

Abstract

The Internet of Things (IoT) has rapidly gained importance due to its ability to connect devices, enabling automation and intelligent decision-making across various domains, including healthcare, industrial automation, agriculture, smart cities, and logistics, among others. Despite its immense potential, the deployment and maintenance of IoT networks are accompanied by a range of critical challenges that restrict their efficiency, scalability, and reliability. One of the foremost challenges lies in ensuring efficient and reliable data routing, especially as the number of interconnected devices continues to grow. The dynamic nature of IoT networks, where nodes may frequently join or leave the network, and where the topology can change due to mobility or environmental factors, complicates the task of establishing optimal routing paths. Additionally, IoT devices (IoDs) are typically resource-constrained in terms of energy, processing power, and memory. Therefore, energy efficiency becomes a crucial requirement to prolong network lifetime and ensure sustainable operation. Another significant issue is the prediction and management of node faults. Due to harsh environmental conditions, hardware limitations, or battery depletion, nodes in an IoT network may fail unexpectedly, leading to data loss, communication breakdowns, and reduced quality of service (QoS). Designing systems that can proactively detect or predict such failures and adapt routing strategies accordingly is essential for maintaining robust and fault-tolerant networks.

While significant progress has been made in the field of IoT, with numerous studies addressing several aspects such as data routing, energy efficiency, and fault tolerance,

several critical challenges still remain unresolved. Existing research has proposed valuable techniques for optimizing data transmission and predicting node failures; however, these solutions often fall short when applied to large-scale dynamic environments. Many approaches either lack adaptability to frequently changing topologies or do not adequately balance the trade-offs between energy consumption, delay, and throughput. Moreover, fault prediction mechanisms in current literature may rely heavily on static assumptions or fail to integrate with real-time routing strategies, limiting their practical effectiveness. This thesis aims to bridge these gaps by developing novel models and algorithms that jointly optimize routing and fault management, taking into account both static and dynamic IoT topologies, and striving for improved scalability, robustness, and performance. This thesis makes four key contributions to the state of the art in IoT networks.

The first contribution of this thesis is in the development of a novel fault-aware routing approach for static networks. It uses the local outlier factor (LOF) to detect potentially faulty nodes via unsupervised learning and employs a Q-learning framework for optimal multi-hop routing that avoids predicted failures. The method is validated on simulated and real-world IoT testbeds. The results are obtained in terms of accuracy, precision, and recall values concerning the node fault prediction. While the throughput ratio, average data latency, network lifetime, residual energy, and standard deviation of the energy consumed are analyzed to measure the effectiveness of the proposed data routing method. The performance of the proposed methods is also compared with existing methods, validating the effectiveness of the proposed methods.

The second contribution of this thesis focuses on dynamic IoT networks. It presents *optimal relay IoD* selection using *q-learning* (OptRISQL), a novel Q-learning based routing algorithm that selects optimal relay nodes at discrete time intervals, maximizing aggregate rewards between device-gateway pairs by adjusting the network's Q-matrix. The performance of the proposed method is evaluated on simulated environments and

real-field dataset. Moreover, when compared to various existing methods, the acquired findings indicate the proposed method's improved network performance in terms of energy efficiency and QoS.

The third contribution of this thesis is the development of a novel energy-efficient and QoS-aware data routing framework designed for dynamic IoT networks, incorporating advanced fault prediction capabilities. The proposed approach combines a fault prediction method based on a long short term memory (LSTM) deep learning model with an adaptive routing strategy driven by actor-critic reinforcement learning. This integration enables real-time, adaptive routing that improves data throughput, energy use, and network reliability in dynamic settings.

The fourth contribution of this thesis is the introduction of small-world characteristics (SWC) into IoT networks by strategically adding long-range connections, aiming to maintain a low average path length (APL) and high average clustering coefficient (ACC). An actor-critic reinforcement algorithm selects these links to maintain a low APL and high ACC, improving latency, throughput, and scalability in simulated IoT scenarios.

These works make substantial contributions to advancing IoT networks by addressing critical issues related to energy efficiency, data routing, and fault management, ultimately improving the robustness and efficiency of IoT systems in real-time and large-scale applications. We have performed extensive simulations and real-field testbed experiments of our proposed methods and compared the results with existing state-of-the-art algorithms. The simulation and testbed results show that the proposed methods outperform existing state-of-the-art approaches in terms of network lifetime, delay, energy consumption, and throughput, among other parameters.