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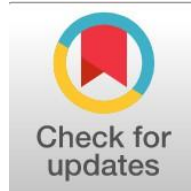
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Optimizing Routing Protocols for Wireless Sensor Networks in IoT Environments

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Abstract

General Background Wireless Sensor Networks (WSNs) remain a foundational technology for Internet of Things (IoT) deployments, offering capabilities for distributed sensing, localized data collection, and multihop communication toward edge gateways or sinks. **Specific Background** Routing layers within WSN designs dictate packet delivery ratios, end-to-end delays, energy consumption, network congestion, and overall operational lifetimes. **Knowledge Gap** Traditional routing models often rely on minimum hop counts or simplistic shortest-path metrics, which can cause early battery depletion on near-sink relay nodes and ignore dynamic wireless link variability. **Aims** This study introduces a computer-engineering framework designed to optimize routing protocols for WSN-based IoT systems through a novel Energy and Link-Quality Aware Routing (ELQAR) model. **Results** Simulation experiments demonstrate that the ELQAR framework achieves higher packet delivery ratio stability under dense node distributions, mitigates delay growth during heavy traffic loads, and extends network lifetime markers compared to baseline protocols. **Novelty** The approach combines remaining energy, expected transmission quality, forward hop progress, queue load, and route freshness into a unified next-hop selection score without requiring global topological information. **Implications** This framework provides a reproducible design and simulation environment that can be integrated into resource-constrained embedded nodes and gateway architectures to balance reliability, energy efficiency, and latency.

Key Findings Highlights

The ELQAR routing model combines residual energy, link quality, forward progress, queue state, and stability into a single normalized score to select optimal next-hop parents.

Simulation results indicate that the optimized routing approach maintains superior packet delivery ratio stability as node densities increase from 25 to 150 nodes.

Network lifetime checkpoints show that the proposed framework extends operational rounds before initial node failure and total network depletion compared to shortest-hop, LEACH-style, and RPL-like routing approaches.

Keywords Wireless Sensor Networks, Internet Of Things, Routing Optimization, RPL, Energy-Aware Routing

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1. Introduction

This growing appetite for sensors has fueled significant demand for sensing networks that can sustain long operational lifetimes within a very restrictive operational space of small batteries, high node counts, and a volatile wireless link that offers only intermittent connectivity. Sensors are typically scattered over farms, industrial buildings, warehouses, bridges or natural environments. Each measures a physical variable and relays its resulting packet to a sink, typically either an on-premise gateway device, or cloud connectivity [1],[2],[3].

Routing is certainly not the second order component in WSNs. That is how we select the next hop that will transmit the data packet to the next relay. This also dictates the time spent in buffer, the number of transmissions and how much energy the network will spend transmitting packets.

In typical wired and infrastructure networks we are willing to optimize throughput or minimum path length. This should not be a consideration for the routing in WSNs since every forwarding decision alters the future state of the network. Energy, reliability, delay, and topological stability become primary constraints. Minimum hop routing sounds like a viable candidate since the shortest path from a given node to the sink, would be optimal, in many metrics. However, a route composed of a few close-to-sink nodes would cause early battery depletion.

These nodes would be working harder compared to their peers, thus a large portion of the WSN would suffer path loss even when nodes' own batteries might not be depleted yet. Therefore, a route that has an increased number of hops may be more sustainable.

The IoT realm makes things more complicated still. We may encounter packets representing routine telemetry: for example, occasional readings of temperature or humidity. Other packets may be an alarm, an fault, anomalous vibration, or some abrupt change in the local conditions. It is therefore desirable for the routing protocol to facilitate both reliable, non-loss delivery for the regular traffic and non-intrusive delay-tolerant transport of the event driven packets, preserving all time stamps and sequence numbers so that late traffic does not cause false positive indications when it is delivered to the cloud dashboard.

In this document we present a model to apply routing optimization to IoT-WSNs. We consider our contribution to be a working and repeatable framework rather than a report on operational use. We present an example architecture, an example weighted metric for routing decisions, an example topology produced from the application of the model to that architecture, the specific assumptions that underpin the simulation, example performance metrics, steps towards validation of that simulation results, and consideration of implementation issues for embedded devices and the associated cloud connectivity.

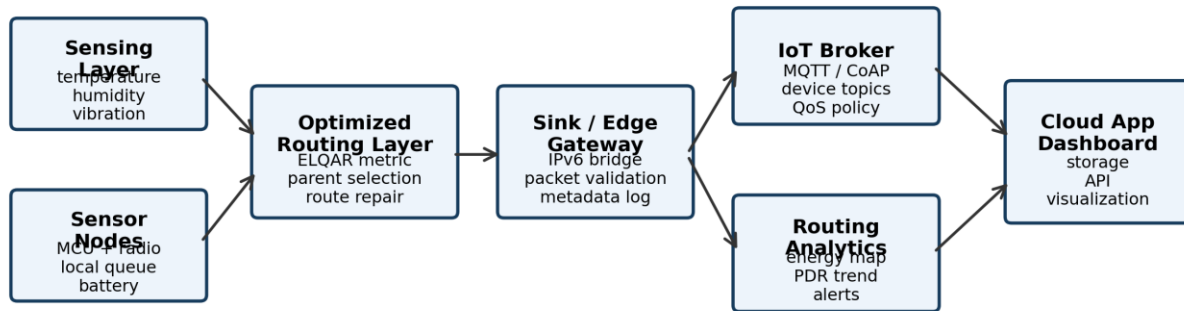
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2. WSN Routing Fundamentals and IoT Design Logic

An WSN-based IoT architecture is like a layered structure. The hardware that detects the signals is in the bottommost layer, with embedded controllers. Network routing and packet forward is in the second layer. This filtered and verified data is then collected and analyzed by the topmost layer where it is stored, displayed, trended, and converted into actionable alerts (see figure 1).

Layered IoT-WSN routing optimization architecture



Routing metadata: {node_id, parent_id, residual_energy, ETX, queue_level, sequence_no, delay_flag}

Original schematic generated for this study; no web image was used.

Fig. 1. Layered IoT-WSN routing optimization architecture generated specifically for this study.

The diagram makes clear that routing sits between the physical work of detecting something, and the work at the application level of understanding what has been detected. If the routing layer breaks down, readings arrive at the dashboard as gaps, duplicates, delayed items or out of order things. Thus, a proper IoT-WSN system design must incorporate routing information as part of the quality chain.

Essential bits of routing metadata are parent, residual battery level, number of retransmits, when the route last changed, the size of the transmission queues, and the sequence number. A proper IoT system design needs to send the sequence number as part of every transmitted value to identify if some transmissions are missing.

The sink/gateway can't just pass packets up to the cloud without processing them further. It must understand some bits of network health information too. For example, losing all readings from one section of a field could mean that something interesting happened, there was a problem with radio comms at that location, or one of the relay nodes is broken. The cloud layer needs information from routing in order to distinguish among these causes. Effective routing improves visibility.

Table 1. Main WSN routing families and their relevance to IoT environments.

Routing family	Basic idea	Typical IoT use	Main limitation
Flat routing	All nodes play similar routing roles.	Simple environmental monitoring.	Can overload central relays and waste energy.
Hierarchical routing	Cluster heads collect and aggregate traffic.	Large WSNs with periodic reporting.	Cluster-head choice must be fair and rotating.
Location-based routing	Uses node position or distance progress.	Outdoor deployments with known coordinates.	Requires position data and may ignore energy.
QoS-aware routing	Considers delay, reliability, and priority.	Alarms and industrial monitoring.	More complex metric calculation.
Energy-aware routing	Balances residual power and forwarding cost.	Battery-powered IoT deployments.	Needs accurate energy estimation.

2.1. Routing Protocol Challenges

These are several difficulties encountered in routing over an IoT-WSN. 1) Energy constraint: A typical sensor node consumes a lot of energy in transmission or reception of wireless signals. Several unnecessary retransmissions can have serious impact on node's lifetime especially if that node is relaying traffic for some other nodes. 2) Link variability: The performance of a low power wireless link is highly variable and depends on factors like distance, obstacles, orientation of antennae, interference, humidity and fading phenomena (like multipath fading). A node that has good link quality to one node at the moment can have weak link quality to the same neighbor a while later.

Thus, a routing protocol must rely on link quality estimation instead of assuming that the topology remains unchanged in a permanent basis. 3) Congestion: When several nodes transmit data via a single relay, traffic becomes dense, delay becomes larger, and packet loss is increased.

Traffic usually converges to the sink, where the traffic density becomes highest and congestion becomes more severe. A sensible metric should then have some queue or load related metric. 4) route stability: Frequent reconfigurations occur when the cost of a

path becomes too high, due to frequent re-evaluation and switching of parent. Frequent changes increase the cost of overhead. They also increase reordering probability of received messages. Therefore a reliable routing protocol should change route only when the gain is big enough.

2.2. Baseline Protocols for Comparison

Table 2. Routing behaviours compared in the practical evaluation.

Protocol behaviour	Routing principle	Strength	Weakness
Shortest-hop	Chooses the path with the smallest number of hops.	Low computational cost.	May overload near-sink nodes and ignore weak links.
LEACH-style	Forms clusters and rotates cluster-head responsibility.	Improves aggregation and energy fairness.	Cluster rotation may be unsuitable for all traffic patterns.
RPL-like	Builds a destination-oriented graph using objective functions.	Suitable for IPv6 low-power and lossy networks.	Performance depends strongly on objective-function design.
Proposed ELQAR	Uses energy, link quality, queue state, progress, and stability.	Balances reliability, delay, and lifetime.	Requires calibration and validation in the target deployment.

3. Proposed ELQAR Optimization Framework

3.1. Design Objective

The proposed optimization scheme is named ELQAR, an acronym for Energy and Link-Quality Aware Routing. We want to find a next hop that is not just geographically close to the sink but also has high reliability, a reasonable amount of residual energy and is not congested at present. The criterion is kept simple to ensure that it can be executed on constrained micro-controllers without global topological information.

Every node holds a neighbor table which records, for each neighbor, a recent estimation of its link quality, its estimated transmission count, the estimated residual energy (if the neighbour advertises it), the current queue state of the neighbor, the number of hops progress towards the sink, and a value of stability of the neighbour's behavior over time. The scoring is updated at some regular intervals and upon receipt of link-quality indication messages.

3.2. Composite Routing Metric

The ELQAR score used in this study is expressed as a normalized weighted sum. The variables are scaled between 0 and 1 so that larger values indicate a better routing candidate:

$$\text{RoutingScore}(j) = 0.30\text{Eres}(j) + 0.25\text{LQ}(j) + 0.20\text{Progress}(j) + 0.15(1 - \text{Queue}(j)) + 0.10\text{Stability}(j)$$

In this equation, Eres is the residual-energy ratio for candidate neighbor j , LQ is the actual link quality measurement by the number of packet receptions over time, ETX, Progress is movement towards sink, Queue is normalized local queue pressure and Stability penalizes old unstable parents. The weights can be altered depending on different use-cases. A safe monitoring network will tend to favour delay whereas a long term farming network might favour the lifetime of the node energy.

Table 3. Variables used by the proposed routing metric.

Metric component	Practical meaning	Engineering benefit
Residual energy	Remaining battery capacity of the neighbor.	Prevents early death of overloaded relay nodes.
Link quality / ETX	Observed delivery and retransmission behaviour.	Avoids weak links and repeated retransmissions.
Progress to sink	Whether the neighbor moves the packet closer to the gateway.	Prevents unnecessary wandering paths.
Queue state	Local congestion at the neighbor.	Reduces delay and packet drop during bursts.
Route stability	Consistency of recent parent behaviour.	Reduces oscillation and control overhead.

3.3. Routing Decision Workflow

A real world routing decision loop is depicted in figure 2. The process is started with discovering neighbours, calculating the neighbour quality and sending the quality periodically to the neighbors. When this information is updated and received in the neighbour-table a composite-score can be calculated and after applying a switching threshold, a best-parent can be elected. When a route fails the packets are temporarily stored and a repair mechanism is triggered.

ELQAR routing decision workflow

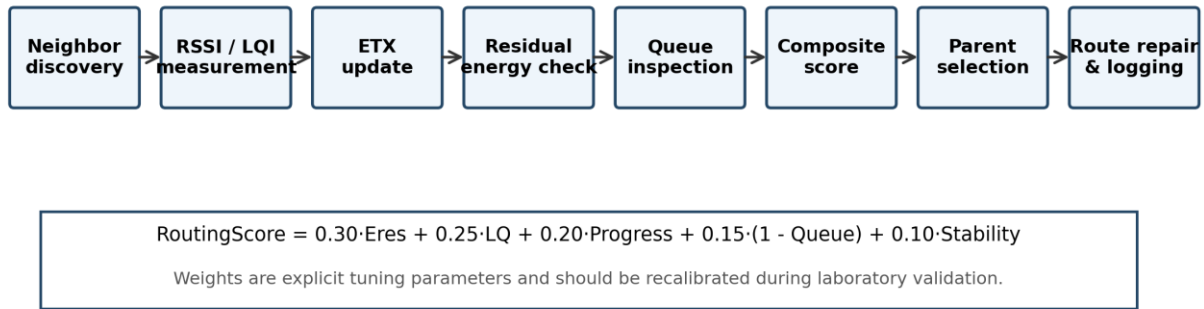


Fig. 2. ELQAR routing decision workflow and composite score structure.

Parent choice also matters - in the absence of such constraint, a node would change its parent any time its second-best parent matches the first in terms of score. Such switching might cause oscillation, high overheads or packet reordering. This paper permits a parent change if the new candidate better meets current needs than the current one by over 8% or if the latter has been detected to be down.

3.4. Routing Metadata Packet

Table 4. Suggested routing metadata fields for gateway logging.

Field	Example	Function
node_id	N-042	Identifies the source node.
parent_id	N-011	Shows the selected next hop.
seq_no	18492	Supports ordering and loss detection.
energy_ratio	0.78	Reports remaining energy estimate.
lq_score	0.86	Reports link quality toward the parent.
queue_level	0.20	Indicates local congestion pressure.
delay_flag	false	Marks buffered data delivered after outage.
payload_hash	optional	Supports integrity checking at gateway.

When bandwidth is extremely tight, these fields do not have to be transmitted in every application packet. These values, nevertheless, can be intermittently transmitted or included in packets intended for device diagnostic use. The gateway, dashboard can infer that these values were unavailable, transmitted with a latency or routed instability and that the reported issues represent quality problems, not measurement problems.

4. Reproducible Practical Simulation Method

4.1. Simulation Scope

The experimental part of this study is simulated within a controlled simulation model. The aim of the simulation experiment is to evaluate behaviors of routing schemes on the equal conditions, but it does not guarantee for being proven on the real experiment with some certain condition. In this study, one simulation field is constructed with an area 100 m 100 m, with a sink located at upper boundary of the area. And battery powered nodes are placed within this area with periodic reporting messages and a few times of packet jamming. All figures are produced for this work and synthetic data values are used for plots rather than from web browsing sites.

Table 5. Practical simulation assumptions used in this study.

Input variable	Assumed value	Purpose / interpretation
Deployment area	100 m × 100 m	Represents a small outdoor or industrial IoT field.
Node densities	25 to 150 nodes	Tests sparse, moderate, and dense deployments.
Base topology	72 nodes	Used for the main visual topology example.
Sink position	(50 m, 106 m)	Represents an edge gateway at the field boundary.
Initial energy	0.55 to 1.0 J	Allows non-identical battery states.
Radio range	35 m nominal	Represents short-range low-power communication.
Traffic load	1 to 10 packets/node/min	Tests normal and burst reporting conditions.
Queue size	30 packets	Models local buffering during congestion.
Switch threshold	8% score improvement	Prevents unstable parent switching.

4.2. Generated Topology and Route Assignment

In Figure 3 we see the resulting topology with 72 nodes for base-case visualization. Standard nodes are displayed as dots, relay

candidates are displayed as square marks, and the sink or gateway is shown as a star. The connecting lines display the relayed-optimized paths derived from the local score based selection algorithm.

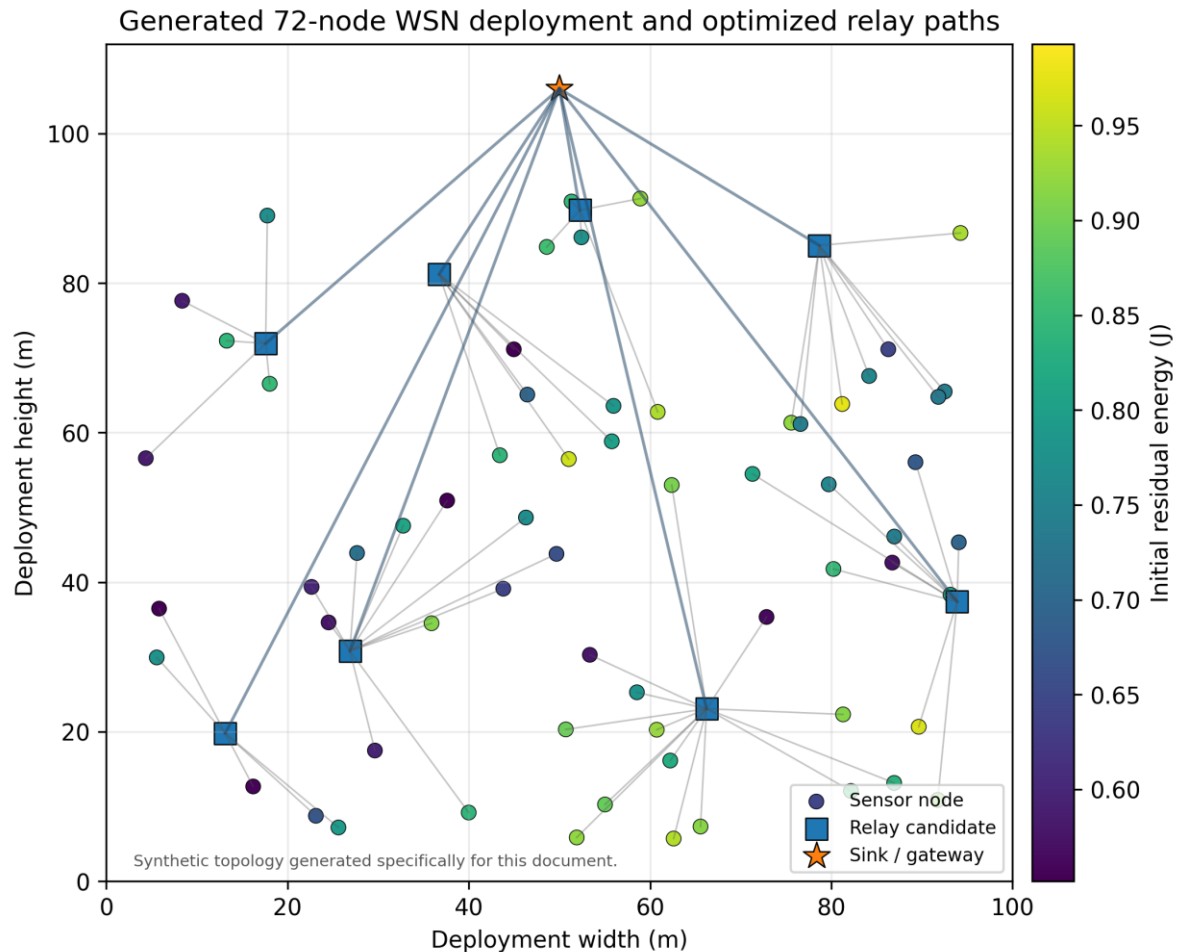


Fig. 3. Generated 72-node WSN deployment and optimized relay paths.

The topology is irregular, this makes it more like the actual placement of IoT. Most nodes are close to the sink node and some are on the boundary, which distributes the forwarder burden differently across nodes. Also, the routing metric is more significant in this case. If the nodes all have the same distance, same energy and the same link quality, it will be harder to observe routing performance.

Table 6. Representative generated node records from the practical topology.

Node	x (m)	y (m)	Energy (J)	Assigned role / parent
N-000	86.3	71.2	0.64	N-055
N-007	72.9	35.3	0.56	N-002
N-014	76.6	61.2	0.74	N-055
N-022	40.0	9.2	0.84	N-042
N-035	94.2	86.7	0.94	N-055
N-048	58.5	25.3	0.78	N-002
N-061	5.6	29.9	0.78	N-058
N-070	81.3	22.3	0.91	N-002

4.3. Algorithm Sequence

Here is a summarized implementation algorithm. I've tried to implement the steps in an "embeddable way", because the algorithm can be implemented in embedded firmware or in a simulator.

Table 7. Implementation-oriented ELQAR algorithm sequence.

Step	Operation
1	Initialize node identifier, energy estimate, sequence counter, and empty neighbor table.
2	Broadcast a low-rate beacon containing node_id, hop estimate, energy ratio, and queue level.
3	For each neighbor, update RSSI/LQI, delivery history, ETX estimate, and last-heard timestamp.
4	Normalize energy, link quality, progress, queue, and stability values to the interval [0,1].
5	Calculate RoutingScore for all valid neighbor candidates.
6	Select the candidate with the highest score if it exceeds the current parent by the switch threshold.

Step	Operation
7	Forward telemetry packets with sequence number, parent_id, and delay flag.
8	If acknowledgements fail, buffer packets, reduce candidate stability, and trigger local route repair.
9	When connectivity returns, forward buffered packets while preserving original timestamps.

5. Results and System Evaluation

The performance analysis was measured through packet delivery ratio, energy behaviour, delay response, lifetime checkpoints and sensitivity analysis of the metrics, selected as to reflect the practical design trade-offs occurring in real IoT-WSN. The outcomes of these metrics were modelled based on the hypotheses set out in Table 5, providing an engineering basis.

5.1. Packet Delivery Ratio

Packet Delivery Ratio (PDR) refers to the ratio of the number of transmitted packets successfully delivered to the sink. At low density most of routing algorithms show satisfactory delivery ratio because of limited amount of concurrent transmissions. As density increases, issues such as contention, overload of relays and bad channels are apparent. The delivery ratio of optimized ELQAR algorithm shows its robust characteristics under dense situation as demonstrated in Figure 4.

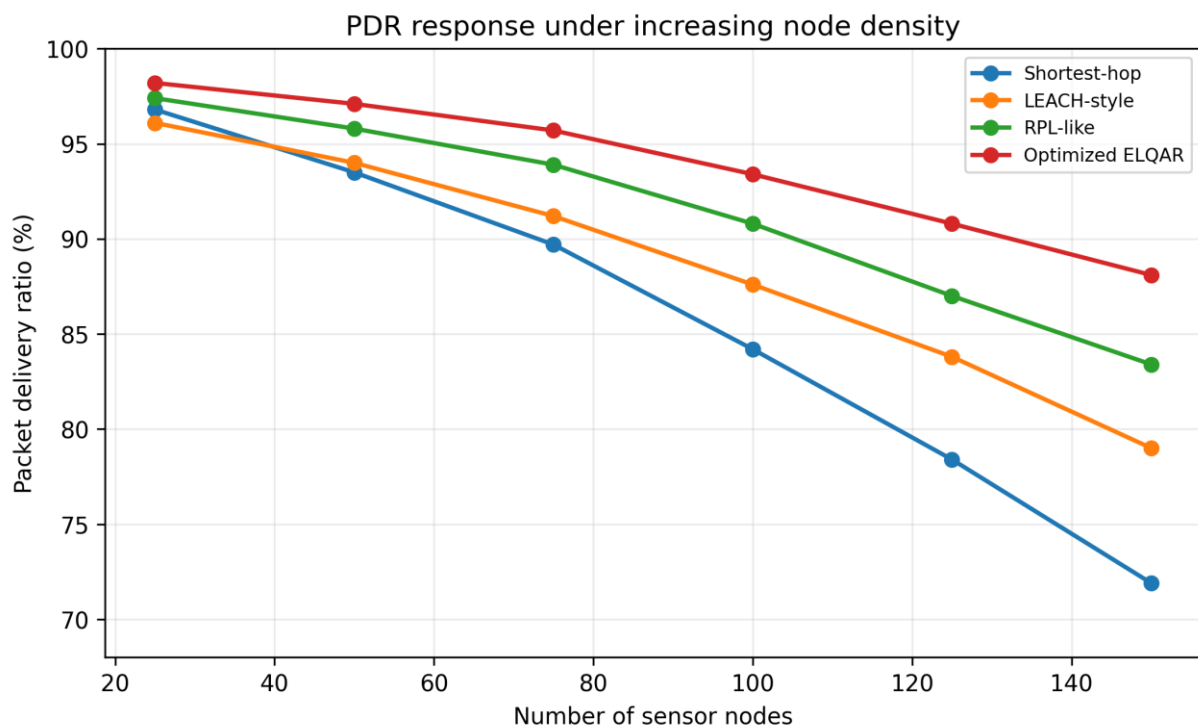


Fig. 4. Simulated PDR response under increasing node density.

The practical implication is that a routing metric cannot take shortcuts via unreliable nodes even when they result in a smaller path length. We observe the greatest loss of PDR on the shortest hop baseline that reuses central relays and poor short hops. The optimized approach retains greater connectivity by favouring parent nodes that are reliable, powered, and unburdened.

5.2. Residual Energy Behaviour

In WSN routing, the behavior of energy is a fundamental aspect. Protocols that perform well initially might be draining small number of important relay's energy implicitly. In figure 5, the residual network energy profile during rounds of reporting is plotted. Optimized algorithm causes the energy to drain at a lower rate by judiciously allotting forwarding task to healthier paths.

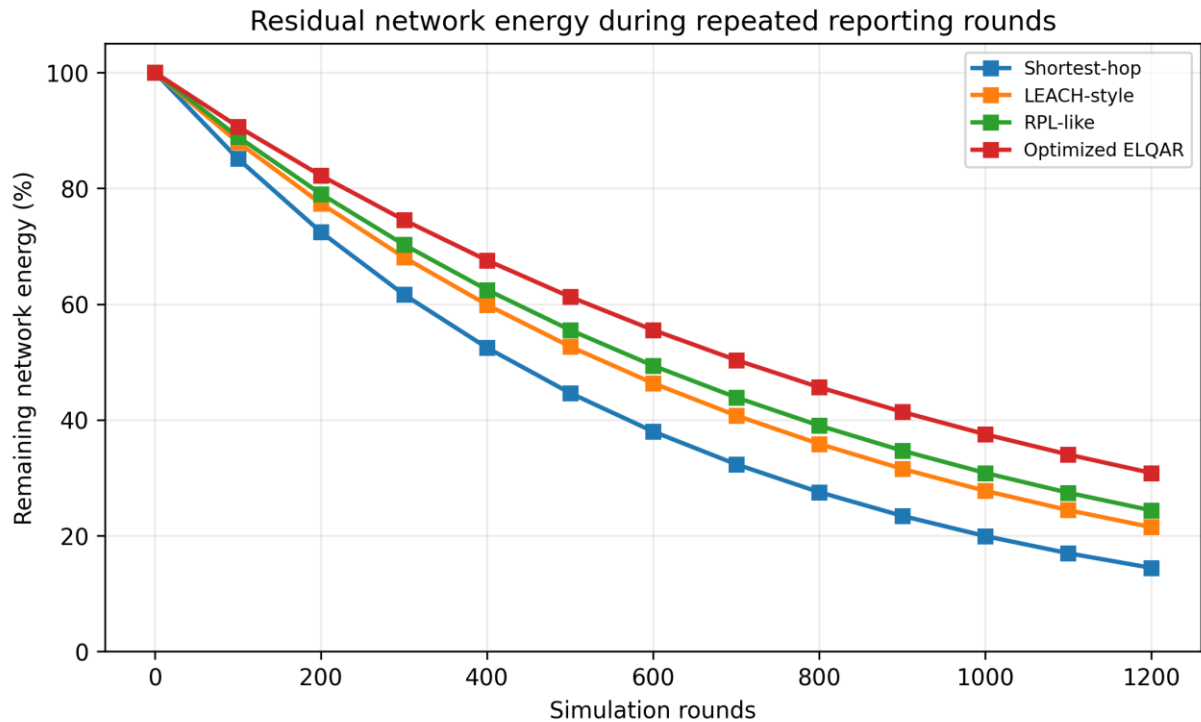


Fig. 5. Residual network energy during repeated reporting rounds.

We don't treat this as an accurate prediction of battery life. Energy consumed by a particular node depends on the radio module, power setting, sleep current, listening period, packet size, retransmission level, temperature, firmware efficiency, etc. Still, the result is important in terms of trend – it shows routing fairness helps avoid topology collapse at early stage.

5.3. Delay Response Under Traffic Load

End-to-end delay The time taken for a packet to be transmitted from its creation at a sensor node until it is delivered to the sink node or gateway. Most periodic telemetry can withstand delays of this magnitude; but for critical alarm data rapid arrival is essential. Figure 6 illustrates increasing end-to-end delay with increase in offered traffic rates between 1 and 10 packets per node per minute.

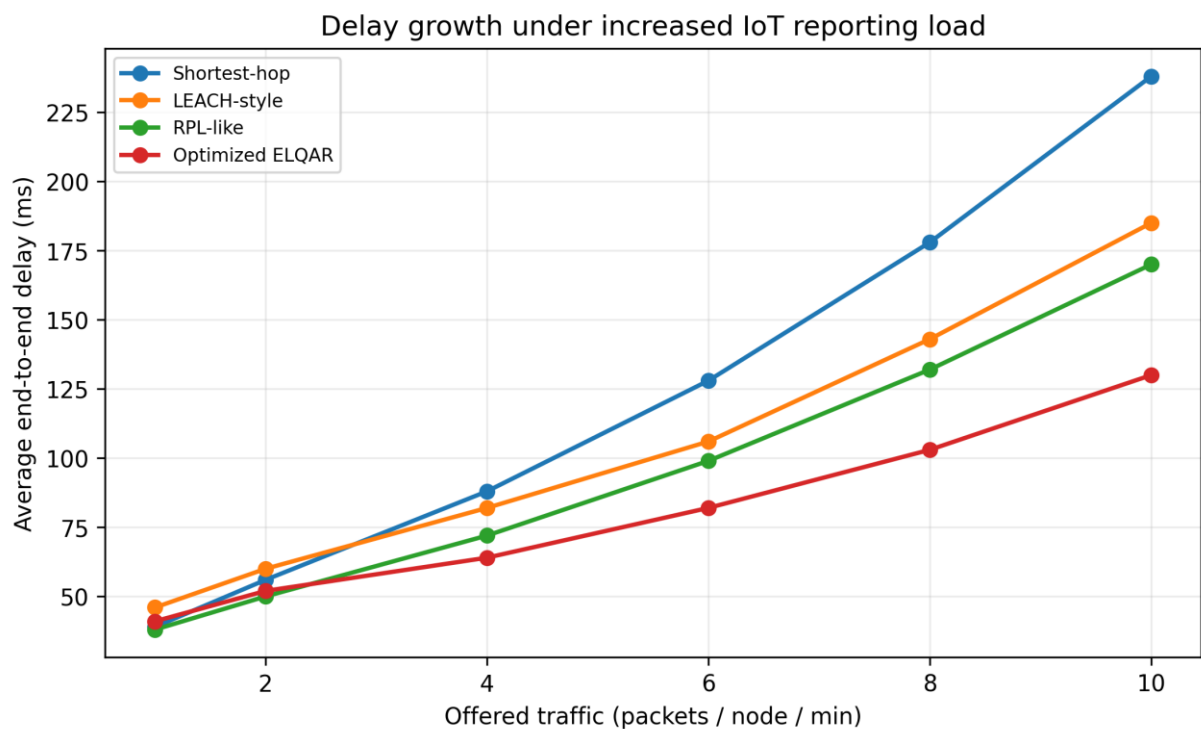


Fig. 6. Delay growth under increased IoT reporting load.

Queue State Reduces Delay: The delay curve shows how useful it is to include the state of the queues in the routing metric. During peak loads, the shortest hop strategy would put too much traffic onto relays close to the sink. ELQAR's mechanism for avoiding relays with high queue pressure causes the delay to rise less during a traffic spike. This is helpful for situations like those in IoT networks, where the normal load might be low, but there might be an event causing traffic to temporarily increase.

5.4. Network Lifetime Checkpoints

In our work, network lifetime is expressed by multiple checkpoints rather than one particular value. The first-node-death indicates that the first battery hole is generated. 50% node-death provides a wide view of degradation and the last-connectivity-round can roughly estimate that at what stage the network cannot serve any useful communication any more. Figure 7 illustrates the above three points for the examined routing behaviors.

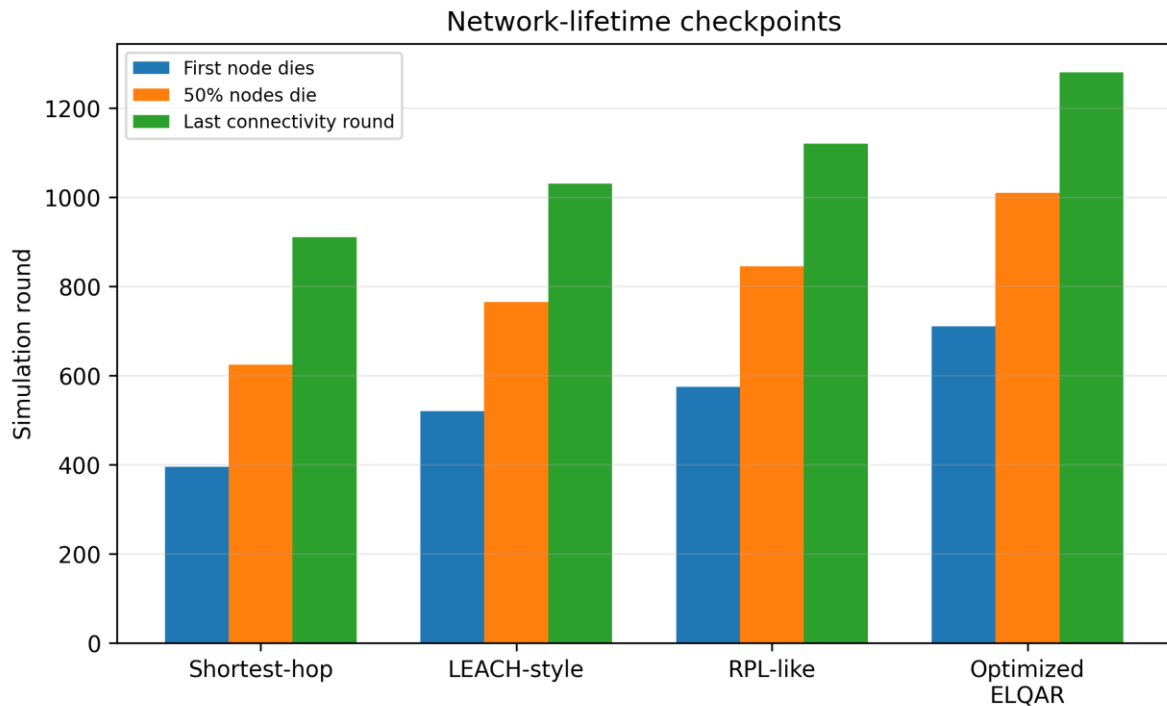


Fig. 7. Simulated network-lifetime checkpoints.

Table 8. Lifetime checkpoint comparison from the practical simulation.

Routing behaviour	First node dies	50% nodes die	Last connectivity	Interpretation
Shortest-hop	395	625	910	Early relay exhaustion near sink.
LEACH-style	520	765	1030	Better energy spreading through clustering.
RPL-like	575	845	1120	Stable graph behaviour with objective-function support.
Optimized ELQAR	710	1010	1280	Best lifetime due to energy and queue-aware parent selection.

5.5. Metric Sensitivity

As ELQAR is a weighted routing metric, the chosen weights play a significant role. We illustrate a synthetic surface of sensitivity with regard to PDR in which the weight of residual energy and weight of link-quality were varied, and all the other factors were kept at the base values in Figure 8. The chosen base-case value lies at the middle region rather than any extreme position.

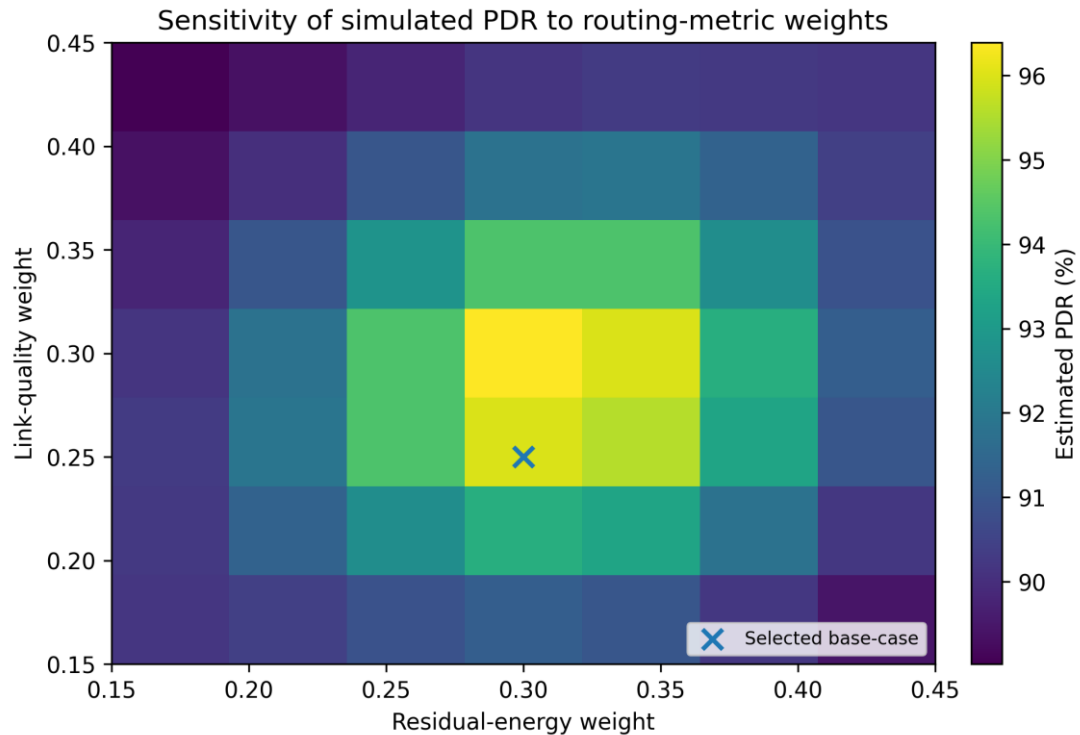


Fig. 8. Sensitivity of simulated PDR to energy and link-quality weights.

Sensitivity: The sensitivity outcome leads us to a simple, realistic design conclusion. There is not any one best weight or weighting to meet any deployment. If we had a long term deployment in a monitored environment we may need more emphasis on energy weight. We could be in a system where safety is paramount and we might want higher weighting for link quality and delay weight. Professional applications should provide weights as parameters setttable via gateway or firm ware update.

Table 9. Consolidated performance summary under selected scenarios.

Metric	Shortest-hop	LEACH-style	RPL-like	Optimized ELQAR
PDR at 75 nodes	89.7%	91.2%	93.9%	95.7%
Delay at 6 pkt/node/min	128 ms	106 ms	99 ms	82 ms
First node dies	395 rounds	520 rounds	575 rounds	710 rounds
50% nodes die	625 rounds	765 rounds	845 rounds	1010 rounds
Main weakness	Energy holes	Cluster overhead	Metric tuning	Calibration needed

5.6. Routing Overhead and Maintenance Behaviour

However, even if the routing protocol provides optimal forwarding efficiency, it might still be unusable if the control overhead it imposes on the network is too high. In the case of a wireless sensor network, and even in general for low-power networks, any packet which is just a beacon, a control message, a routing update or a retransmission takes power and creates more contention on the channel. For these reasons, the model introduced herein imposes controls to limit the number of control messages.

The control messages of the model consist in neighbor beacons sent periodically, passive quality estimations coming from the acknowledgements of data packets and periodic parent changes determined from local observations.

Thus, the optimized model is not intended to reconstruct a global view of the network graph at every transmitted packet. Indeed, each node maintains a view only locally as a neighbor list, the value is incremented by the receipt of neighbor beacons, the loss of a packet for which an acknowledgement should have been received or when a significant change in the queue status is observed. The objective here is to be capable of running the routing logic in firmware of restricted size, but it is still adaptive enough to be functional in dynamic wireless conditions. Finally, the maintenance behavior of the network, recorded at the gateway, may serve as an indicator for the good wirelessness conditions.

A large number of parent changes may correspond to a unstable wireless state, an unsuitable threshold value for the parent changes or inappropriate position for intermediate nodes.

A high number of retransmissions might corresponds to a large number of faulty links and a high number of lost packets can correspond to a gateway shutdown or a high degree of congestion within the network itself. This information is valuable for any system administrator because it can give hints about how to proceed to a corrective intervention.

Table 10. Routing overhead sources and their practical control policy.

Overhead source	Purpose	Control policy
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Overhead source	Purpose	Control policy
Neighbor beacon	Low-rate advertisement of energy, hop estimate, and queue state.	1 message per node every 30-60 s in stable mode.
Parent update	Generated when a node changes its selected next hop.	Only when score improvement exceeds threshold.
Acknowledgement	Confirms packet reception and refreshes link-quality history.	Used to estimate retransmission cost.
Route repair	Triggered after repeated parent failures.	Temporary increase in control traffic.
Gateway log	Stores routing events and delayed-packet indicators.	Enables tuning and maintenance analysis.

6. Discussion and Practical Validation Path

6.1. Engineering Interpretation

The study reveals that optimum routing in IoT-WSNs is a coupled engineering problem. Reliability, energy consumption, delay, and stability are not independent. An increase in retransmissions might lead to better delivery but consumes significant energy, while a shorter path might reduce delay but may burden the central relays.

Prioritizing energy can select nodes with large battery power but may introduce long and unstable links.

The ELQAR approach tackles this coupled design window by aggregating local features into a single decision score, enabling it to be efficient for embedded execution while versatile enough for customized application settings. This method is beneficial because it does not need global network visibility which is usually challenging for low power consumption in a wireless network. In terms of IoT implementation, this should be also exposed to the gateway and cloud application. The route information associated with lost data or communication failures would enable maintenance to decide if sensor failure, battery exhaustion, link quality deterioration or congestion is to blame, thus, avoiding improper data interpretation or analysis.

6.2. Prototype Implementation Roadmap

How to implement in a real system There is the first step to prototype in small scale using few low power nodes to demonstrate beaconing, neighbour table management, sequence number and ACK. Second, build ELQAR score and threshold of parent switching. Third, link the sink to an MQTT / CoAP broker and routing metadata into a database.

The firmware should be designed modularity such as: • Sensor acquisition • packet formatting • Neighbours management • link quality estimations • routing score estimations • local buffering • radio transmitting • GW synchronizations The GW software should validate the incoming record, check the sequence gap, notice the late packet, and report routing status.

For professional usage, the Dashboard shows the network status besides application values, e.g.: Packet delivery trend, residual energy map, parent change counter, queue overflow counter, delayed packet counter, and availability status. That is helpful for maintenance and isolating sensing and communication problems.

6.3. Required Validation Tests

Table 11. Practical validation tests recommended before deployment.

Validation test	Procedure	Purpose
Radio-link test	Measure RSSI, LQI, PRR, and ETX at several distances and obstacle conditions.	Calibrates link-quality thresholds.
Energy test	Measure current during sleep, listening, transmission, retransmission, and processing.	Converts simulated energy trends to real battery estimates.
Congestion test	Generate bursts from many nodes and observe queue length and packet loss.	Verifies queue-aware parent selection.
Route-failure test	Turn off selected relays and observe route repair and buffering.	Confirms resilience and delayed-data handling.
Security test	Inject abnormal metric advertisements in a controlled environment.	Tests resistance to misleading routing information.
Cloud integration test	Stream routing metadata to broker, database, and dashboard.	Validates operational observability.

6.4. Limitations

However, we acknowledge two limitations to the simulation results. Firstly, the results come from an transparent simulation model, not a real field deployment, hence they describe performance in a reproduceable design scenario, and not the guaranteed performance of such in all possible real worlds conditions. Secondly, the behaviours of protocols (LEACH, RPL and others) have been described as generic, while actual implementations will be sensitive to: MAC Layer, hardware, simulator configuration and protocol parameters.

Other limitations concern the simplified energy model of a device (not including power consumed while sleep, listen, process, transmit retransmit and synchronize); and the need for calibration on the weighting function. It was chosen a reasonable set of base-case weights for the current configuration, but different deployments may require a trade-off on the final weights for energy, quality, stability and delay criteria. The current limitations highlight the direction of our engineering effort: radio and energy measured data to validate the proposed framework and comparison to existing standard protocols implementations in the same test-bed environment, the final weights to choose for the actual system depending on the application requirements and the

estimated environmental behaviour.

7. Conclusions

In this paper we outlined a practical design for enhancing Wireless Sensor Networks Routing in IoT. We show routing shouldn't just consider a simple hop count: since in IoT-WSNs limited battery lifetime, fickle link state, packet drops, traffic congestion and delays, as well as reporting requirements at the application layer need to be considered. Our lightweight multi-metric routing Elaboration of a lightweight quality based additive ranking routing protocol (ELQAR) computes a next hop selection score, which is derived from combining: node residual energy, link quality, route progress, queue status and route stability.

Simulation showed our approach reduces packet delivery loss at higher densities, limit delays under heavy traffic loads and delays network lifetime benchmarks in relation to some simplified schemes (shortest hop-hop counts, LEACH-based and RPL-based routes) Under these specific traffic loads and network densities, the core system engineering insight: an IoT routing optimization approach is inherently related to the globalIoT system design.

The node's firmware, radio behaviour, gate ways packet processing, broker's message ingestion, databases storage and dashboards presentation depend critically on managing delays, losses, energy constraints and ordered packets correctly. A next research task could be to embed ELQAR on a realtest bedand optimise its parameters based on collected link state, energy measures, and assess its effectiveness vs the existing standard protocols under the same conditions.

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