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Hybrid Based Cross Layer Optimization of Wireless Sensor Networks

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Abstract: Due to their many advantages over traditional communication techniques, wireless sensor networks, or WSNs, are seen as a potential substitute for evaluation, diagnosing, and operating remote electrical equipment. The task of addressing Value of Service (QoS) issues in WSNs continues to be challenging. This article presents the findings of a thorough experimental investigation to maximise multi-objective QoS in the WSN protocol layers. At the Physical Layer (PHY) layer, a Link Quality Estimate is constructed to evaluate the condition of the links in a WSN. A Quality of Service (QoS) Enhanced MAC technique is used at the MAC layer to reduce contentions between nodes and provide priority to mission-critical data. A routing technique for multi-objective QoS optimisation is presented at the Network (NWK) layer. These algorithms work together across layers to improve the system's dependability and decrease latency. The results show that the proposed algorithms are superior when measured against the state-of-the-art. The proposed algorithms outperformed the ZigBee protocol and the basic Distribution Grid wireless communications system in real-world tests, which demonstrated that they offered a better level of service (QoS) with mission-critical traffic.

Keywords: *Performance of Services (QoS), Cross-Layer Optimisation, Link Health Estimator, QoS Upgraded MAC, Multifunction access controls (MAC), Network (NWK) layer, Wireless Sensor Network (WSN).*

1. Introduction

From monitoring the outdoors to industrial automation, wireless sensor networks, also called WSNs, constitute a potent and flexible innovation that are being used in a wide range of applications. These networks are made up of a large number of tiny sensor nodes working together to collect or relay input to a centralised server or sink. Problems with WSNs, however, are insufficient power, data transport, and computing capacity because of their resource-constrained nature.[1]. In order to overcome these obstacles and boost WSNs' overall performance, researchers have turned their attention to Cross Layer Optimization (CLO) techniques. To boost network efficiency, a novel method was developed called cross-layer optimisation by breaking the traditional networking protocol layering stack and enabling direct interactions between different layers[2]. The conventional layered architecture, while simple and modular, can lead to inefficiencies and suboptimal performance when applied to resource-limited WSNs. By allowing communication and information exchange between different layers, CLO can exploit interaction among the layers and make more intelligent decisions regarding resource utilization and data transmission[3].

The design of an analytical model for Cross Layer Optimization is a crucial step in this process. Analytical models provide a systematic and theoretical framework to analyse the behaviour of a WSN under various conditions and parameter settings. These models help network designers and researchers to gain valuable insights into the network's performance, identify potential bottlenecks, and optimize various parameters to achieve desired objectives[4]. The analytical model for CLO in WSNs should consider multiple aspects, including energy consumption, data routing, congestion control, channel access mechanisms, and quality of service (QoS) provisioning. By incorporating these factors into the model, researchers can quantitatively evaluate the impact of cross-layer interactions on the network's overall efficiency and reliability. One of the primary objectives of designing an analytical model for CLO in WSNs is to strike a balance between energy efficiency and data transmission reliability[5]. Energy is a scarce resource in WSNs, and To find the sweet spot between data precision and power consumption, the analytical model should be used. By allowing cross-layer interactions, the model can optimize the transmission power levels of sensor nodes, adjust data aggregation techniques, and intelligently schedule data transmissions to conserve energy without compromising the data's quality[6].

Furthermore, the analytical model must account for the dynamic nature of WSNs, as nodes may join or leave the network, and environmental conditions may vary over time. The network topology and traffic patterns may evolve over time, thus it must be flexible, ensuring that the cross-layer optimizations remain effective and relevant[7].

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2. Related Works

[8]discussed several cross-layer design strategies that are used in Wireless Sensor Networks (WSN) and explores some cross-layer recommendations that have been offered by researchers. At the conclusion of the study, some of the difficulties that arose during the implementation of CLD in Wireless Sensor Networks are discussed. [9]a new routing paradigm for cross-layer designs was presented. In addition, the best cluster head is selected using the moth flame integrated dragonfly approach, a novel hybrid algorithm. Finally, study of living nodes and network lifetimes demonstrate the new model's advantages over existing models. [10]This study addressed the problem of a cross-layer data structure for wireless sensors in networks by using game theory and supermodel game theory.

[11]Cross-layer optimisations significantly affect network performance metrics like better energy efficiency, reliability, latency reduction, and security. This article describes a number of delayed MAC, MIMO-MAC layer transport techniques, along with analysis including cross-layer optimisation. [12] Outlined needs, common practises, and obstacles in standardised architecture. As a result, we developed an inter- and intra-layer communication-based architecture for the future generation of wireless networks. All levels may benefit from the new cross-layer approach to energy efficient modules, since it can be used to optimise energy from a single-layer parameter.

2.1 Link Quality Estimator

In-depth study of LQE as a tool for assessing WSN media channels has resulted from its popularity[13]. LQEs can be categorised as either software- or hardware-based. The signal strength that is received indicator (RSSI), whose may be obtained immediately from the transceiver's software registers together with the connection quality indicator (LQI), is a typical measure of hardware-based LQEs. They can assess a link's quality far more quickly than their software-based competitors. Due to the fact that RSSI and LQI are calculated with incomplete samples of successfully received packets, they are unable to communicate the link quality status when a packet is lost.[14]. Hardware-based LQEs may be affected by the hardware circuit quality of the transceiver, the antenna's level of directivity, and the surroundings.

Measures like the rate of packet delivery (PRR) and RNP (required packets) are essential for LQEs used in software. The percentage of packets that were received is known as the packet reception risk (PRR). Its RNP is the percentage of sent to received packets divided by received packets divided by sent packets, while vice RNR is the reverse.[15]. forward and backward PRR data are used to derive the anticipated transmission count (ETX), another software-based LQE. These three LQE measurements implemented in software might provide a more precise picture of the health of wireless communication networks. However, when connection quality fluctuates, it might make matters worse for software-based LQEs, since their estimation algorithms often need additive delay to acquire enough statistical information to increase estimation accuracy.

2.2 MAC Algorithm Based on Quality of Service

In order for nodes inside a WSN to communicate with one another via a shared medium, the MAC protocol provides channel access control techniques. Both schedule-based and contention-based categories may be used to describe QoS MAC protocols.

When it comes to schedule-based MAC protocols[16], It is common to employ the temporal division multiple entry (TDMA) technique. The TDMA mechanism assigns node access time windows. Because each node utilises a different time slot to access the media channel, collisions are reduced and data transmission latency is maintained. Although TDMA protocols have several advantages for collision-free media access, they also have some disadvantages. Examples include predefined scheduling, poor utilisation of the free channels, and clock synchronisation. Another MAC method based on timetables[17], rate allocation algorithms dynamically allocate resources to users in order to reduce communication delay[18][19]. To accomplish QoS in MAC, however, copious information transmission is required, which significantly increases protocol complexity and adds overhead[20].

In this study, our goal is to provide a cross-layer optimisation in the protocols used by the PHY, MAC, and Multi-hop WSNs may benefit from adding NWK layers to increase their end-to-end QoS performance.

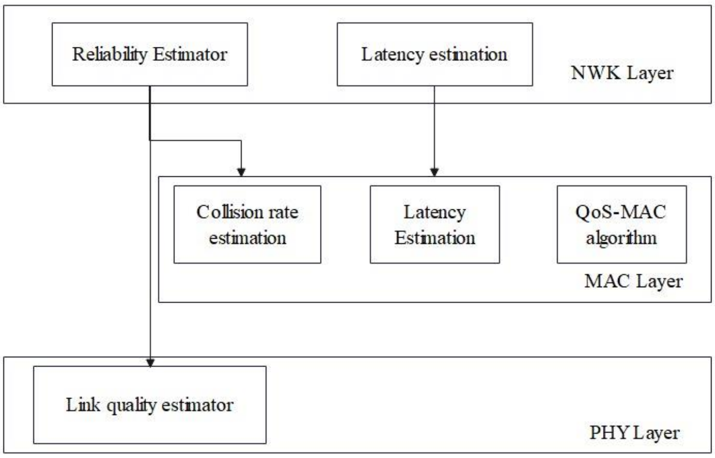


Fig 1 *Cross-layer QoS optimization framework of WSN*

3. Quality of Services Provided in Layers

3.1 Wireless Link Quality Evaluation in PHY Layer

Physical layer (PHY) examination of wireless connection quality is the emphasis of this section, begin by analysing the various factors that influence the Link Quality metric, Packet Reception Rate (PRR). By understanding these influencing factors, we gain insights into the performance of wireless links between nodes. Subsequently, we introduce an approach known as Link Quality Evaluation (LQE), which serves as a valuable tool for assessing the quality of links connecting neighbouring nodes in the network.

Factors Influencing WSN Link Quality: The PHY layer in WSN employs OQPSK modulation. The BER for OQPSK may be calculated as

$$L_e = R\left(\sqrt{2.\gamma_{(f)}.\frac{X_N}{Q}}\right) \quad (6)$$

where X_N signifies the transceiver's noise bandwidth. Q denotes the transmission data rate in kbps. As an expression of the sender-to-receiver separation, d, the ratio of noise to signal (SNR) of a radio signal can be expressed by the function f. The definition is as follows of γ(f) :

$$\gamma_{(f)} = 10^{(P_r(f)-P_n)/10} \quad (7)$$

where Pr(f) is the peak power of the intercepted signal as an estimate of frequency in dBm and Pn is the surrounding noise level measured in decibels per megahertz. Packet integrity is checked using the technique known as the CRC (cyclic redundant check) algorithm. A error could prevent a packet from being received. Consequently, we may come up with a word for the data packet reception rate:

$$L_{rr} = (1-L_e)^{8l} \quad (8)$$

the size of the packet, in bytes, is denoted by *l*.

Consequently, we can express the theoretical Link Quality model as (4) by plugging in (6) and (7) into (8):

$$L_{rr} = \left(1-R\left(\sqrt{2.10^{(P_r(f)-P_n)/10}.\frac{X_N}{Q}}\right)\right)^{8l} \quad (9)$$

The amount of background noise, denoted by Pn, and the intensity of the received signal, denoted by Pr(f), are the two primary parameters that influence Link Quality.

3.1.1 Link Quality Estimator:

The the PRR family, is the variable that controls the LQE's link quality. The notation represents the connection performance estimate result that node Vi calculated between node Vi & its neighbour Vj. And is the most current PRR that was determined when the opening wp was open between Vi and Vj. Considering as Vi succeeded in communicating with Vj by sending wp packets and receiving an acknowledgement from Vj in return, this could be described as

$$Lrr_{vi,vj} = \frac{r}{Y_p} \quad (10)$$

The value that is chosen for Y_p will have a significant impact on the result that is calculated for $Lrr_{vi,vj}$. For instance, if Y_p is too high, the amount of time necessary to compute $Lrr_{vi,vj}$ will also be elevated. As a direct consequence of this, the sensitivity of LQE decreases. However, if Y_p is too small, the changes in r will cause

$Lrr_{vi,vj}$ to vary in a somewhat big range, which will damage the stability of the LQE result. This can only happen if the range is quite large. The value of Y_p is determined to be 10, based on a combination of sensitivity, the reliability of LQE, and the outcomes of this study's field tests.

Once packet delivery to Vj is complete, Vi will increment the window Y_p counter by 1 and update the Link Quality estimation result $Lrr_{vi,vj}$ accordingly.

$$Lrr_{vi,vj} = \beta_p.Lrr_{vi,vj} + (1-\beta_p).Lrr_{vi,vj} \quad (11)$$

where β_p is a constant smoothing factor with values from 0 (no change) to 1 (maximum possible reduction in weighting). When β_p is smaller, older $Lrr_{vi,vj}$ are discounted from the estimate more quickly, although this may come at the expense of accuracy. When β_p is increased, more of the historical value of $Lrr_{vi,vj}$ is taken into consideration; nevertheless, the estimate result is unable to represent the change in $Lrr_{vi,vj}$ in an efficient manner. In this study, β_p has been set at 0.6 in order to strike a compromise between the measures of efficacy and precision of estimate results.

3.2 Quality of Service in MAC Layer

Because the WSN's MAC Protocol has to be able to offer QoS along with latency limitations for a variety of traffic types in order to support WSN traffic, the node that is transmitting the crucial packet needs to have preferred access to the media channel. It is critical to ensure that the timing of the report falls within a predetermined limit even in the event of the worst-case scenario.

3.2.1 QoS-MAC Algorithm:

Our QoS-MAC has two queues where data packets will be stored based on their relative importance and the guarantees they need in terms of network latency and throughput. The high priority (HP) queue is where the most important packets go, whereas the low priority (LP) queue is where everything else goes. Our QoS-MAC approach is made up of three rules: one for intra-node competition and two for inter-node competition.

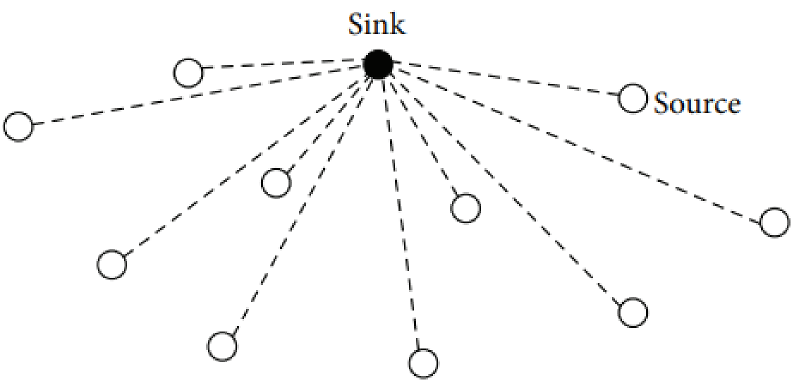


Fig 2 Network topology of QoS-MAC algorithm simulation

Rule 1: The LP messages will be disregarded if the nodes CSMA/CA mechanism notices that there are additional packets pending in the LP backlog but the HP queue seems empty. This rule is valid if there aren't any HP packets in the queue.

Rule 2: When compared to nodes transmitting Low Probability (LP) packets, nodes sending Heavy Probability (HP) packages have a shorter fixed backoff time, more backoffs, and an increased frequency of CCA detection. For channel access, both groups of terminals are in opposition to one another.

Rule 3:A node cannot send an HP packet unless its CCA timing for detection is faster than a node transmitting an LP packet. The most valuable packets (HP) are forwarded to a different queue than the other traffic (LP) in order to be sent. Our QoS-MAC methodology is based on three criteria: one for competition within a node und two for competition amongst nodes.

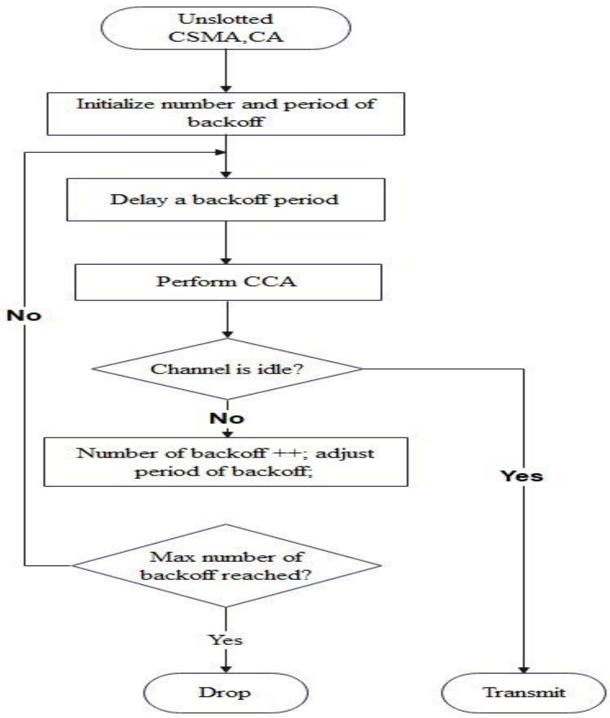


Fig 3 Flowchart for CSMA/CA

3.2.2 Collision Rate Estimation:

Each transmission item that is attempted to be sent when utilising unslotted CSMA/CA will first generate a collision and will then be destroyed once it reaches the maximum quantity that the CSMA/CA algorithms is required to back off.

HP packet collision rates are kept current in the Y_d^h transmissions window. Packet loss during Y_d^h transmissions is represented by n_d^h. Node v_i HP packet collision rate in counting window Y_d^h is denoted by the formula $cr_{vi}^h = \frac{n_d^h}{Y_d^h}$. In light of this, node v_i revises its shedding rate using the WMEWMA technique, expressed as, once Y_d^h transmissions conclude.

$$cr_{vi}^h = \beta_c . cr_{vi}^h + (1-\beta_c).\frac{n_d^h}{Y_d^h} \qquad (12)$$

where β_c is the degree of weight reduction and 0 < β_c < 1is the range of values for β_c. The values of Y_d^h and β_c, like w_p and β_p, impact the responsiveness and stability of cr_{vi}^h.

3.2.3 MAC Layer Latency Estimation:

Time spent waiting for CSMA/CA channel access contention and time spent by the transmitter from beginning to send the packet until it receives an acknowledgment (ACK) are both factors in the MAC layer delay of a packet.

When the most recent transmission is an LP (or HP) packet, the EWMA approximation of cad_{vi}^l as a function of the LP (or HP) channel access delay is updated. This occurs for node v_i, cad_{vi}^l, and cad_{vi}^h, which designate the channel access delay of low priority packet as well as elevated priority packet, respectively.

$$cad_{vi}^l = \beta_d . cad_{vi}^l + (1-\beta_d).(t_{backoff}^l + t_{CCA}^l) \qquad (13)$$

$$cad_{vi}^h = \beta_d . cad_{vi}^h + (1-\beta_d).(t_{backoff}^h + t_{CCA}^h) \qquad (14)$$

How long does it take the LP (HP) package to arrive back after being sent? When an LP (HP) packet is determined to have a totally clear channel while waiting in queue, it is indicated by the symbol. It has a range of that denotes the lighter weight.

assuming that the LP and HP packet sizes are equivalent. Both LP and HP packets, as well as the transmission delay, are regarded as equal. As a result, is used to describe the overall latency of a node sending an LP(HP) packet, which may be written as.

3.3 Quality of Service in NWK Layer

QoS Optimisation's role in NWK's functionality. This process entails building a static routing table according to the WSN topology's known geographical details. To evaluate transmission reliability and latency, the PHY layer and MAC layer information is employed by the reliability estimator and the latency estimator, respectively.

3.3.1 Reliability Estimator:

The dependability of data transmission between the current node and its neighbours is calculated using the reliability estimator of the NWK Layer. In a perfect world, the wireless link's dependability would determine how reliable a transmission is; nevertheless, the media access controller (MAC) layer's CSMA/CA procedure could lead to the packet being refused. As a result, our dependability estimate takes into account both the MAC layer's collision rate and the PHY layer's Link Quality.

If the packet's collision rate cr_{vi} is high enough, the MAC layer will not be able to send it. Node vi packet reception ratio to neighbour node vj is denoted by the network quality measure $L_{rr}(vi,vj)$ mentioned above. Therefore, vi's receipt of the packet is a necessary condition for the transmission to be considered successful. For HP packets specifically, we may calculate the outcome of the reliability estimator between vi and vj by

$$\eta^{h}_{vi,vj} = L_{rr}(vi,vj).cr^{h}_{vi}$$

3.3.2 Latency Estimator:

The latencies suffered at each intermediary node in a multi-hop communication are simply added to determine the overall communication latency. The latency estimator's objective is to provide a rough estimate of the lag of the node its its neighbours. assuming that it communicates via its neighbour node about the MAC layer transit delay and the quantity of packets in queue. As a result, for HP packets, the delay of selecting - as the next hop node, indicated as, may be expressed as the time it takes for all of the packets currently in's HP queues to be transferred.

$$d^{h}_{vivj} = Tr^{h}_{vj}.L^{h}_{vj}$$

3.3.3 Objective function:

The Quality of the service is a function of Latency and Reliability, hence in this work we proposed a hybrid ABC-GOA algorithm for cross layer optimization. Which further suggest a with minimised Latency and maximised Reliability.

Mathematical formulation of the objective function is given as

$$f(L,R) = \sum_{k=1}^{n-1}[Tr^{h}_{vj} * L^{h}_{vj}] - P_{rr}(vi,vj)cr^{h}_{vi}$$

Where,

L→ Latency

R→ Reliability

Tr^{h}_{vj} → Transfer Delay

L^{h}_{vj} → Number of packets

$P_{rr}(vi,vj)$ → Packet reception rate

cr^{h}_{vi} → Collision rate

ABC-WOA is a powerful hybrid optimization algorithm (Algorithm 1) that fuses the strengths of Artificial Bee Colony (ABC) as well as Whale Optimization Algorithm (WOA). The integration is essential as it synergizes global exploration of ABC with WOA's powerful exploitation, enabling efficient convergence to optimal solutions in complex optimization problems across diverse landscapes.

Algorithm 1 Hybrid Whale Optimization Algorithm - Artificial Bee Colony (WOA-ABC) Optimization

1. **Initialization:**
2. Set the algorithm parameters including MaxIter, nWhales, nScouts, and nOn lookers.
3. Randomly initialize whale and scout bee positions within the problem's search space.
4. **Fitness Evaluation:**
5. Evaluate the fitness value of each whale and scout bee based on the objective function.

Whale Optimization Phase (WOA):

for each whale do

Eight, reposition the whale using the most recent data and a random coefficient 'A' between zero and two.

Calculate the new whale position as:

New Position = Best Whale Position − A × (C × Best Whale Position −Current Whale Position)

The position update factor, C, is a random coefficient in the range [0, 1].

end for

Artificial Bee Colony Phase (ABC):

Select n Onlookers bees from the scout bee population based on their fitness values.

For each onlooker bee, choose another bee randomly and generate a new candidate position using the employed bee update formula:

New Position = Current Position + C × (Current Position –Other Bee Position)

Here, C is a random coefficient within the range [-1, 1].

Scout Bee Updates:

Replace the nScouts worst-performing bees with new random positions within the search space.

Fitness Re-evaluation:

Updated whales and scout bees, using the objective function, are evaluated for their fitness level.

Termination Criteria Check:

23. Check to see if the desired accuracy has been attained or if the MaxIter number of iterations has been used. If so, halt optimisation and give back the best-found answer.

Iterative Refinement:

Repeat steps for WOA and ABC phases until the termination criteria are met.

Optimal Solution Retrieval:

After the optimization process, return the best-found solution obtained from the population of whales and scout bees.

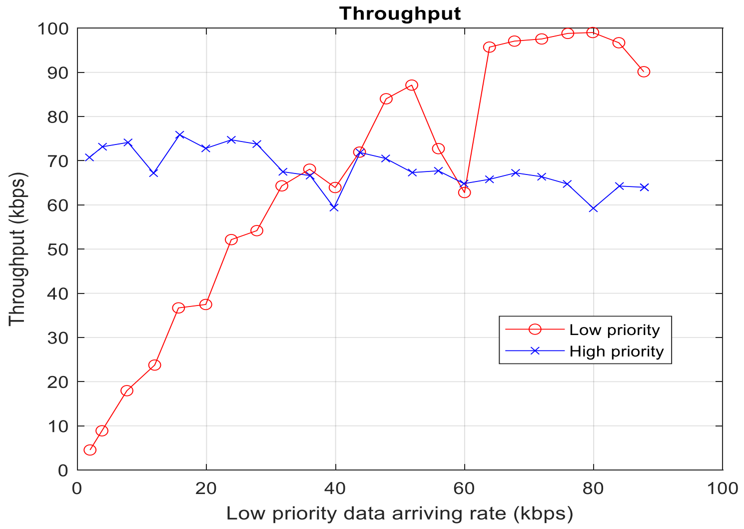
4. QoS-MAC Simulation

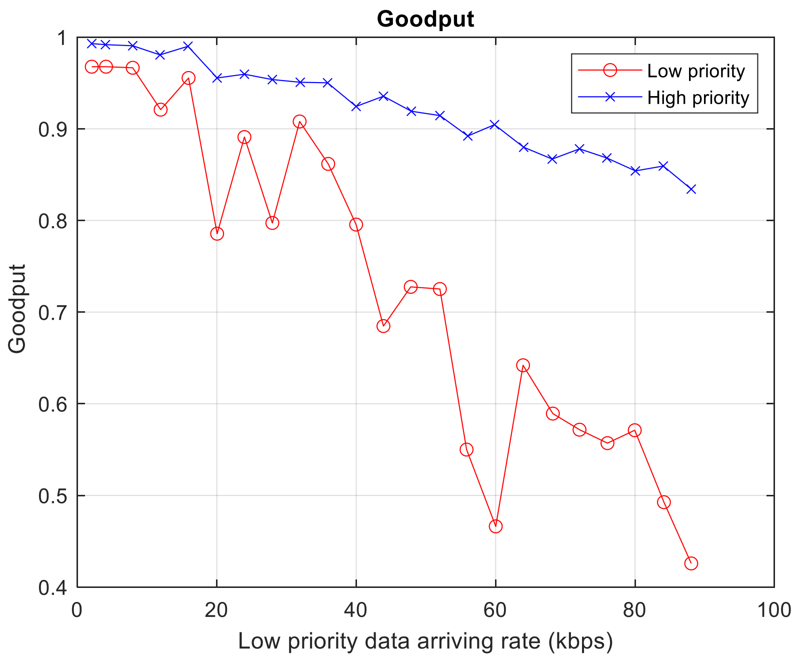
Ten source nodes and one sink node make up the network, all of whom are located close to one another. The sink node receives packets from source nodes that are potentially High Priority (HP) nor Low Priority (LP). Achieving QoS involves changing some settings, like (1) decreasing HP backoff to decrease latency and (2) increasing LP minimum backoff to prevent interruptions, and (3) decreasing CCA duration for HP packets to effectively interrupt LP transmissions. This enhances the overall network performance and ensures better QoS in the QoS-MAC algorithm.

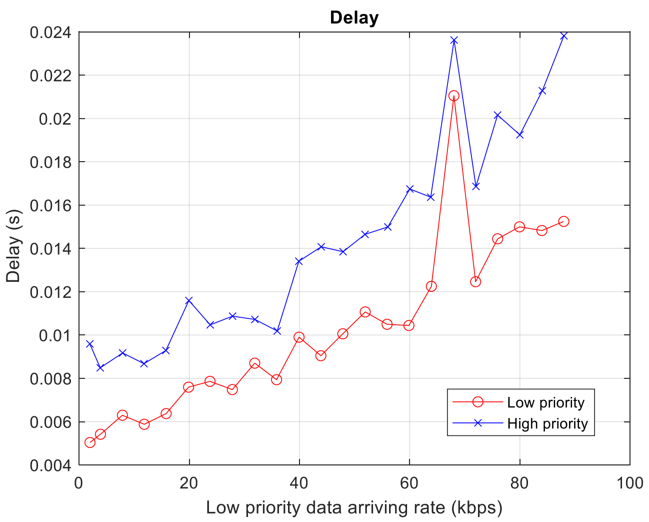
	Queue size (bytes)	Packet size (bytes)	Backoff period (ms)	Number of back offs	CCA duration (ms)
HP	400	60	0.48	10	0.082
LP	400	60	1.81-9.26	10	0.4

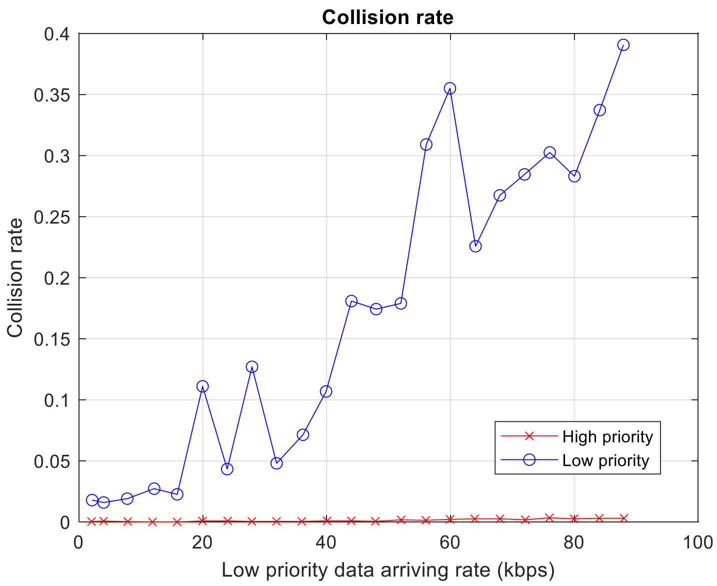
When in both cases all nodes are trying to send traffic at once, the network experiences the worst-case scenario, leading to congestion. This results in the data traffic surpassing the maximum bandwidth capacity

(250 kbps), damaging the level of service provided. As a result, as shown in the following figures, there are consequences for several indicators of network performance.

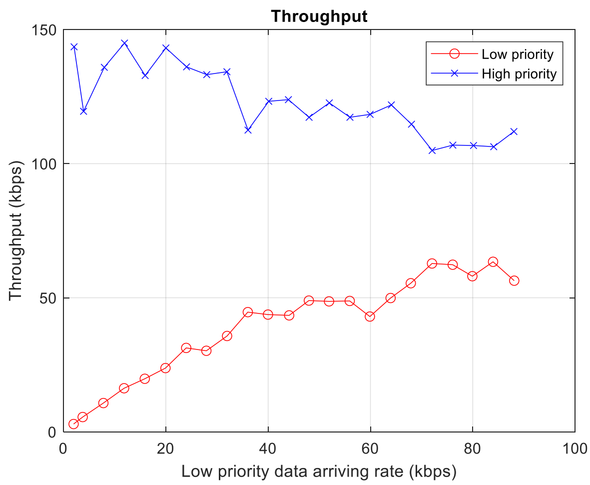


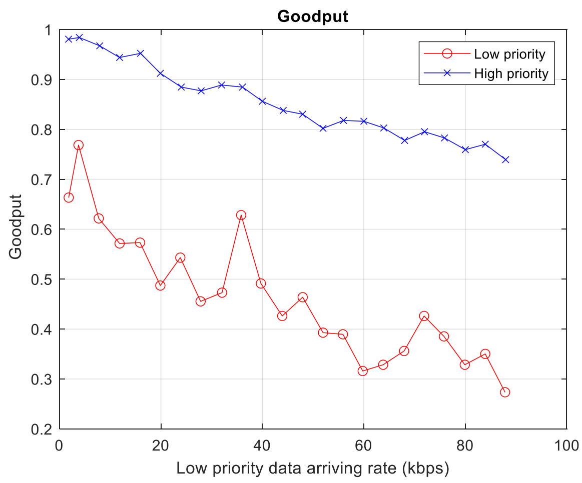


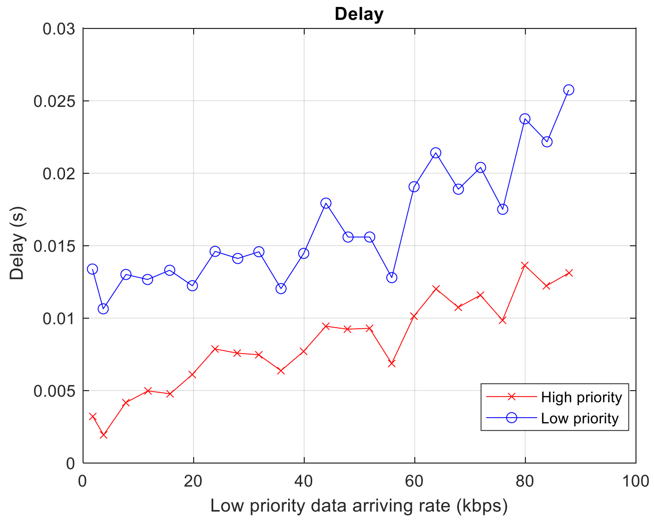


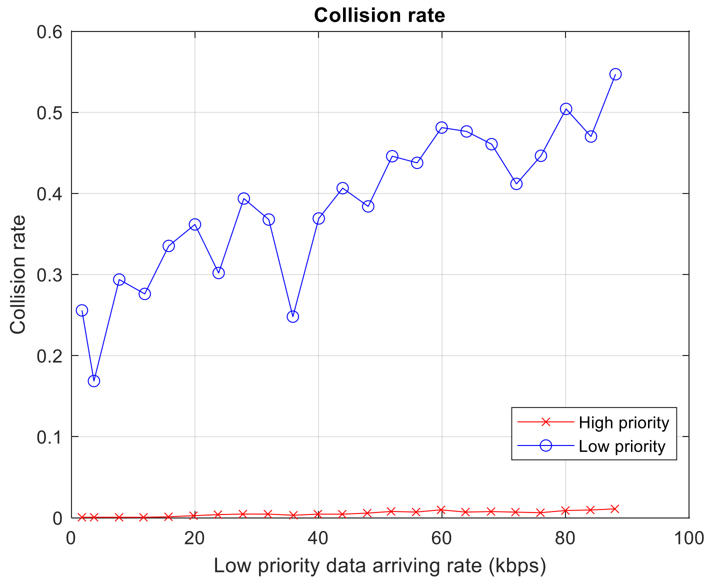


From the above figures, several observations can be made. Despite the network bandwidth saturation, High Priority (HP) traffic suffers minimal losses in both throughput and goodput. HP traffic achieves a throughput of over 60 kbps (out of a total generated traffic of 80 kbps) and maintains a goodput above 80%.In contrast, Low Priority (LP) traffic behaves differently. Its throughput increases initially with increasing λl (arrival rate), but it eventually plateaus at around 100 kbps, significantly below the traffic arrival rate of 310 kbps. As a result, the goodput for LP traffic reduces to around 40%. In addition, HP traffic regularly enjoys a 50% reduction in network latency compared to LP traffic. High-performance (HP) traffic has an almost zero collision rate, whereas low-performance (LP) traffic's accident rate has risen to 40%.









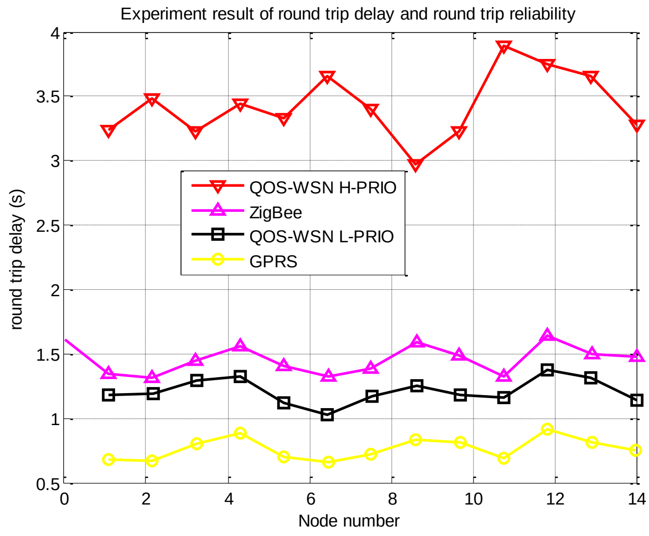
The experiment results for scenario (b) follow the same structure as scenario (a), with the Lower Priority (LP) traffic arrival rate (l) varying between 0.5 kbps to 23 kbps at 1 kbps steps and the High Priority (HP) transport arriving rate (h) set at 16 kbps. The performance disparity will further expand as the amount of HP vs LP information being transmitted rises. Finally, the outcomes from the Wireless Sensor Network, or WSN, throughput research show that the QoS-MAC algorithms effectively enhances the overall level of service for HP packets in both test instances. Improved and differentiating service levels for information flow in the WSN are ensured by the technique, which establishes restrictions on issues like latency of the network, throughput, and collision frequency.

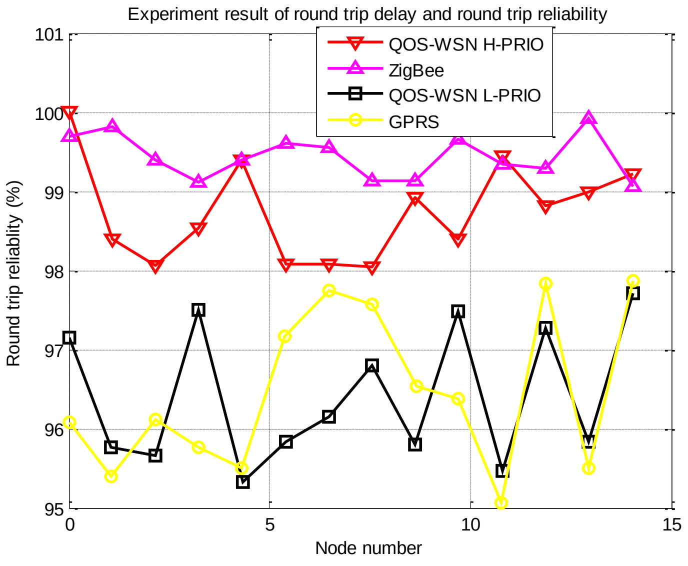
4.1 Experimental Results:

Here, we detail the practical application and evaluation of our proposed Cross-layer QoS Optimisation for WSNs in the Power Grid setting of Huangshan city, China. We conduct a comparative analysis of our approach with two other communication methods: GPRS and ZigBee, and provide an overview of their respective backgrounds.

GPRS: In the Power Grid of Huangshan city, distribution transformers are equipped with Transformer Supervisory Terminal Units (TTUs). These TTUs transmit their data to the Distribution Manager System (DMS) using the GPRS (General Packet Radio Service) model. GPRS operates on a public cell phone network, making its communication susceptible to interference from other cell phone devices.

ZigBee: The Power Grid of Huangshan city has a demonstration project named "Wireless Sensor Networking Research and Practice for Power Industry in Small-and-Medium Sized Cities." This initiative will collect distribution transformer operational data and transmit it to the DMS. To facilitate TTU connection, it uses a ZigBee network to provide a separate wireless LAN. The project consists of ZigBee coordinator/Sink nodes and ZigBee router/sensor nodes, with a Sink node distributed throughout the several subnetworks. However, ZigBee's potential efficiency is hindered by the absence of a Quality of Service mechanism.





In regard to round trip latency with High Priority (HP) packets, the data shown in the following graph indicates that their QoS-WSN (the quality of Service supported Wireless Sensor Network) performs better than both ZigBee and GPRS. Round trip delays for High Priority (HP) transmissions in our QoS-WSN are roughly 0.5 seconds, which is considerably shorter compared to the 1.1 a few seconds with ZigBee и the 3.2 seconds with GPRS.In addition, our QoS-WSN's HP packets have a round trip dependability of almost 99%, which is 1% greater than GPRS and 3% higher than ZigBee.

5. Conclusion

This article concludes by taking a close look at how Cross-layer the quality of Service (QoS) tuning may help Wireless Sensor Networks (WSNs). Given the QoS requirements of the apps that they support, WSN traffic is split into two categories. Three WSN standard levels are used to implement the suggested methodologies, with a Link Reliability Estimation incorporated into the Bodily (PHY) layer for assessing link quality in difficult circumstances. The QoS-MAC approach is proposed to address the issue of congestion across WSN nodes & to make the best use possible of the channel's wireless assets to transmit two types of packets. The combined ABC-WOA algorithm also enables end-to-end multiple-purpose (reliability and possibly latency) QoS optimisation over multi-hop transmissions. Results demonstrate significant improvements in reliability and latency when compared to cutting-edge techniques. The inclusion of wireless channel control for congestion and Link Quality estimation may be partially responsible for these improved results. The effectiveness of the suggested strategies is further demonstrated through verification by experiment in the Chinese city of Huangshan's distribution grid. Positive outcomes demonstrate that the algorithms are successful in delivering QoS of traffic that is distinguished based on its requirements. The suggested Cross-layer improvement strategies also outperform both older GPRS and ZigBee protocols in terms of critical traffic performance. In conclusion, the unique contributions made in this research to cross-layer QoS optimisation offer a viable strategy to enhance WSN performance in practical applications. Power grids and other areas where QoS is essential for network operation and dependability can benefit from the algorithms' capacity to prioritise traffic, improve reliability, and cut latency.

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