of these systems. As shown in Figure 1.3, large-scale IoT deployments typically rely on multi-hop routing, where data packets are forwarded through multiple intermediate nodes before arriving at their final destination. While this approach extends network coverage and enables connectivity in environments where direct communication is not possible, it also introduces several drawbacks. Firstly, multi-hop routing increases communication latency, as each hop adds a delay while the packet is processed and transmitted. This delay can be particularly problematic

for time-sensitive applications such as healthcare monitoring or industrial automation, where decisions must be made rapidly and accurately. Additionally, multi-hop routing can cause network congestion and inefficient bandwidth utilization. As packets traverse shared communication channels, simultaneous transmissions by neighboring nodes may collide, leading to packet loss and the need for retransmissions. This further wastes energy and bandwidth resources while degrading overall network throughput and reliability. Given these challenges, it is crucial to design routing protocols that are both energy-efficient and adaptive to changing network conditions. Efficient routing can reduce unnecessary transmissions, balance the energy load among nodes, and optimize path selection to minimize latency and congestion. Adaptive protocols, on the other hand, can respond dynamically to network topology changes, node failures, or varying traffic demands to maintain consistent QoS.

- **Dynamic Nature of IoT Networks:** In many real-time IoT networks, devices referred to as IoDs frequently change their physical locations at distinct points in time. This mobility leads to the formation of time-varying IoT networks, where the connectivity between devices is not static but continuously evolving. Unlike traditional fixed networks, the network topology in time-varying IoT environments is dynamic, often changing rapidly due to the movement of devices. As a result, several challenges occur in time-varying IoT networks [39]. One significant challenge arises from the increased scale and density of IoDs in the network. As the number of devices grows, so does the volume of data they generate, which can quickly become overwhelming to manage and analyze effectively. Handling this massive influx of data requires scalable and efficient data aggregation and processing techniques, capable of extracting meaningful insights without overburdening network resources. Moreover, maintaining uninterrupted and energy-efficient data transmission is particularly difficult in such dynamic environments. Since

IoDs continuously change their locations, previously established communication links may break, requiring frequent route updates and rediscoveries. This constant adjustment can lead to increased latency, packet loss, and higher energy consumption—critical concerns for battery-powered IoDs deployed in remote or inaccessible areas [40]. The mobility of devices also raises issues related to network stability and QoS, as unpredictable topology changes can disrupt ongoing data flows and reduce reliability. To address these challenges, there is a pressing need to develop communication protocols that are both reliable and robust, specifically tailored for dynamic IoT networks.



(a) (b)

Figure 1.4: An IoT network (a) without small-world characteristic (b) with small-world characteristic, demonstrating efficient routing and connectivity with minimal hops

- **Network Path Length and Clustering Coefficient:** IoT networks demand low-latency data transmission to support timely and accurate decision-making, particularly in real-time applications such as healthcare monitoring, autonomous systems, industrial automation, and smart transportation [41]. In these scenarios, even minor delays in data delivery can compromise system performance, safety, or operational efficiency. As shown in Figure 1.4a, nodes are connected in a more linear or sparse fashion, with limited inter-connectivity between distant parts of the network. As a result, data packets must traverse a greater number of intermediate nodes to reach their destination, increasing the overall path length, latency, and energy consumption. This setup is less efficient and more prone to congestion, especially under high data loads or when nodes begin to fail. Therefore, minimizing communication delay is a fundamental requirement in the design of IoT architectures. To achieve this, short-range communication protocols such as Zigbee, BLE, or Wi-Fi Direct, which operate over limited distances with low transmission power, have emerged as a key strategy. By reducing the physical distance over which data must travel between nodes, short-range communication can significantly decrease transmission time, reduce the risk of packet loss, and lower energy consumption. These advantages contribute not only to reduced latency but also to improved reliability and efficiency in data exchange. Furthermore, short-range links support the formation of densely connected local clusters of nodes, which exhibit high clustering and shorter average path lengths—properties often associated with small-world networks. Such network structures are known to facilitate faster and more efficient routing, as data can traverse the network through fewer intermediate hops. As shown in Figure 1.4b, this characteristic enables better connectivity and optimized data routing with minimal delays. Incorporating small-world characteristics is therefore crucial for enabling responsive, energy-aware, and robust IoT systems. It allows for the creation of scalable and resilient network topologies that can maintain low-latency performance even as the number of devices and the complexity of interactions increase.

1.3 Motivation

The rapid expansion of the IoT has revolutionized numerous domains, including smart cities, healthcare, industry, and environmental monitoring. As IoT networks continue to scale in size and complexity, they face a growing number of challenges related to data transmission, energy efficiency, fault tolerance, and adaptability. These challenges are further compounded by the dynamic nature of IoT environments, where devices operate under severe resource constraints and often in unpredictable conditions. Ensuring reliable, timely, and efficient communication in such settings is critical for the success of real-time IoT applications. Addressing these critical challenges is what primarily motivates this research work. The aim is to explore and develop intelligent, adaptive mechanisms that can enhance routing efficiency, handle node faults proactively, and support robust performance in dynamic, large-scale IoT networks. Authors in [42] present a distance ring exponential generator-based framework for data routing for low power wide area network (LPWAN). A dynamic maximum connectivity distance that is allowed for maintaining the ubiquitous connectivity in the multi-hop network is proposed. Utilization of multi-hop and variable-hop frameworks yields improved energy saving for the critical IoD, resulting in high network connectivity. Yet, this method involves a recursive process until a final transmission distance is obtained, which increases the network overhead manifold. In [43], the authors investigate a novel dynamic routing algorithm based on energy-efficient relay selection (DRAEERS) that improves the network's energy efficiency. The paper validates the application of dynamic weight links and signifies that it leads to an optimal multi-hop route for data transmission. However, its computational complexity increases with network size, which may hinder scalability in large-scale deployments.

To address congestion and enhance reliability, a priority-based routing scheme [44] employs priority queue scheduling but requires further advancements in fault tolerance. The energy-efficient routing scheme proposed in [45] focuses on self-organizing networks in intelligent transportation systems. However, they have not integrated AI, machine learning, and edge computing for real-time decision-making. While these protocols offer significant improvements in energy efficiency and reliability, they all face drawbacks such as increased computational overhead, limited scalability, and implementation complexity, particularly in dynamic or large-scale network environments. In [46], authors proposed a relay node selection method that efficiently optimizes data latency and link reliability for time-varying IoT networks, outperforming single-objective approaches. However, its reliance on continuous connectivity updates may increase computational overhead, making real-time implementation challenging in large-scale networks. In [47], the proposed deep reinforcement learning-based routing scheme effectively enhances routing efficiency in dynamic networks by addressing multiple optimization objectives through model fusion. It demonstrates improved flexibility and adaptability compared to traditional routing strategies. However, its reliance on model convergence poses a challenge in highly dynamic environments, potentially leading to incorrect routing decisions. Additionally, the computational complexity of deep learning models may limit real-time deployment in large-scale networks. Authors in [48] proposed a Q-Learning-based routing method using a mobile sink (MS) for efficient data collection in WSN-based IoT networks. By optimizing cluster head selection and using single-hop transmissions, the routing method significantly improves energy efficiency and network lifetime. However, challenges like mobility constraints, environmental noise, and real-world scalability remain.

Detecting node faults in IoT networks presents significant challenges due to environmental constraints, as well as energy and resource limitations. Various approaches have been explored to address this issue. A neural network-based fault diagnosis protocol, described in [49], utilizes a particle swarm optimization-based fuzzy multilayer perceptron to handle multiple fault types, evaluating performance through metrics like detection accuracy and false alarm rates. However, it relies on predefined models or assumptions. An ML-based approach in [50], employs gradient boosting, extreme gradient boosting, and decision trees to automatically identify network failures. In contrast, [51] introduces an energy-efficient fault diagnosis technique using feed-forward neural networks, enabling sensor nodes to independently detect their fault status. However, its dependence on individual sensor nodes may limit performance in large-scale networks. For vehicular networks, [52] proposes the semi-supervised gated recurrent unit (SEMI-GRU) method for anomaly detection, combining data oversampling with semi-supervised learning to improve detection accuracy. However, the use of oversampling may introduce synthetic noise, potentially affecting detection accuracy. These limitations should be adequately addressed; otherwise, these limitations can significantly impair the overall performance and efficiency of the network. This underscores the need to design and develop novel routing techniques that effectively accommodate the dynamic requirements of IoT networks, thereby substantially enhancing overall network performance. The IoT networks have attracted attention due to their low installation cost, low maintenance costs, high flexibility, and a wide range of applications. Besides the advantages, the IoT networks are vulnerable to certain constraints that need to be addressed which is the prime focus of this thesis. Thus, to summarize, the key research areas of this thesis are:

- **Fault Prediction and Reliable Routing in Static Networks:** This work focuses on developing techniques to predict faulty nodes within static IoT networks and optimize the data routing process to maintain network performance, efficiency, and reliability. The goal is to minimize the impact of node failures on the network's operation while ensuring that data reaches its destination optimally.
- **Adaptive Routing in Dynamic Topologies:** It addresses the challenge of data routing efficiently in IoT networks where the topology is constantly changing. The research aims to develop routing protocols that can adapt to the dynamic nature of IoT networks while minimizing latency, energy consumption, and congestion, ensuring reliable communication even in highly mobile environments.
- **Integrated Fault-Tolerant Dynamic Routing:** This thesis aims to combine node fault prediction and optimal data routing in dynamic IoT networks. The goal is to create a unified approach that predicts and compensates for faulty nodes while simultaneously optimizing the routing strategy for real-time, energy-

efficient, and reliable data transmission.

- **Introduction of Small-World Characteristics:** It focuses on introducing small-world network characteristics in IoT networks by strategically placing long-range connections, this technique aims to improve the efficiency of data routing by reducing the average path length (APL) and enhancing the network's connectivity and robustness, while ensuring scalability. The small-world property can enhance network performance by minimizing the number of hops required for data transmission, improving both reliability and energy efficiency.
- **AI and ML-Driven Network Intelligence:** It enhances IoT network performance through AI and machine learning techniques, such as reinforcement learning or neural networks, to optimize routing decisions and fault management.

1.4 Objectives of the Thesis

The primary objective of this thesis is to develop intelligent, energy-efficient, and fault-tolerant data routing mechanisms for IoT networks operating in both static and dynamic environments. The design of data routing mechanisms for IoT networks presents several significant challenges, particularly in achieving seamless operation across varying deployment scenarios. These networks are often composed of resource-constrained devices that must function under strict energy limitations, making power-efficient communication a fundamental requirement. Moreover, IoT environments are inherently prone to faults due to node failures, unstable links, and unpredictable environmental conditions, which can severely disrupt data transmission. The situation becomes even more complex in dynamic settings, where frequent topological changes and varying node availability demand high adaptability and responsiveness from the routing protocols. Ensuring reliable, uninterrupted, and efficient data flow in the face of such constraints requires addressing a delicate balance between adaptability, resource management, and fault resilience. To solve the above mentioned problems, the following objectives are set for this thesis work.

1. **Objective 1:** To design and develop an integrated approach that simultaneously addresses node fault prediction and energy-efficient data routing in a static IoT network.

   Realized by: Energy-efficient and QoS-aware data routing in node fault prediction based IoT networks [2].

2. **Objective 2:** To design and develop adaptive and energy-efficient routing protocols for dynamic IoT environments to create routing strategies capable of responding to frequent changes in network topology.

   Realized by: OptRISQL algorithm: toward performance improvement of time-varying IoT networks using Q-learning [53].

3. **Objective 3:** To design and develop a unified framework for fault-tolerant and optimal data routing in dynamic networks.

   Realized by: An energy-aware and QoS-enhanced routing with node fault prediction for consumer IoT networks using ML frameworks [1].

4. **Objective 4:** To incorporate small-world characteristics in IoT networks by strategically adding long-range links to reduce average path length (APL) and maintaining high average clustering coefficient (ACC).

   Realized by: Node fault prediction assisted small-world IoT networks using ML frameworks: towards performance improvement [54].

1.5 Thesis Contributions

The key contributions of this thesis are presented as follows.

1. **Energy-Efficient and QoS-Aware Data Routing in Node Fault Prediction Based IoT Networks:** The first work of this thesis proposes a novel joint node fault prediction-based optimal data routing method for a static IoT network. The method utilizes a novel unsupervised learning-based local outlier factor

(LOF) method for predicting forthcoming faults. The method classifies the faulty state of a sensor node as an outlier when plotted with the normal state of the sensor node. Subsequently, a novel data routing method is proposed that utilizes a Q-learning framework towards multi-hop data routing. The Q-values decide the optimal routing path, where the data transmission path is altered based on predictions made on the faulty nodes. The performance of the proposed methods is evaluated over both simulated IoT testbeds and real-field datasets.

2. **OptRISQL: Toward Performance Improvement of Time-Varying IoT Networks Using Q-Learning:** The second work of this thesis considers a dynamic IoT network in which the devices select an optimal relay IoD at various discrete time instants to improve network performance. Thereafter, a novel reinforcement learning-based data routing algorithm in the time-varying multi-hop IoT network is proposed for optimum data routing. The proposed algorithm, *Opt*imal *R*elay *I*oD *S*election Using *Q-L*earning (OptRISQL), selects the optimum relay IoD for data routing using Q-learning. The proposed method maximizes the aggregate reward value between specified device-gateway pairs by adjusting the network's Q-matrix at discrete time instants to identify optimal relay IoD. The proposed method's applicability and effectiveness are demonstrated using a simulated IoT testbed and real-field datasets.
3. **Energy-Aware and QoS-Enhanced Routing With Node Fault Prediction for Consumer IoT Networks Using ML Frameworks:** The third work of this thesis presents a novel energy-efficient and QoS-aware data routing framework tailored for a dynamic IoT network, integrating advanced fault prediction capabilities. We introduce a novel fault prediction method using an long short term memory (LSTM)-based deep learning model and an adaptive routing strategy powered by actor-critic reinforcement learning. Validated through real-field IoT testbeds, our approach demonstrates improved performance and reliability, sur-

passing existing methods in medium- and large-scale networks. For instance, the proposed method maintains higher data throughput, longer lifetime, and higher residual energy.

4. **Node Fault Prediction Assisted Small-World IoT Networks Using ML Frameworks: Towards Performance Improvement:** The final contribution of this thesis is introducing the small-world characteristics (SWC) in an IoT network by strategic placement of long-range connections while maintaining low APL and high ACC and ensuring scalability and robustness. We introduce SWC into the network using an actor-critic reinforcement learning algorithm. Several data routing experiments have been conducted to validate the effectiveness of the proposed approach using simulated small-world IoT networks. We analyze major network parameters such as lifetime, latency, and throughput.

1.6 Thesis Organization

The organization of the thesis are as follows:

- **Chapter 2** presents the literature survey of the existing techniques in the related area, namely state-of-the-art data routing techniques for static and dynamic IoT networks, machine learning-based data routing techniques, enabling small-world characteristics in IoT networks, and fault detection techniques within IoT networks. This chapter provides an in-depth overview of related research and the challenges faced by IoT networks.
- **Chapter 3** introduces the proposed methodology for enhancing QoS and energy efficiency in IoT networks. It presents a novel fault prediction method using unsupervised learning (LOF) and an optimal data routing approach via Q-learning. The chapter discusses how these techniques improve network performance by avoiding faulty nodes and optimizing data transmission. It also outlines the evaluation of the proposed methods using both simulated and real-field IoT testbeds.

The results are compared with existing approaches, demonstrating the effectiveness of the proposed solution.

- **Chapter 4** presents a novel approach for optimal data routing in time-varying IoT networks. It introduces a reinforcement learning-based algorithm, OptRISQL, for selecting the best relay IoD at discrete time instants to improve network performance. The method uses Q-learning to optimize data routing, minimizing hops, transmission delay, and interference while enhancing energy efficiency and QoS. The chapter highlights the algorithm's effectiveness through simulation and real-field IoT testbed evaluations, comparing it to existing methods. Results demonstrate the proposed method's superior performance in real-time, large-scale IoT applications.
- **Chapter 5** introduces an energy-aware and QoS-enhanced data routing framework for dynamic consumer IoT networks, integrating advanced fault prediction using the auto-encoder anomaly detection with fuzzy (ADF) framework. It proposes an adaptive routing strategy powered by actor-critic reinforcement learning to optimize routing decisions while predicting and managing node faults in real time. The approach is validated through simulations and real-field IoT datasets, demonstrating significant improvements in data throughput, latency reduction, and network lifetime compared to existing methods. The chapter highlights the novel integration of fault prediction with adaptive data routing to ensure reliable communication and energy efficiency in large-scale IoT applications.
- **Chapter 6** introduces a novel approach for optimizing data routing in small-world IoT networks by incorporating SWC using an actor-critic reinforcement learning algorithm. It proposes a joint method for dynamic node fault prediction and data routing, enhancing network performance by improving reliability, reducing latency, and increasing throughput. The chapter presents a comparative analysis of fault prediction models, including density based spatial clustering (DBSCAN),

and evaluates the proposed method through simulations. Results demonstrate that the proposed approach significantly outperforms existing methods, offering improved network lifetime and performance in large-scale IoT networks.

- **Chapter 7** presents a summary of all thesis contributions and concludes this thesis. The chapter also provides future directions for research that would help researchers in the field of intelligent node fault prediction and route optimization mechanisms for IoT networks.