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Original Research Article

MOBILITY-AWARE ENERGY-EFFICIENT ROUTING OBJECTIVE FUNCTION FOR IOT-BASED HEALTHCARE SYSTEMS

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Abstract: Healthcare Internet of Things (IoT) deployments rely on wearable and implantable sensors that are energy-constrained and frequently mobile, which complicates reliable multi-hop communication. We propose MAEER-OF, a Mobility-Aware Energy-Efficient Routing Objective Func- tion for RPL that jointly considers link reliability, residual energy, and node mobility for parent selection. Implemented in NS-2, MAEER-OF improves network lifetime, reduces control over- head, and sustains higher packet delivery ratios than baseline RPL and MRHOF across mobility and density regimes. The results indicate a practical path to long-lived, mobility-robust eHealth networks.

Keywords: IoT, eHealth, NS-2, mobility-aware routing, energy efficiency, RPL.

INTRODUCTION

IoT-driven eHealth systems enable continuous monitoring and timely interventions via body- worn and ambient sensors. However, limited battery capacity and patient movement induce frequent topology changes, stressing standard routing. RPL—the de facto IPv6 routing proto- col for Low-Power and Lossy Networks (LLNs)—is effective in static scenarios but its default objective functions (OF0 and MRHOF) optimize hop count or ETX alone, overlooking resid- ual energy and mobility. This can overload popular parents, accelerate battery depletion, and degrade reliability.

Contributions. (i) We design MAEER-OF, a composite objective that integrates ETX, residual energy, and mobility into RPL's parent selection; (ii) we implement it in NS-2 with explicit energy accounting and mobility models; (iii) we experimentally show that MAEER- OF extends lifetime, reduces control overhead, and improves packet delivery versus RPL and MRHOF.

Related Work

RPL and LLNs. In Low-Power and Lossy Networks (LLNs) [1], the IPv6 Routing Protocol for LLNs (RPL) organizes nodes into a Destination-Oriented Directed Acyclic Graph (DODAG) and selects parents using an objective function. OF0 and MRHOF remain the baseline [2], but their reliance on hop count or ETX alone often concentrates traffic and reduces lifetime.

Energy-aware routing extensions. Beyond ETX, researchers have integrated residual en- ergy, queue occupancy, and adaptive weights to balance consumption. Recent work introduced dynamic weight adjustment for RPL in industrial IoT [3], and cluster-based energy optimization for mobile eHealth sensors [4]. These studies show that adjusting the objective function in real time helps avoid early node failure [5].

1Mobility and link stability. Mobility-driven link breakage remains a key limitation. Several 2024–2025 methods use predictive mobility scores to anticipate topology changes and proac- tively reroute [6]. Others combine link quality with velocity estimation to reduce route oscil- lation under patient movement [7]. However, these techniques often focus only on reliability, with less emphasis on energy fairness.

Healthcare IoT focus. Very recent healthcare-oriented protocols explore secure and long- lived operation under mobility [8]. For instance, a lightweight trust-enhanced RPL for patient data was proposed in [9], while [10] introduced context-aware parent selection using patient activity patterns. Yet these works either emphasize trust or context detection rather than a bal- anced joint metric. MAEER-OF directly addresses this gap by combining energy awareness with mobility adaptation while keeping routing overhead low [11].

A number of recent sur- veys have addressed energy-efficiency challenges in wireless body area networks (WBANs), especially for continuous healthcare applications. These works typically investigate routing so- lutions, medium access control (MAC) protocols, or combined cross-layer techniques aimed at reducing power consumption and extending system lifetime. In [12] offered one of the earli- est dedicated reviews of energy-aware routing in WBANs, focusing on classical network-layer strategies such as thermal-constrained, mobility-oriented, and cluster-based schemes. While valuable for foundational understanding, that review narrowly emphasized the network layer and did not analyze other protocol layers or holistic cross-layer designs. The author in [13] pro- vided a broader taxonomy of routing methods, including thermal-aware, cluster-based, QoS- driven, cross-layer, movement-adaptive, cost-efficient, and secure protocols. Their analysis highlighted temperature control and lifetime extension but gave little attention to MAC-level optimizations, energy-aware data handling (aggregation, compression), or energy harvesting, now essential for long-term sustainability. More recent surveys ([14], [15]) explore the integra- tion of emerging technologies to achieve end-to-end energy savings, yet none comprehensively synthesize routing, MAC, data-processing, and harvesting strategies in a single unified review — the gap our work addresses.

Proposed Method

Composite Metric. For node i and candidate parent j,

1 LinkCosti→j = α ·
i→j

+ β REj
REmax

+ γ ·

1 Mobj
Mobmax

, (1)

where α, β, γ weight link reliability, residual energy, and mobility (defaults: 0.3, 0.5, 0.2). The path cost used for ranking is
PathCosti = Rankj + 1 − LinkCosti→j .
(2) Higher LinkCost (good link, high energy, low mobility) reduces PathCost and increases the chance j is selected.

Algorithm 1 MAEER-OF Parent Update (at node i)
1: On DIO from neighbor j: estimate ETXi→j , obtain/estimate REj , Mobj .
2: Compute LinkCosti→j via (1) and PathCosti via (2).
3: if no parent or PathCosti improves beyond hysteresis then
4: Set j as preferred parent.
5: end if

TABLE 1. Simulation Parameters

Parameter	Value
Simulator	NS-2.35
Area	500 m × 500 m
Nodes	20, 40, 60, 80, 100
Sink	1 static node
Mobility Model	Random Waypoint (1–5 m/s)
Traffic	CBR over UDP, 250 kbps
Packet size	30 bytes
MAC/PHY	IEEE 802.15.4
Initial Energy	2.5 Ah @ 3 V per node
Metrics	PDR, Lifetime, Overhead, Energy
Weights	α = 0.3, β = 0.5, γ = 0.2

Parameter Guidance. α emphasizes reliability; β balances load to avoid hotspots; γ pe- nalizes highly mobile parents. In energy-sensitive, moderate-mobility settings, $\beta > \alpha \geq \gamma$ is effective; higher mobility warrants increasing γ.

Implementation in NS-2

We extended NS-2.29 to: (i) compute ETX from per-link delivery statistics; (ii) export node residual energy from the energy model; (iii) derive a per-node mobility indicator from instan- taneous speed (normalized by a configured Mobmax); and (iv) integrate (1)–(2) into the RPL routing agent's parent selection with hysteresis to avoid oscillations. No PHY/MAC changes were required (IEEE 802.15.4 stack used as-is).

RESULTS AND DISCUSSION

We compare MAEER-OF to RPL (OF0/MRHOF) using the settings in Table 1. We report percentage improvements for higher-is-better metrics (Lifetime, PDR) and percentage reduc- tions for lower-is-better metrics (Overhead, Energy), avoiding negative signs.

Network Lifetime. MAEER-OF delays first-node death and increases average operating time by distributing forwarding across nodes with adequate energy and stable links. This avoids persistent "hot parents" observed under ETX-only selection.

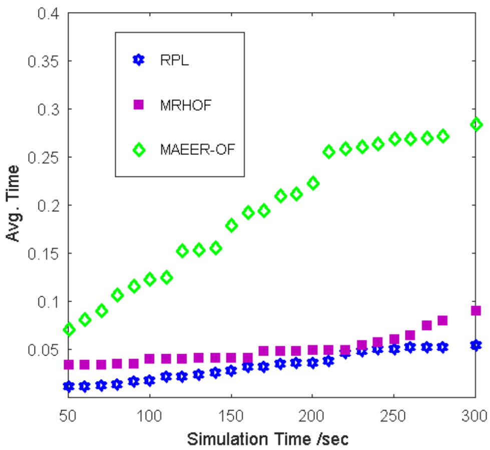

FIGURE 1. Average network lifetime versus simulation time.

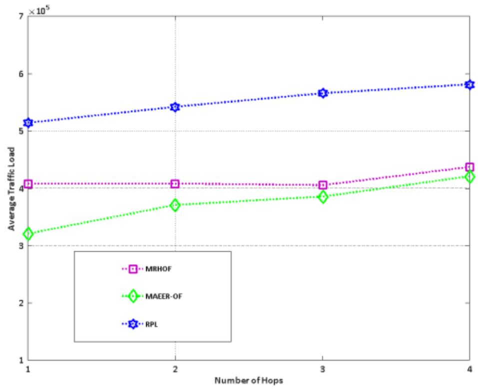

FIGURE 2. Control traffic overhead versus hop count.

Control Overhead. By preferring low-mobility parents with good link quality, MAEER- OF reduces DODAG repairs and parent switches. Compared to RPL, overhead is reduced (e.g., up to 20% at four hops), improving scalability.

Packet Delivery Ratio (PDR). MAEER-OF sustains higher PDR in dense and mobile sce- narios by limiting transient link breaks and retransmissions, outperforming MRHOF that opti- mizes ETX alone.

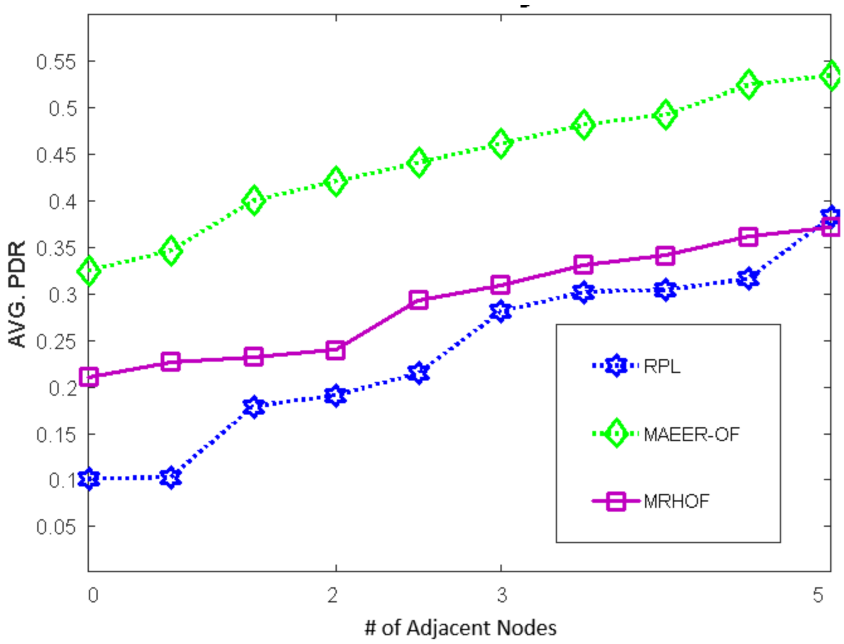

FIGURE 3. Packet delivery ratio versus number of adjacent nodes.

TABLE 2. MAEER-OF vs. Baselines: Improvements (higher-is-better) and Re- ductions (lower-is-better).

Improvements	vs RPL	vs MRHOF
Network Lifetime (Increase)	65%	42%
Packet Delivery Ratio (Increase)	45%	18%
Reductions	vs RPL	vs MRHOF
Control Overhead (Reduction)	20%	12%
Average Energy (Reduction)	30%	17%

Limitations and Future Work

Our evaluation used Random Waypoint mobility and a single 802.15.4 PHY. Other mobility processes (e.g., Gauss–Markov, trace-driven hospital flows) and heterogeneous radios may yield different dynamics. We plan to: (i) adaptively tune (α, β, γ) online; (ii) integrate lightweight security/privacy to protect medical data without harming energy goals; and (iii) validate at larger scale in NS-2 and on a physical tested.

CONCLUSION

This work presented MAEER-OF, a mobility-aware and energy-efficient objective function for RPL that unifies link reliability, residual energy, and node mobility in parent selection. Im- plemented and evaluated in NS-2, MAEER-OF achieved clear gains over baseline RPL and MRHOF, including longer network lifetime, reduced control signaling, and higher packet de- livery ratios under varying mobility and density. These results demonstrate that considering mobility alongside energy can significantly stabilize IoT healthcare networks and prolong their operation.

Future work will focus on adaptive tuning of the weighting parameters to respond to real-time network dynamics, incorporating lightweight security to protect sensitive patient data, and vali- dating the approach under alternative mobility models and larger-scale deployments. Together, these steps will bring MAEER-OF closer to practical, reliable eHealth applications.

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