Run-Time, Metric-Aware Relay Reselection in Bluetooth Mesh Networks

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***Abstract*—Bluetooth Mesh uses managed flooding, in which relay-enabled nodes may retransmit previously unseen messages, increasing redundant forwarding and energy cost as network density grows. Connected Dominating Set (CDS) methods reduce this by selecting a sparse relay backbone, but prior Bluetooth Mesh CDS studies focus on constructing that backbone rather than updating it as conditions change. We investigate run-time relay reselection by periodically re-executing distributed K2 pruning and incorporating local metrics into its pruning decisions. We evaluate two variants. Energy-Aware K2 (EA-K2) uses residual energy, while Multi-Metric K2 (MM-K2) combines residual energy, node degree, and packet reception ratio (PRR). In a 200-node BMSim mobility scenario, static K2 achieves 32.2% median per-source packet delivery ratio (PDR) at the lowest evaluated traffic load, compared with 66.1% for periodically reselected EA-K2 and 71.2% for All-Relay. At that load, energy per delivered packet is $1.08\times$ the All-Relay value for static K2 and $0.76\times$ for EA-K2. At a 5000 ms packet-generation interval under static non-ideal links, PRR-based MM-K2 reaches 59.3% median PDR, close to 61.0% with all metrics and above 37.3% with degree only (All-Relay: 78.0%). These preliminary results motivate run-time reselection under topology change and show that metric choice affects the observed reliability–energy trade-off. Open questions concern reselection triggers, signalling overhead, and metric composition.**

***Index Terms*—Bluetooth Mesh; relay selection; connected dominating set; energy efficiency; network dynamics**

I. Introduction

Bluetooth Mesh (BM) extends Bluetooth Low Energy to many-to-many IoT connectivity through managed flooding [1], [2]. A relay-enabled node may retransmit a received message when the message is absent from its message cache and its TTL permits another hop. Although this mechanism improves robustness, enabling every node as a relay increases redundant transmissions, energy consumption, and advertising-channel contention as network density grows [3], [4].

To reduce this overhead, a subset of nodes can be selected as relays while preserving multi-hop reachability. Connected Dominating Set (CDS) methods provide one way to construct such a relay backbone. K2 pruning [5] is a distributed CDS heuristic that determines relay status using two-hop neighbourhood information. Existing Bluetooth Mesh CDS studies focus primarily on constructing relay sets rather than periodically updating them as conditions change [4], [6].

A relay set selected at initialization may become outdated as topology changes. Moreover, the original K2 pruning procedure is driven by topological coverage and does not explicitly account for changing node or link conditions such as residual energy or link quality. We therefore periodically re-execute K2 using local one-hop and derived two-hop neighbourhood information and evaluate two metric-aware variants. Energy-Aware K2 (EA-K2) incorporates residual energy into the pruning decisions, whereas Multi-Metric K2 (MM-K2) combines residual energy, node degree, and packet reception ratio (PRR). The fixed reselection period is used only as a controlled evaluation setting; designing a condition-based trigger remains an open question.

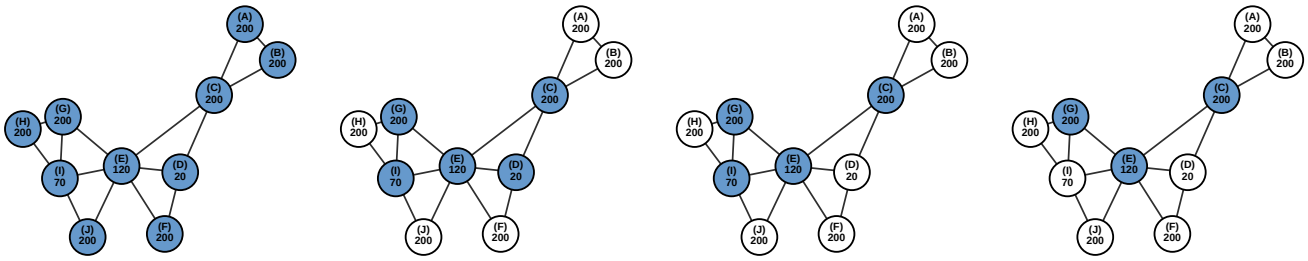
Preliminary BMSim results show that performance depends on network conditions. Under mobility at the lowest evaluated traffic load, static K2, which selects the relay set only at initialization, achieves 32.2% median per-source packet delivery ratio (PDR), with energy per delivered packet equal to $1.08\times$ that of All-Relay, the baseline in which every node relays. Periodically reselected EA-K2 achieves 66.1% median per-source PDR with $0.76\times$ the All-Relay energy per delivered packet. Thus, in these runs, static K2 combines lower delivery with no energy-per-delivered-packet advantage over All-Relay. In the static ideal-link control, periodically reselected EA-K2 achieves slightly higher median PDR at the heavier loads but requires more energy per delivered packet than static K2 at all evaluated loads. Under static non-ideal links, PRR-aware and all-metrics MM-K2 achieve higher median per-source PDR than degree-only ranking.

Contributions. This poster paper makes two contributions: (i) run-time relay reselection through periodic K2 re-evaluation using local one-hop and derived two-hop information; and (ii) metric-aware K2 pruning through EA-K2 and MM-K2. We evaluate these methods across three BMSim scenarios.

II. Background and Related Work

CDS-based relay selection. A dominating set is a subset of nodes such that every node is either in the set or adjacent to one of its members. A connected dominating set (CDS) additionally induces a connected subgraph, allowing the selected nodes to form a relay backbone. Finding a minimum CDS is NP-hard, so practical approaches use heuristics; both CDS construction and backbone maintenance under topology changes have been studied in ad hoc and sensor networks [7]. Wu and Li proposed a localized marking process followed by two pruning rules that remove redundant marked nodes while preserving

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(a) Initial: all nodes relay. (b) After marking phase. (c) After pruning Rule 1. (d) After pruning Rule 2.

Fig. 1. EA-K2 on a 10-node example; labels show node identifiers and residual energy, and filled nodes act as relays. After marking, Rule 1 removes D in favour of higher-energy E; Rule 2 removes I, whose neighbourhood is covered by G and E. The surviving relay set $\{\mathrm{C}, \mathrm{E}, \mathrm{G}\}$ remains connected.

domination and connectivity [5]. This two-hop marking-and-pruning heuristic is referred to as K2 in prior Bluetooth Mesh work [4]. Node identifiers provide a deterministic ordering among eligible nodes during pruning.

Relay selection in BM. Measurement studies show that excessive relaying in Bluetooth Mesh can increase contention, delay, and energy consumption [3], [8]. Experimental work also shows that enabling a suitable relay subset can reduce redundant forwarding while maintaining delivery performance [9], [10]. Hansen et al. [4] evaluated distributed CDS algorithms for Bluetooth Mesh, including K2, while Reno et al. [6] compared centralized, localized, and distributed relay-selection approaches. Other studies applied centralized CDS methods to smart-home networks [11], proposed a Minimum Relay Tree [12], or used a genetic algorithm within a Digital Communication Twin to optimise relay sets [13]. These works provide mechanisms for constructing or optimising Bluetooth Mesh relay sets. Our focus is periodic, metric-aware reassessment of relay-set membership during operation.

Energy-aware role assignment beyond BM. Energy-aware role assignment is well established in wireless sensor network clustering. LEACH [14] rotates cluster-head responsibility across rounds, whereas HEED [15] periodically selects cluster heads using residual energy and a secondary communication-cost criterion. These approaches demonstrate the broader value of incorporating node state into communication-role assignment, but address clustering rather than CDS-based relay selection in Bluetooth Mesh. We therefore do not claim novelty for energy-aware role assignment as a general concept; rather, we study how energy, topology, and link-quality information affect repeated K2-based relay selection in Bluetooth Mesh.

Run-time adaptation in BM. Silvestre-Blanes et al. [16] dynamically adjust relay retransmission count and transmit power using locally observed reliability and neighbour information. Their approach changes the operating parameters of active relays, whereas ours re-evaluates which nodes belong to the relay set during operation.

III. Run-Time Relay Reselection

Run-time reselection extends initialization-time K2 by reapplying its marking-and-pruning procedure during network operation. At each reselection step, nodes recompute their marking state using stored one-hop neighbourhoods, derived two-hop information, and local metric values. The resulting relay set is used until the next step. In our evaluation, reselection occurs every 60 s; this fixed period enables controlled comparison with initialization-time selection, while condition-based triggering and its overhead remain open questions.

Energy-Aware K2. The network is modelled as a connected undirected graph $G = (V, E)$, where an edge connects two nodes within communication range. Let $N(v)$ denote the one-hop neighbours of node v, and let $N[v] = N(v) \cup \{v\}$ denote its closed neighbourhood. Each node maintains a Boolean marking variable $m(v)$ and residual energy $E(v)$. At the start of each execution, $m(v)$ is set to true. After marking and pruning, node v acts as a relay if and only if $m(v)$ remains true. During the marking phase, $m(v)$ remains true if v has two neighbours that are not adjacent; otherwise, it is set to false. Three rules then remove redundant marked nodes. Rule 1 unmarks v if a higher-energy marked neighbour covers $N[v]$. Rule 2 unmarks v if two adjacent marked neighbours jointly cover $N[v]$ and v has the lowest residual energy among the three. Rule 3 unmarks v if all marked one-hop neighbours of v form a connected set, collectively cover $N[v]$, and have higher residual energy than v. Compared with original K2, EA-K2 uses residual-energy comparisons and adds Rule 3. Fig. 1 illustrates the marking phase and Rules 1–2; Rule 3 is not activated in this example.

Multi-Metric K2. MM-K2 retains the marking phase and three pruning rules of EA-K2 but replaces the residual-energy comparisons with

$$W(v) = W_1 D_n(v) + W_2 \frac{P_m(v)}{100} + W_3 \frac{P_a(v)}{100} + W_4 \frac{E(v)}{E_{\max}}. \quad (1)$$

Here, $D_n(v) = \min(d(v)/T_D, 1)$, where $d(v) = |N(v)|$ and $T_D = 7$. $P_m(v)$ and $P_a(v)$ are the median and mean PRR, in percent, over the one-hop links of v, while $E(v)/E_{\max}$ is the fraction of the common initial energy capacity that remains. Each coefficient is set to 0 or 1 to compare metric combinations rather than optimise their weights. During pruning, $W(v)$ replaces residual energy in the three EA-K2 rules; when their

TABLE I
ADDITIONAL SIMULATION PARAMETERS

Parameter	Value
Simulated time	300 s
Advertising interval	20 ms
Scan window / interval	30 / 30 ms
Transmission range	11.26 m
Random back-off	10 ms
Buffer size	6
Network Transmit Count	0
Relay Retransmit Count	0
Packet size	38 B
Initial TTL	127
Reselection period	60 s
Runs per configuration	2

coverage and connectivity conditions permit pruning, nodes with higher $W(v)$ are preferred for retention.

IV. Preliminary Evaluation

Setup. We use BMSim [17], an event-driven BM simulator, with the parameters in Table I. A total of 200 nodes are placed uniformly at random positions in a 120×120 m area, with the placement constrained to ensure network connectivity. One node is the sink, and the other 199 generate traffic toward it at intervals of 400, 1000, or 5000 ms.

The configured transmission range is 11.26 m. In the non-ideal scenario, link quality is represented by a fixed PRR matrix whose values are drawn uniformly from $[20\%, 90\%]$. MM-K2 uses these configured values as its link-quality metric. In the mobility scenario, BMSim relocates 20 nodes every 50 s using Random Waypoint. Energy is obtained from BMSim's model of radio-state durations using nRF52840 current-consumption figures.

We report the distribution of per-source PDR across the source nodes and total network energy divided by the aggregate number of delivered packets, normalised separately at each load to the corresponding All-Relay value. Each configuration is simulated twice. Fig. 2 summarises the results for the three evaluated scenarios.

(a) Static network, ideal links. This panel serves as the control. At a 5000 ms packet-generation interval, all three schemes achieve near-complete delivery (98.3% All-Relay and 96.6% for both CDS schemes), and static K2 uses $0.59\times$ the All-Relay energy per delivered packet, against $0.68\times$ for EA-K2. Under heavier load, both CDS schemes achieve lower median PDR than All-Relay; at 400 ms, median PDR is 17.8% for static K2 and 22.6% for EA-K2 versus 30.7% for All-Relay, as All-Relay's additional forwarding paths provide useful redundancy despite higher contention. Without topology change, EA-K2 thus yields slightly higher median PDR than static K2 at heavier loads, but higher energy per delivered packet at all loads.

(b) Mobility, ideal links. Static K2 degrades most strongly because its relay set remains tied to the initial topology: at 5000 ms its median PDR is 32.2%, compared with 71.2% for All-Relay and 66.1% for EA-K2. Static K2's normalised energy per delivered packet rises from $0.86\times$ to $0.95\times$ to $1.08\times$ as traffic thins. Because this metric divides total network energy by successful deliveries, the sharp delivery loss can erase the saving obtained from fewer forwarding nodes. In these runs, the periodically reselected EA-K2 configuration remains at $0.79\times$, $0.77\times$, and $0.76\times$, suggesting that refreshing a metric-aware relay set can preserve both delivery performance and the backbone's energy advantage under topology change.

(c) Static network, non-ideal links. With a fixed topology and fixed non-ideal per-link PRRs, we compare Degree (1000), Energy (0001), PRR (0110), and All Metrics (1111), where the digits follow (W_1, W_2, W_3, W_4) and $T_D = 7$. Differences in delivery performance become clear at a 5000 ms packet-generation interval: degree alone reaches 37.3%, residual energy 50.8%, PRR 59.3%, and all metrics together 61.0% (All-Relay: 78.0%). PRR-based ranking therefore performs close to the all-metrics configuration and substantially above degree-only ranking in this scenario. The all-metrics variant also has the lowest normalised energy per delivered packet at $0.77\times$, whereas degree-only is $1.00\times$ and shows no per-packet energy advantage over All-Relay in this scenario.

V. Discussion and future work

Future work will address three main aspects. First, the signalling and energy overhead of periodic reselection should be quantified; with one neighbourhood-and-metric advertisement per node every 60 s, the control traffic is approximately 3.3 messages/s network-wide, but this overhead is not yet included in the simulations. Second, the fixed 60 s reselection interval should be replaced by condition-based triggers, such as neighbourhood changes, residual-energy thresholds, or PRR degradation, while avoiding excessive updates and oscillations. Finally, the MM-K2 metric composition should be refined, particularly the relative contribution of mean and median PRR compared to degree and residual energy.

VI. Conclusion

This paper treats Bluetooth Mesh relay selection as a run-time decision and studies which local metrics should guide that decision. In the evaluated mobility scenario, static K2 falls to 32.2% median PDR at the lightest load and its energy per delivered packet reaches $1.08\times$ the All-Relay reference, while the periodically reselected EA-K2 configuration reaches 66.1% at $0.76\times$. Under a static topology with non-ideal links, PRR-aware and all-metrics rankings substantially outperform degree-only ranking. These preliminary results support continued study of run-time,

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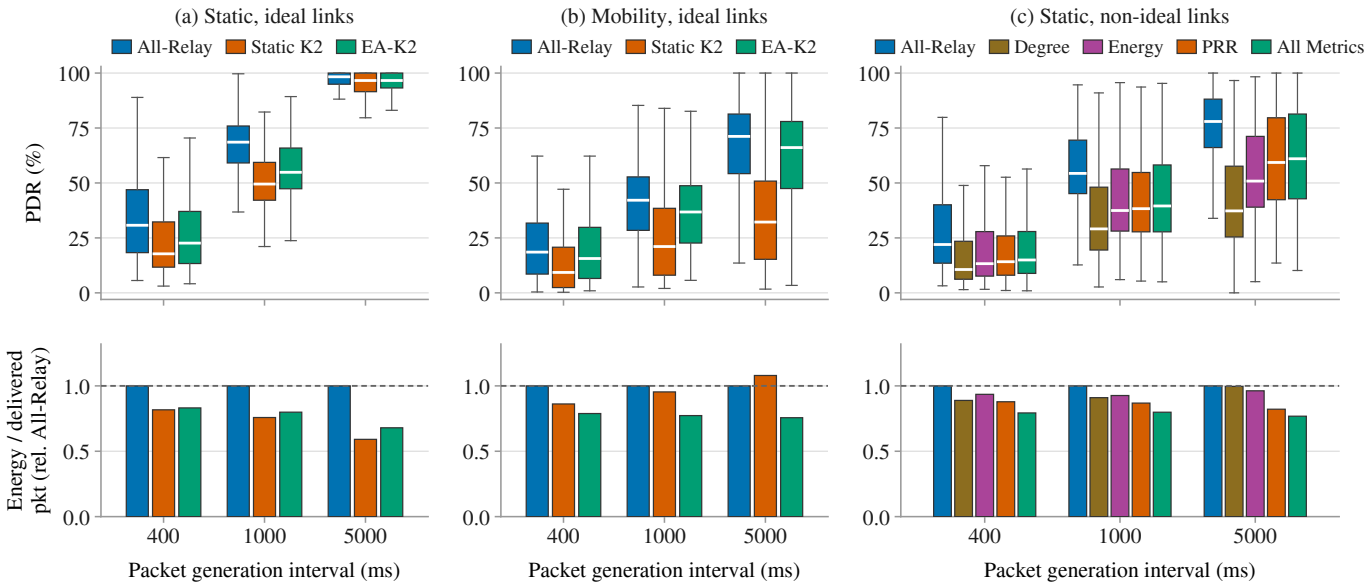


Fig. 2. Top: PDR distribution over source nodes. Bottom: total network energy per delivered packet, normalised to All-Relay at each load (dashed 1.0 line). Under mobility (b), static K2's energy advantage erodes, and its normalised energy per delivered packet slightly exceeds All-Relay at 5000 ms.

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