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

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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).

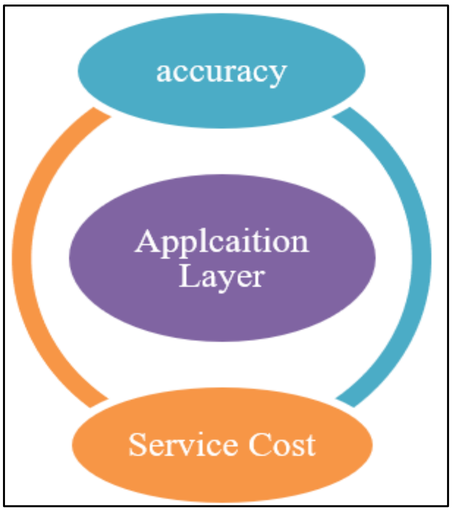

Fig. 1: Qos constraints for the application layer

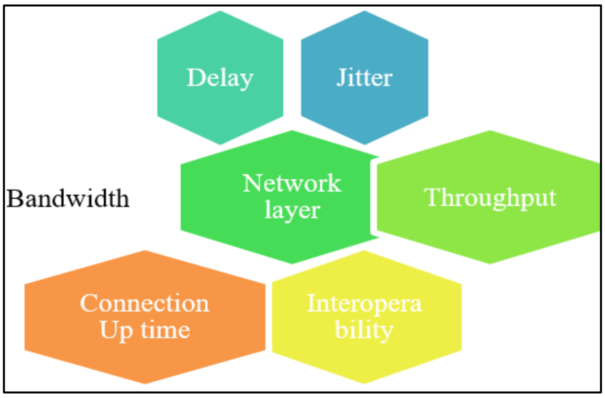

Fig. 2: Qos constraints for network layer

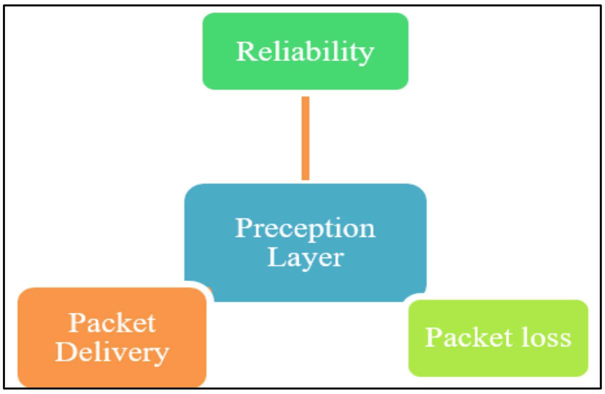

Fig. 3: Qos constraints for the perception layer

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.

Seyyedabbasi *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 Hariharan (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 data cache to minimize the transmission delay. Analysis shows that the data cache can deliver data on a priority basis and consume less energy than the traditional LEACH protocol.

Dowlatshahi *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/awake 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*. (2023a) 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, IIoT and smart manufacturing, as shown by Zaidi *et al*. (2023). Unevenly distributed edge service providers can negatively impact the performance of IIoT 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
Step 6: Repeat the above steps as required
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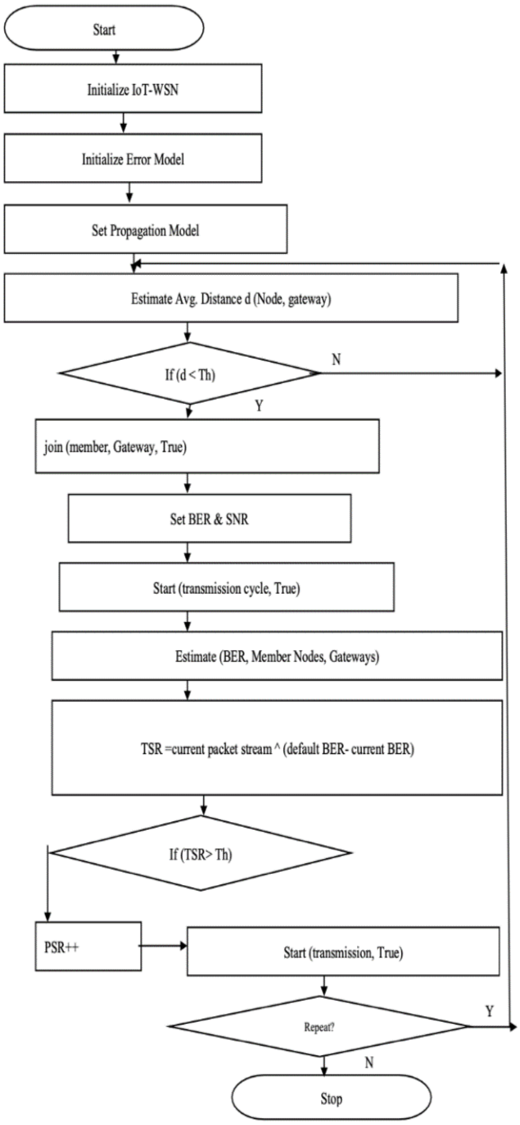

Flow Chart 1: QEC scheme

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.

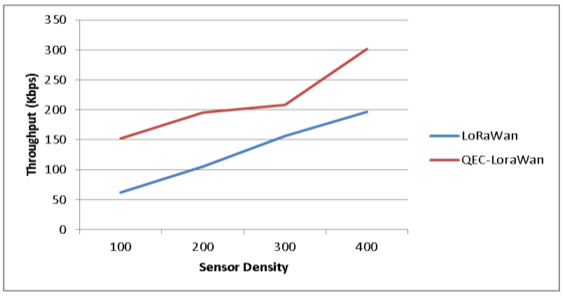

Fig. 4: Throughput-QEC-LoRaWAN/LoRaWAN

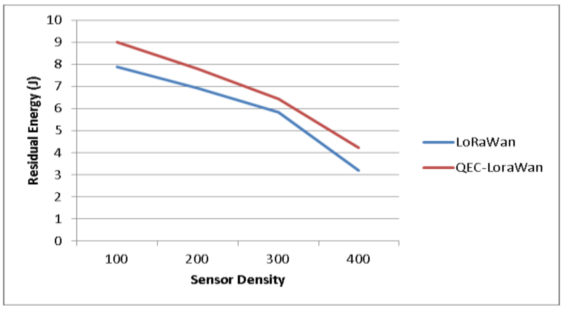

Fig. 5: Residual energy-QEC-LoRaWAN/LoRaWAN

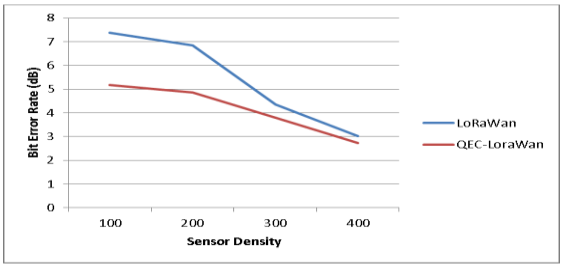

Fig. 6: Bit error rate- QEC-LoRaWAN/LoRaWAN

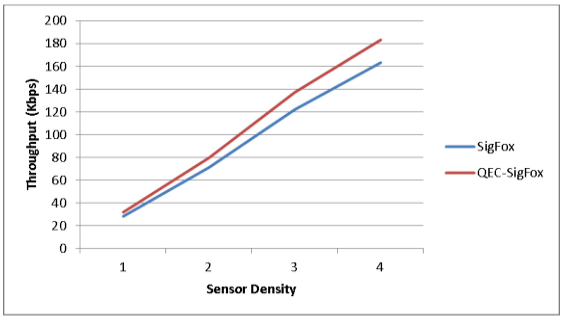

Fig. 7: Throughput-QEC-SigFox and SigFox

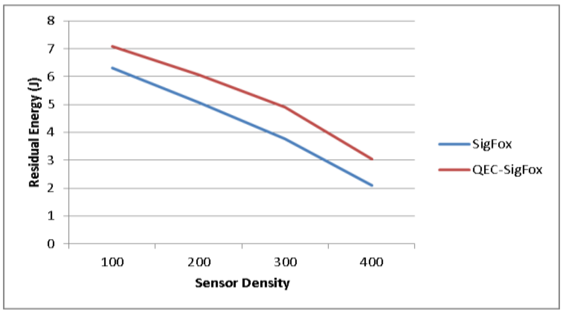

Fig. 8: Residual energy-QEC-SigFox and SigFox

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.

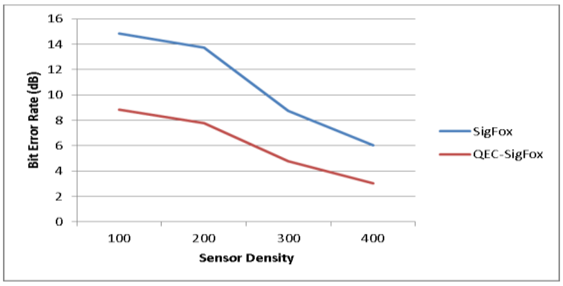

Fig. 9: Bit error rate-QEC-SigFox/SigFox

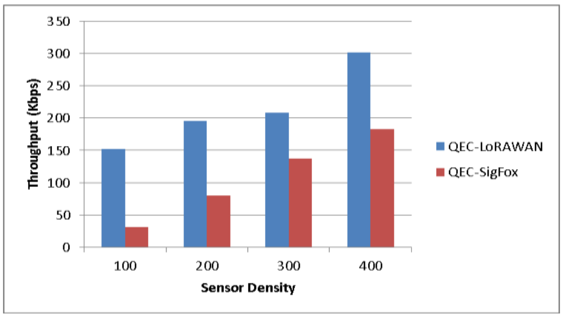

Fig. 10: Throughput comparison of QEC-LoRaWAN and QEC-sigfox

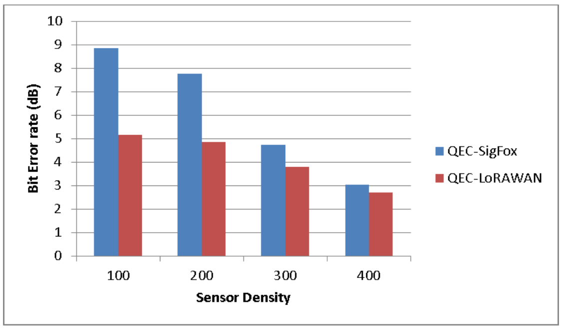

Fig. 11: Bit error rate comparison of QEC-LoRaWAN and QEC-Sigfox

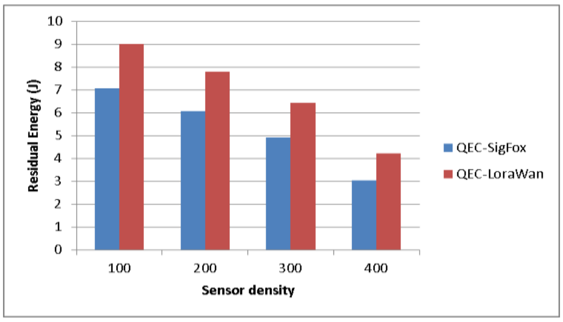

Fig. 12: Residual energy comparison of QEC-LoRaWAN and QEC-sigfox

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.

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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

Ahmed, A., Wang, X., Hawbani, A., Farooq, M. U., Qureshi, T., & Ullah, S. (2020, August). Ee-tar: Energy efficient and thermal aware routing protocol for software defined wireless body area networks. In *2020 IEEE 8th International Conference on Information, Communication and Networks (ICICN)* (pp. 51-55). IEEE. https://doi.org/10.1109/ICICN51133.2020.9205064

Ali, H., Tariq, U. U., Hardy, J., Zhai, X., Lu, L., Zheng, Y., ... & Antonopoulos, N. (2021). A survey on system level energy optimisation for MPSoCs in IoT and consumer electronics. *Computer Science Review*, *41*, 100416. https://doi.org/10.1016/j.cosrev.2021.100416

Bedi, P., Goyal, S. B., Kumar, J., & Kumar, S. (2023). Analysis of energy-efficient cluster-based routing protocols for heterogeneous WSNs. In *Comprehensive Guide to Heterogeneous Networks* (pp. 217-247). Academic Press. https://doi.org/10.1016/B978-0-323-90527-5.00003-4

Bishoyi, P. K., Misra, S., & Kumar, N. (2021). Collaborative and efficient body-to-body networks for IoT-based healthcare systems. *IEEE Internet of Things Journal*, *9*(14), 12147-12154. https://doi.org/10.1109/JIOT.2021.3133794

Bomgni, A. B., Sindjoung, M. L. F., Tchibonsou, D. K., Velempini, M., & Myoupo, J. F. (2022). NESEPRIN: A new scheme for energy-efficient permutation routing in IoT networks. *Computer Networks*, *214*, 109162. https://doi.org/10.1016/j.comnet.2022.109162

Devassy, D., Immanuel Johnraja, J., & Paulraj, G. J. L. (2022). NBA: Novel bio-inspired algorithm for energy optimization in WSN for IoT applications. *The Journal of Supercomputing*, *78*(14), 16118-16135. https://doi.org/10.1007/s11227-022-04505-4

Dowlatshahi, M. B., Rafsanjani, M. K., & Gupta, B. B. (2021). An energy aware grouping memetic algorithm to schedule the sensing activity in WSNs-based IoT for smart cities. *Applied Soft Computing*, *108*, 107473. https://doi.org/10.1016/j.asoc.2021.107473

Gupta, Z., & Bindal, A. (2022, April). Comprehensive survey on sustainable smart agriculture using IOT technologies. In *2022 2nd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE)* (pp. 2640-2645). IEEE. https://doi.org/10.1109/ICACITE53722.2022.9823837

Gupta, Z., Gupta, Z. & Bindal, A. K. (2023a). Delay-Conscious Service Quality Constraint in IoT Sensor Networks for Smart Farming. *Journal of Computer Science*, *19*(8), 1029-1049. https://doi.org/10.3844/jcssp.2023.1029.1049

Gupta, Z., Bindal, A. K., Shukla, S., Chopra, I., Tiwari, V., & Srivastava, S. (2023b). Energy efficient IoT-sensors network for smart farming. *International Journal on Recent and Innovation Trends in Computing and Communication*, *11*(5), 255-265. https://doi.org/10.17762/ijritcc.v11i5.6612

Gupta, Z., Bindal, A., & Chopra, I. (2023c). Smart Agriculture: A Comprehensive and Analytical Survey. In *2023 6th International Conference on Contemporary Computing and Informatics (IC3I)* (Vol. *6*, pp. 2521-2526). IEEE. https://doi.org/10.1109/IC3I59117.2023.10397737

Jain, S., & Agrawal, N. (2020, September). Development of energy efficient modified LEACH protocol for IoT applications. In *2020 12th International Conference on Computational Intelligence and Communication Networks (CICN)* (pp. 160-164). IEEE. https://doi.org/10.1109/CICN49253.2020.9242619

Jeevanantham, S., & Rebekka, B. (2022). Energy-aware neuro-fuzzy routing model for WSN based-IoT. *Telecommunication Systems*, *81*(3), 441-459. https://doi.org/10.1007/s11235-022-00955-6

Kumar, D. V., & Majid, M. A. (2022). High-performance, energy-efficient and memory-efficient FIR filter architecture utilizing 8x8 approximate multipliers for wireless sensor network in the Internet of Things. *Memories-Materials, Devices, Circuits and Systems*, *3*, 100017. https://doi.org/10.1016/j.memori.2022.100017

Kumar, M. P., & Hariharan, R. (2022). SPEED-UP and energy-efficient GPSR protocol for WSNs using IOT. *Measurement: Sensors, 23,* 100411. https://doi.org/10.1016/j.measen.2022.100411

Lu, Y., Zhai, D., & Yang, J. (2022, May). Energy Efficient Access Scheduling Mechanism for Monitoring on Power Line Supported by Wide Band Based IoT Networks. In *2022 IEEE 5th International Conference on Electronics Technology (ICET)* (pp. 1003-1007). IEEE. https://doi.org/10.1109/ICET55676.2022.9825438

Manda, S., & Singh, C. (2023). CVFP: Energy and trust aware data routing protocol based on Competitive Verse Flower Pollination algorithm in IoT. *Computers and Security*, *127*, 103035. https://doi.org/10.1016/j.cose.2022.103035

Mnasri, S., & Alrashidi, M. (2022). Energy-efficient IoT routing based on a new optimizer. *Simulation Modelling Practice and Theory*, *119*, 102591. https://doi.org/10.1016/j.simpat.2022.102591

Mokabberi, A., Iranmehr, A., & Golsorkhtabaramiri, M. (2023, February). A Review of Energy-efficient QoS-aware Composition in the Internet of Things. In *2023 8th International Conference on Technology and Energy Management (ICTEM)* (pp. 1-6). IEEE. 10.1109/ICTEM56862.2023.10083692

Pahuja, M., & Kumar, D. (2023, July). Energy-efficient stable election protocol for IoT-based healthcare systems using wireless sensor networks. In *2023 14th International Conference on Computing Communication and Networking Technologies (ICCCNT)* (pp. 1-7). IEEE. https://doi.org/10.1109/ICCCNT56998.2023.10307041

Pradhan, B., Das, S., Roy, D. S., Routray, S., Benedetto, F., & Jhaveri, R. H. (2023). An AI-assisted smart healthcare system using 5G communication. *IEEE Access*. https://doi.org/10.1109/ACCESS.2023.3317174

Raj Kumar, N. P., & Bala, G. J. (2022). A cognitive knowledged energy-efficient path selection using centroid and ant-colony optimized hybrid protocol for WSN-assisted IoT. *Wireless Personal Communications*, *124*(3), 1993-2028. https://doi.org/10.1007/s11277-021-09440-w

Rani, S. S., & Sankar, K. S. (2023). Improved buffalo optimized deep feed forward neural learning based multipath routing for energy efficient data aggregation in WSN. *Measurement: Sensors*, *27,* 100662. https://doi.org/10.1016/j.measen.2022.100662

Seyyedabbasi, A., Kiani, F., Allahviranloo, T., Fernandez-Gamiz, U., & Noeiaghdam, S. (2023). Optimal data transmission and pathfinding for WSN and decentralized IoT systems using I-GWO and Ex-GWO algorithms. *Alexandria Engineering Journal*, *63*, 339-357. https://doi.org/10.1016/j.aej.2022.08.009

Sheth, S. D., Verma, Y., Kaur, G., & Chanak, P. (2021, July). An energy optimized routing algorithm for IoT-enabled WSN. In *2021 4th International Conference on Computational Intelligence and Communication Technologies (CCICT)* (pp. 308-312). IEEE. https://doi.org/10.1109/CCICT53244.2021.00064

Shreyas, J., Deepa, H., Udayaprasad, P. K., Chouhon, D., Srinidhi, N. N., & SM, D. K. (2022, January). Energy optimization to extend network lifetime for IoT based wireless sensor networks. In *2022 4th International Conference on Smart Systems and Inventive Technology (ICSSIT)* (pp. 90-93). IEEE. https://doi.org/10.1109/ICSSIT53264.2022.9716477

Shukla, A., & Tripathi, S. (2020). An effective relay node selection technique for energy efficient WSN-assisted IoT. *Wireless Personal Communications*, *112*(4), 2611-2641. https://doi.org/10.1007/s11277-020-07167-8

Singh, R. K., Berkvens, R., & Weyn, M. (2020, January). Energy efficient wireless communication for IoT enabled greenhouses. In *2020 International Conference on COMmunication Systems & NETworkS (COMSNETS)* (pp. 885-887). IEEE. https://doi.org/10.1109/COMSNETS48256.2020.9027392

Suresh, B., & Prasad, G. S. C. (2023). An Energy Efficient Secure routing Scheme using LEACH protocol in WSN for IoT networks. *Measurement: Sensors*, *30*, 100883. https://doi.org/10.1016/j.measen.2023.100883

Uthayakumar, G. S., Jackson, B., Durai, C. R. B., Kalaimani, A., Sargunavathi, S., & Kamatchi, S. (2023). Systematically efficiency enabled energy usage method for an IOT based WSN environment. *Measurement: Sensors*, *25*, 100615. https://doi.org/10.1016/j.measen.2022.100615

Yang, T., Zhai, F., Xu, H., & Li, W. (2022). Design of a secure and efficient authentication protocol for real-time accesses of multiple users in PIoT-oriented multi-gateway WSNs. *Energy Reports*, *8*, 1200-1211. https://doi.org/10.1016/j.egyr.2022.02.061

Zaidi, A., Keshta, I., Gupta, Z., Pundhir, P., Pandey, T., Rai, P. K., ... & Soni, M. (2023). Smart Implementation of Industrial Internet of Things using Embedded Mechatronic System. *IEEE Embedded Systems Letters*. https://doi.org/10.1109/LES.2023.3309985