Chapter 8

Conclusion and Future Scope

This chapter provides an overall conclusion of the thesis and offers suggestions for further research. It also outlines key directions for investigation that will assist researchers in the field of IoT-enabled WSNs.

8.1 Conclusion

The Internet of Things (IoT) is an advancing technology that profoundly influences the social, economic, and technical aspects of our lives. IoT applications like e-healthcare, agriculture, transportation, Industry 4.0, and environmental monitoring have significantly transformed our lifestyles. In these applications, continuous monitoring of physical objects generates huge amounts of heterogeneous data that need to be collected efficiently for further processing and decision-making. The large number of sensor nodes that are used to collect heterogeneous data from physical objects creates several challenges during the data collection process. This requires intelligent data-gathering mechanisms to ensure high network performance within IoT-enabled Wireless Sensor Networks (WSNs). This thesis presents a concise review of the challenges faced by IoT-enabled WSNs, including limited battery life, the energy hole problem, obstacle avoidance issues, and network partitioning. Furthermore, research gaps are identified accordingly. Based on identified research gaps, this thesis presents some research objectives designed to address the challenges faced by IoT-enabled WSNs. The thesis also describes objective wise research contributions to fill the identified research gaps. Extensive simulations and testbed experiments have been performed on the proposed approaches. Simulation and testbed results show the proposed approaches outperform as compared to the existing state-of-the-art algorithms. The research conducted in this thesis can be summarized as follows:

- An MOGWO-based intelligent data routing scheme for homogeneous IoT-enabled WSNs has been proposed in Chapter 3. The proposed approach includes a novel clustering mechanism where the transmission distance, hop counts, and distance among nodes are considered for energy balancing between the deployed nodes. In the proposed scheme, RPs selection and rotation are done to prevent premature death of the network. The parameters like network lifetime and energy consumption rate are considered for MS-based data routing, showing significant improvement in network performance. The simulation results show that the proposed approach outperforms the existing state-of-the-art approaches, such as WRP, DC-ACO, MOPSO, and EAPC and significantly increases network lifetime. The proposed scheme can be applied for healthcare, smart city, livestock monitoring, and home automation.

- A deep policy dynamic programming-based intelligent data routing scheme for IoT-enabled WSNs has been proposed in Chapter 4. The EERPS algorithm is used to select the optimal CHs as well as the optimal number of RPs. The cluster formation and CHs selection are done based on the capacities of the SNs. It significantly reduces the overall energy consumption of the network. The proposed algorithm selects energy-efficient CHs and reduces the hops between SNs and CHs. It helps to prevent extensive battery drain of SNs due to communication overload. It also prevents premature death of the network. Furthermore, optimal numbers of RPs are used for the MS-based data collection. The DPDP algorithm is used to design an optimal data collection path for MS. Simulation, and testbed experiments prove that the EERPS-DPDP scheme outperforms the existing state-of-the-art approaches. The EERPS-DPDP scheme increases the network stability period by 56% than GA-SMT, 44% than TEO-MCRP, 38% than EDEDA, and 29% than IRDA. The EEERPS-DPDP scheme improves network lifetime by 54% than GA-SMT, 42% than TEO-MCRP, 37% than EDEDA, and 32% than IRDA. The stability period and high network lifetime indicate that the proposed EERPS-DPDP scheme is more effective for preventing the early death of nodes within the network. It also prevents the network segmentation. The EERPS-DPDP scheme reduces energy consumption by 55% than GA-SMT, 46% than TEO-MCRP, 35% than EDEDA, and 31% than IRDA. The EERPS-DPDP scheme decreases the data loss by 53% than GA-SMT, 42% than TEO-MCRP, 35% than EDEDA, and 32% than IRDA. Furthermore, the EERPSDPDP scheme reduces the data collection delay by 53% than GA-SMT, 46% than TEO-MCRP, 38% than EDEDA, and 31% than IRDA. The EERPS-DPDP scheme can be applied in the healthcare industry, industrial automation, home automation, and smart cities.

- An MS-based optimal obstacle-aware energy-efficient data routing scheme for IIoT-enabled WSNs has been proposed in Chapter 5. It uses the MRFO algorithm to identify the optimal RPs and create optimal clusters within the network. An EBS-A* algorithm is used to develop a smooth obstacle-avoiding optimal data-gathering path for MS. The proposed scheme keeps a safe distance between the designed path and obstacles, which reduces the risk of MS collision with obstacles. It also designs a smooth path that enables smooth MS movement in the network. It significantly improves the network performance in terms of residual energy, stability period, network lifetime, data gathering delay, and MS safety assessment.

The proposed scheme is lightweight as compared to existing approaches and easily implementable in resource-constrained WSNs. The simulation and testbed results indicate that the proposed scheme outperforms as compared to the existing state-of-the-art algorithms. The proposed approach is applied to develop an obstacle-aware data routing scheme for industrial safety and machine monitoring in the chemical industry. The proposed approach is applicable in both indoor and outdoor scenarios. Furthermore, the proposed approach can be applied in various areas such as healthcare, agriculture, smart cities, home automation, the manufacturing industry, and livestock monitoring.

- An MDC-based novel network cut detection algorithm and network recovery algorithm have been proposed in Chapter 6. The proposed algorithms identify the network cut and enable the recovery of isolated segments in WSNs. Furthermore, this chapter proposes an RLBSO algorithm to identify optimal RPs and design the optimal data collection tours for MDC. The proposed approach minimizes the path length for MDC which reduces the data collection delay. The proposed approach also minimizes the energy consumption of sensor nodes, which enhances network lifetime. The proposed approach significantly improves the network performance in terms of network lifetime, data collection ratio, energy consumption, and latency. The simulation and testbed results show that the proposed approach performs better as compared to the existing state-of-the-art approaches. The proposed approach is applicable in various areas, such as smart cities, environmental monitoring, and livestock monitoring.

- An intelligent indoor fire emergency evacuation system using IoT-enabled WSNs for smart buildings has been proposed in Chapter 7. The proposed algorithm performs competently in all types of scenarios by planning an optimal evacuation path for trapped individuals. The selected path is safe in current and future fire scenarios. Therefore, the proposed DESSN algorithm significantly reduces large detours, backtracking, panic, and casualties/deaths. The simulation results show the proposed algorithm's effectiveness in planning a shortest-safe path by anticipating future fire scenarios.

8.2 Scope for future work

Research is an iterative and ongoing process. This thesis focuses on addressing the challenges faced by IoT-enabled WSNs. The goal is to develop intelligent data-gathering techniques that improve the effectiveness of these networks and align with the demands of the current IoT technology. There are numerous avenues for further exploration. Here are some suggestions for future work in this area:

- In the future, an attempt will be made to enhance the reliability of the proposed scheme with a node and communication fault detection approach.
- To improve energy efficiency, data compression and prediction-based data reduction during the MS-based data collection can be taken into account.
- In the future, multiple MS for data collection with varying MS movement speeds can be taken into account to enhance network performance.
- Future work can also explore data collection using MSs, which have limited buffer space and battery capacity.
- Furthermore, future works can also incorporate dynamic obstacle avoidance in the data collection path design for MS.
- Additionally, faulty node localization and recovery with a proper congestion control mechanism will also be considered in future works.
- In the future, the proposed indoor fire emergency evacuation system can be extended for other types of emergencies like earthquakes and citizens' rescue in a war zone.