Minimising Energy Consumption in WSN-IoT Networks by Focusing on Quality of Service

Anuradha, Tarun Gulati, Rajbhupinder Kaur, Zatin Gupta, Amit Kumar Bindal and Garima Singh

1Department of Electronics and Communication Engineering, Maharishi Markandeshwar Engineering College, Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana, India
2Department of Engineering, Guru Kashi University, Talwandi Sabo, Punjab, India
3Department of Computer Science and Engineering, Sharda University, Greater Noida, Uttar Pradesh, India
4Department of Computer Science and Engineering, Maharishi Markandeshwar Engineering College, Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana, India
5Department of Computer Science and Information Technology, KIET Group of Institutions, Ghaziabad, Uttar Pradesh, India

Abstract: IoT networks are low-powered networks and resource allocation and efficient utilization are critical concerns. Network resources are allocated to the intermediate nodes to perform the various operations (sense, transmit, re-transmit, data aggregation, etc.). These operations are managed by the different layers (M.A.C., routing and PHY). Each layer consumes resources W.R.T. their operations and there is a need to manage the resource consumption W.R.T. the individual layer. Due to bit error rate and signal-to-noise ratio factors, the transmission of the network may be degraded and there is a need to ensure the transmission quality under these constraints. In this study, an energy-efficient scheme for IoT networks will be proposed to resolve the discussed factors and its performance will be analyzed with LoRaWAN/SigFox using various QoS parameters (throughput, residual energy, bit error rate etc.).

Keywords: Internet of Things, Energy Consumption, Resource Optimization, Wireless Sensor Network, Quality of Service

Introduction

IoT networks are capable of transmitting data over long distances. Still, the quality of transmission may be affected due to various factors, i.e., environmental conditions, distributed coverage area, data exchange between heterogeneous end devices, and other obstacles, i.e., buildings, etc., and bit error rate and signal-to-noise ratio, both of which are critical QoS constraints that can directly degrade the overall quality of transmission as well as retransmission, which may consume excessive resources. The metrics of the QoS constraints in IoT networks (Pahuja and Kumar, 2023).

Figure 1 shows the QoS constraints for the application layer. It ensures that high-quality data is delivered to end users with optimal service costs, including payload, availability, priority, etc.

Figure 2 shows the QoS constraints for the network layer. It ensures that data must be transmitted over a heterogeneous environment with minimal delay/jitter and should use the optimal network resources (Bishoyi et al., 2021; Pradhan et al., 2023).

Fig. 1: Qos constraints for the application layer
As shown in Fig. 3, the reception layer ensures reliable packet transmission/retransmission over the network with optimal packet loss. IoT networks may use different routing and communication strategies and the factors mentioned above may vary. It is also quite complex to manage these factors with individual standards. All these factors also affect the overall network performance and network lifespan may be degraded due to excessive resource consumption. This study will present a QoS-enabled solution to ensure reliable communication over IoT networks (Suresh and Prasad, 2023; Ahmed et al., 2020; Seyyedabbasi et al., 2023; Rani and Sankar, 2023; Mokabberi et al., 2023).

**Literature Survey**

Sheth et al. (2021) introduced a routing method to improve resource consumption over WSN-IoT networks. It uses a heuristic algorithm to select intermediate nodes with higher energy levels for optimal routing paths. Outcomes show its performance in terms of extended network life span w.r.t. battery consumption.

Lu et al. (2022) developed an energy-efficient scheduler for WSN-IoT. It estimates the slots for data transmission based on different parameters (e.g., residual energy, distance from cluster head, burst cycle, etc.). Experiments show that optimal slot adjustment may reduce energy consumption compared to traditional schedulers.

Shreyas et al. (2022) proposed a scheduler to regulate the transmission duty cycle for WSN-IoT networks. It periodically shuffles the node's states (sleep and awake) W.R.T. residual energy. Outcomes show that it can improve the network efficiency/lifespan under energy constraints.

Jeevanantham and Rebekka (2022) integrated fuzzy logic with a WSN-IoT network that builds a training model by selecting the shortest routes. Analysis shows that its performance depends on the accuracy of the training model. However, it can optimize energy consumption as well as transmission quality.

Devassy et al. (2022) extended the cluster head selection method by integrating a swarm intelligence technique. It also uses a fusion algorithm to select optimal routes between intermediate nodes and the base station to minimize resource consumption. Outcomes show its performance in terms of extended network life span/optimal energy consumption, etc.

Raj Kumar and Bala (2022) used an ant colony approach to select optimal routing paths by estimating different parameters (i.e., channel condition/route cost/sensors health, etc.). Simulation shows that it can enhance the network performance, but its energy consumption varies W.R.T. location/distance of intermediate nodes/base station.

Manda and Singh (2023) proposed a routing method for WSN-IoT that builds routing strategies by estimating link quality/residual energy of nodes/trust level, etc. Simulation shows that its performance depends on the optimal selection of the factors mentioned above and network efficiency can be achieved with higher trust values v/s minimum delay factor.

Mnasri and Alrashidi (2022) used a genetic method-based routing solution. It estimates the local routes between intermediate nodes and gateways using current congestion level/residual energy/link quality, etc. Simulation shows that it outperforms optimal energy consumption/network life span. However, its performance varies over a scalable network.

Bedi et al. (2023) investigated the issues that can degrade the performance of IoT networks. The study found that energy consumption depends on different factors, i.e., routing strategies, Gateway or cluster head selection, duty cycle rate, distance of nodes from the base station, etc. Analysis data can be further utilized to develop optimal energy solutions for WSN-IoT.

Bomgni et al. (2022) developed a routing scheme for WSN-IoT that regulates the awake and sleep rates for nodes and builds the routing paths accordingly. Analysis shows that it can frequently conserve residual energy by switching the node's state, thus extending the overall network life span.
Seyyedabassi et al. (2023) proposed an energy-efficient routing solution for IoT networks that builds the routing data using different parameters (e.g., number of hops, distance, buffer size, payload, residual energy). Experiments show that it offers minimal routing load, energy consumption with a higher throughput, packet delivery ratio.

Kumar and Hariran (2022) developed a global routing solution for IoT networks that selects the next hop using a greedy approach and collects the data using mobile sinks. It delivers higher throughput using optimal resource consumption compared to traditional greedy approaches.

Kumar and Majid (2022) designed a hardware-based filter that can minimize the impact of noise on signal quality. Analysis shows that it can optimize transmission delay, error rate, latency, etc. However, its accuracy varies with filter density.

Uthayakumar et al. (2023) used onboard capacitors to meet the energy requirements of WSN-IoT. For data transmission, it forms clusters by selecting the sensors with higher residual energy. Analysis shows that it can improve the overall network lifespan compared to traditional energy sources.

Shukla and Tripathi (2020) proposed a routing method for WSN-IoT networks that selects relay nodes based on shortest paths, higher residual energy for data transmissions. Performance comparison with traditional routing methods shows that it consumes fewer resources, thus resulting in an extended network life span.

Singh et al. (2020) presented an energy harvesting solution for WSN-IoT. It estimates the current energy drain w.r.t. requirement and initiates the harvesting process accordingly. Analysis shows that it can efficiently fulfill the energy requirements over scalable IoT networks.

Ali et al. (2021) investigated the resource consumption ratio using IoT-enabled consumer devices in smart cities. The study found that energy consumption depends on different parameters (e.g., the number of computations performed, hardware design, processor types, payload, etc.). Analytical data can be used to develop energy-efficient solutions for IoT-based networks.

Jain and Agrawal (2020) modified the LEACH protocol for WSN-IoT networks. It forms a cluster with higher residual energy and an acceptable resource consumption threshold. It also maintains a cache to minimize the transmission delay. Analysis shows that the cache can deliver data on a priority basis and consume less energy than the traditional LEACH protocol.

Dowlatalshahi et al. (2021) developed a scheduler for WSN-IoT networks over smart cities. It estimates the transmission requirement w.r.t. coverage area and available sensors and finally, it subdivides the coverage area and builds a sleep/wake cycle for each sensor accordingly. Experiments show that it outperforms energy consumption/delay compared to the existing heuristic approach.

Yang et al. (2022) integrated a lightweight security provision for WSN-IoT. It uses session keys between intermediate sensors/gateways and base stations. Simulation shows that it consumes fewer resources than existing security provisions.

Weather, water level, irrigation requirements, plant disease growth, health status, temperature, humidity, and more can be accessed in real-time through the Internet of Things (IoT), as stated by Gupta et al. (2023) environmental factors and operational areas (rural, urban, underwater) affect the performance of IoT networks. These limitations might reduce transmission quality because of delay factors caused by variations in signal propagation. Distances can be covered by low-powered Internet of Things sensors. Packet loss, congestion, collision, and needless retransmission over network resources can result from transmissions that are slowed down by the delay factor. To address the transmission delay problem, this research will present a delay-aware scheme for managing uncertainty across urban and rural IoT networks. We will test its performance under various quality of service constraints (throughput, delay, residual energy, energy consumption, etc.), using 100-400 IoT sensors, LoRaWAN, and Sigfox.

Connected agricultural systems are enhanced by Gupta et al. (2023b). The farm’s coverage area, location (on land or in the water), environmental factors and other factors can all deteriorate IoT networks. Network operations in heterogeneous environments can reduce the lifespan of IoT sensors and waste resources. This study presents a smart farming method that optimizes energy consumption and analyzes its performance using two Internet of Things (IoT) standards: LoRa and SigFox.

Technologies created by Gupta et al. (2023c) have been useful to various businesses, though to different extents. Internet of Things (IoT)-based crop production technologies have helped other sectors, including agriculture. This review article tries to demonstrate the impact of the Internet of Things on intelligent farming. This study will summarise smart agricultural systems that rely on the Internet of Things. New systems were recently created. To get to these conclusions, the study paper covered intelligent agriculture and the advantages of IoT technology. The Internet of Things was also covered in a review article. Issues with price, power usage and lack of understanding limit the application’s potential. Smart agriculture requirements can be more easily discussed using secondary qualitative methods. Expertise in Internet of Things (IoT) systems for smart farming is presented in this article.

High-quality, efficient and cost-effective production requires Industry 4.0, IoT and smart manufacturing, as shown by Zaidi et al. (2023). Unevenly distributed edge service providers can negatively impact the performance of IoT systems. To solve this problem, we offer a Digital Twin (DT) optimized embedded system for smart manufacturing and edge intelligence. Cooperatively
optimizing multidimensional resource allocation including computing, caching and bandwidth while considering maximum delay is the goal of our approach, which employs DT-assisted alliance game resource optimization. A convex optimization problem with linear constraints is used to maximize edge terminal utility and E.S.P. An approximation of the optimal solution is produced by an alternating iterative method. The simulation results demonstrate a significantly higher efficiency in resource utilization compared to the large coalition and Nash equilibrium states. As the number of E.S.P.s increases, the suggested scheme becomes even more advantageous for smart manufacturing systems and large-scale edge intelligence.

According to Gupta and Bindal (2022), the need for agricultural modernization and intensification has grown due to increased quantity and quality of food. Innovative farming concepts are emerging because of the IoT. Internet of Things (IoT) solutions and products are being developed by researchers to tackle agricultural issues. The literature on Internet of Things (IoT) technologies and their agricultural applications is reviewed in this study. This study's scholarly articles came from official journals published in the last ten years. Classifications have been established based on carefully chosen papers. The primary objective of the inquiry is to collect research on various community types, verbal exchange protocols, sensors/devices and Internet of Things (IoT) agricultural applications. Furthermore, it delves into the most significant challenges and issues in the farming sector.

**QoS-aware Energy Efficient Communication**

Following are the steps of the QoS aware energy Efficient Communication (QEC) scheme:

**Transmission Success Rate T.S.R.**

**Packet Success Rate P.S.R.**

Step 1: Initialize IoT-WSN network
Step 2: Initialize error model
Step 3: Set propagation model
Step 4: (a) Estimate the average distance between Intermediate nodes and Gateway
(b) if distance <= threshold, then join (member, Gateway, True)
Else
join (member, Gateway, false)
Step4: Set initial BER/SNR
Step5: (a) Start the current transmission cycle estimate BER/SNR for member nodes and Gateway
TSR= current packet stream ^ (default BER - current BER)
(b) if TSR>Threshold then PSR++
start transmission
else
terminate the current transmission cycle

**Flow Chart 1: QEC scheme**

Step 6: Repeat the above steps as required

Flow chart 1 shows the basic steps of the QEC scheme used with LoRaWAN and SigFox. In step 1, the IoT-WSN network is initialized and in steps 2 and 3, the error model and delayed propagation model are both initialized. In step 4, first, the average distance between intermediate nodes and gateways is estimated and if it is within the threshold limit, only the intermediate node can join the current gateway. After joining, in step 4, BER and SNR are initialized and the current transmission cycle is started. In the next step, the current BER/SNR for member nodes and gateway are estimated and the transmission success rate is calculated. If it is higher than the threshold, data exchange is allowed; otherwise, the intermediate nodes' current transmission cycle is terminated.
Materials and Methods

This study introduces a delay-aware scheme for delay-optimized smart farming using a simulator called NS-3. The simulation-based methodology used in the present study computes the network performance parameters like delay, throughput, energy consumption, residual energy, etc. We have implemented two distinct Internet of Things communication standards (LoRaWAN and SigFox).

Results

Network simulator version-3 (NS-3) is used for analysis and the simulation interval is 600 sec. Sensor nodes vary from 100-400, Rx/TX is 10 and initial energy is 10J. IoT standards are LoRaWAN and SigFox. The simulation scenarios are QEC-LoRaWAN, QEC-SigFox (with the proposed scheme) and LoRaWAN and SigFox (without the proposed scheme). The platform is Linux.

Performance Analysis of QEC-LoRaWAN and LoRaWAN

Figure 4 shows the throughput of two IoT standards, LoRaWAN and QEC-LoRaWAN. Under the constraint of sensor density, QEC-LoRaWAN delivered a higher throughput than LoRaWAN. As the sensor density varied from 100-400 the network’s throughput increased using QEC-LoRaWAN compared to LoRaWAN.

Figure 5 shows the residual energy of two IoT standards, QEC-LoRaWAN and LoRaWAN. It can be observed that QEC-LoRaWAN maintained a higher residual energy level with minimal node density than LoRaWAN. However, it slightly declined as the sensor density varied from 100-400 nodes and with the highest sensor density, it was reduced to its minimal level for both IoT standards.

Figure 6 shows the bit error rate of two IoT standards, QEC-LoRaWAN and LoRaWAN. It can be observed that QEC-LoRaWAN supported a moderate bit error rate with the highest sensor density compared to LoRaWAN. However, it slightly declined as the sensor density varied from 100-400 nodes and with the highest sensor density, it was reduced to its minimal level for both IoT standards.

Performance Analysis of QEC-SigFox and SigFox

Figure 7 shows the throughput of SigFox and QEC-SigFox. Under the constraint of sensor density, QEC-SigFox delivered a higher throughput than SigFox. As the sensor density varied from 100-400, the network’s throughput increased using QEC-SigFox compared to SigFox.
Figure 8 shows the residual energy of QEC-SigFox and SigFox. It can be observed that QEC-SigFox retained a higher level of residual energy with minimal node density than SigFox. However, it slightly declined as the sensor density varied from 100-400 nodes and with the highest sensor density, it was reduced up to its minimal level for both schemes.

Figure 9 shows the bit error rate of QEC-SigFox and SigFox. It can be observed that QEC-SigFox maintained a reasonable level of bit error rate with peak sensor density compared to SigFox. However, it declined marginally as the sensor density varied from 100-400 nodes and with the highest sensor density, it was reduced to its lowest level for both schemes.

Comparison of QEC-LoRaWAN and QEC-SigFox

Figure 10 shows the Throughput comparison of the QEC-LoRaWAN and QEC-Sigfox schemes. Under the constraints of sensor density variations, QEC-LoRaWAN offered higher throughput than QEC-SigFox.

Figure 11 shows the bit error rate comparison of QEC-LoRaWAN and QEC-Sigfox schemes. Under the constraints of sensor density variations, it is higher for QEC-SigFox than for QEC-LoRaWAN. However, it is reduced to its lowest level regarding minimal sensor density.

Figure 12 shows the residual energy comparison of the QEC-LoRaWAN and QEC-Sigfox schemes. Under the constraints of sensor density variations, it is higher for QEC-LoRaWAN than for QEC-SigFox. However, it is reduced to its lowest level relative to the highest sensor density for both schemes.

Discussion

After comparing it to LoRaWAN and Sigfox, the study proposes a method for measuring the bit error rate/signal-to-noise ratio in IoT standards. In comparison to LoRaWAN, QEC-LoRaWAN achieves better throughput and optimal residual energy. With QEC-LoRaWAN, transmission quality is maintained even when the network is not scalable. A comparison of the performance of QEC-LoRaWAN and QEC-Sigfox with that of regular LoRaWAN and Sigfox is also presented in the research. Other Internet of Things (IoT) standards are likely to adopt the suggested approach to guarantee service quality as well.

Conclusion

The study presents a proposed scheme for estimating bit error rate/signal-to-noise ratio in IoT standards, comparing it with LoRaWAN and Sigfox. The results show that QEC-LoRaWAN outperforms LoRaWAN in terms of optimal residual energy and higher throughput. Despite the limitations of a scalable network, QEC-LoRaWAN maintains quality transmission. The research also introduces the concept of QEC-LoRaWAN and QEC-Sigfox, comparing their performance with traditional LoRaWAN and Sigfox. The proposed method is expected to be implemented for other IoT standards to ensure service quality.
Acknowledgement

We would also like to thank the Head of the CSE Department, Dr. Sandeep Goyal, at MMEC, MMDU, for their continuous support & feedback throughout the research process. We would like to thank Dr. Neeraj Mangla and Dr. Neeraj Raheja for their valuable insights and suggestions.

Funding Information

All co-authors approved the manuscript, and no competing financial interests exist.

Author’s Contributions

Anuradha and Amit Kumar Bindal: All experiments coordination, data collection, implementation, analysis, and results.

Tarun Gulati and Zatin Gupta: Manuscript proofreading, edited, correction.

Rajbhupinder Kaur and Garima Singh: Grammar and paper flow.

Ethics

It should be noted that the authors have no conflict of interest. All co-authors have read and approved the manuscript, and no competing financial interests exist. We confirm that the submission is not currently being considered for publication anywhere else.

References


