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Buffer-Constrained Cooperative MAC with Energy-Aware Relay Selection in Mobile Ad Hoc Networks

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Abstract—Cooperative medium access in mobile ad hoc networks (MANETs) requires consideration of relay-buffer availability and energy consumption in addition to wireless-link conditions. This paper proposes a buffer-constrained cooperative medium access control (MAC) framework that integrates source and relay storage allocation, queue-service scheduling, and energy-aware helper selection. A candidate helper is eligible only when its link information is sufficiently recent, a relay-buffer slot can be reserved, the estimated transaction time satisfies a predefined time-saving margin, and the required energy reservation maintains a minimum residual battery level. Direct transmission is retained when no suitable helper is available. The framework distinguishes immediate MAC-layer cooperative forwarding from queued network-layer transit traffic and specifies control exchanges, resource reservations, and timeout handling. Deterministic analytical examples examine buffer-allocation feasibility, helper rejection conditions, and the influence of payload size on cooperation overhead. For an illustrative 1024-byte payload under the stated loss-free assumptions, the calculated transaction time is 2.734 ms with an eligible helper, compared with 4.396 ms for direct transmission. These calculations illustrate a potential transaction-time advantage under the assumed conditions rather than measured network performance. The proposed framework provides a resource-aware protocol specification and a controlled evaluation plan; its network-level effectiveness and potential lifetime benefits remain to be established through simulation or testbed validation.

Keywords—Mobile ad hoc networks, cooperative MAC, buffer allocation, relay selection, residual energy, analytical evaluation.

1. INTRODUCTION

A mobile ad hoc network (MANET) comprises wireless nodes that can originate traffic and forward traffic for other nodes without relying on fixed routing infrastructure. Mobility, shared-channel contention and resource constraints make protocol evaluation sensitive to topology, traffic and operating assumptions [1]. Medium access must therefore be assessed together with the traffic that it admits and the resources required completing each exchange.

A low-rate direct link may sometimes be replaced by two faster transmissions through a helper. Relay-enabled MAC designs such as rDCF and CoopMAC establish this principle [2], [3]. However, an additional transmitter, control messages and packet handling are not free. A favorable pair of link rates does not establish that a helper has available storage, sufficient energy or a beneficial effect on network-wide performance.

The problem considered here is a local decision: for a queued packet and its selected next-hop destination, should the current node transmit directly or nominate one neighboring helper? The decision is made under a configured split between locally generated and relayed traffic. The objective is to select a feasible exchange with a lower estimated completion time while enforcing buffer and active-radio energy constraints. This objective is narrower than globally optimal resource allocation or network-lifetime maximization.

The proposed elaboration brings together an explicit storage quota, a queue-service share, a helper-feasibility test, an acknowledged forwarding sequence and a planned comparison protocol. Established cooperative forwarding, energy awareness and buffer-aware relaying are attributed

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to prior work rather than presented as newly invented concepts.

2. RELATED WORK

2.1 Medium access and cooperative forwarding

Bianchi's analysis of the IEEE 802.11 distributed coordination function demonstrates the importance of contention and backoff in evaluating medium access [4]. The rDCF protocol uses relay-enabled operation in wireless ad hoc networks [2]. CoopMAC employs a helper to replace a slow direct transfer with two faster transmissions and addresses associated MAC signaling [3]. A two-link payload-time comparison is consequently a useful screening calculation, but it is not a saturation-throughput model.

Bletsas et al. study distributed relay selection for cooperative diversity [5]. Their physical-layer diversity setting should not be conflated with the sequential packet forwarding specified here. The present design does not assume simultaneous transmissions, distributed space-time coding or signal combining at the destination. The cooperative action is a source–helper–destination transfer inside a reserved MAC exchange.

2.2 Energy, buffers and fairness

Wang and Li investigate network-lifetime-oriented cooperative MAC design for MANETs [6]. Sami et al. develop an energy-aware cross-layer protocol [7], while Liu et al. examine power-optimized cooperation in wireless sensor networks [8]. These studies motivate accounting for helper energy and circuit activity. Their performance claims cannot be transferred to a different protocol or topology without implementing the relevant models and comparisons.

Hadef et al. study buffer-aided selection with energy awareness [9]. Shamna and Jacob combine energy and throughput objectives [10], while Mousavi et al. address cooperation fairness [11]. These considerations are established, not new contributions. This proposal instead specifies a local admission and selection procedure with explicit assumptions and calculable examples.

Table 1. Selected literature and its role

Prior work	Established consideration	Use in this design
rDCF [2]; CoopMAC [3]	Relay-enabled MAC and two-hop forwarding.	Baseline mechanism and explicit control overhead.
Wang and Li [6]; Sami et al. [7]	Energy/lifetime-aware cooperation.	Battery-reserve checks; no inherited lifetime results.
Liu et al. [8]; Hadef et al. [9]	Power allocation and buffer-aware selection.	Motivation for energy and storage feasibility; not a reproduction of those optimizers.
Shamna and Jacob [10]; Mousavi et al. [11]	Energy/throughput tradeoffs and cooperation fairness.	Per-flow goodput and helper-use reporting in evaluation.

3. PRELIMINARIES AND RESOURCE MODEL

3.1 Network and traffic scope

Consider half-duplex, single-channel nodes with a finite set of supported transmission rates. The routing layer supplies the next-hop destination D for the current transmitter S. A MAC helper H is an additional intermediate transmitter for this one exchange; it does not replace the routing protocol. Direct S–D control connectivity and bidirectional control reception among the three participants are assumed. Route repair for an unreachable destination remains outside the helper-selection procedure.

Each node maintains a source FIFO for locally generated traffic and a relay FIFO for packets forwarded by the routing layer. A selected MAC helper additionally reserves one slot inside its relay quota for the immediate cooperative frame. That frame is forwarded during the current reservation and is not placed behind the ordinary relay FIFO. The distinction avoids treating a tightly timed MAC exchange as store-carry-forward routing.

3.2 Storage allocation and admission

Let B be an integer packet-slot budget and let κ be the configured source-storage fraction. Select κ so that both quotas contain at least one slot. The capacities are

$$B_s = \lfloor \kappa B \rfloor, \qquad B_r = B - B_s \tag{1}$$

The relay capacity is the remainder, rather than a second independently rounded product, so all B slots are accounted for. An arrival is dropped at its class boundary when its quota is full. This initial design does not borrow unused capacity between classes or shrink a live queue below its occupancy. Such policies would need separate definitions and tests.

For helper h, let Qr,h be its ordinary relay occupancy and Zh its reserved helper-slot count. The available capacity is

$$F_h = B_{r,h} - Q_{r,h} - Z_h \tag{2}$$

A cooperative exchange requires Fh ≥ 1 and an atomic reservation before acceptance. Reservation state must be released on completion or timeout. With one half-duplex radio, the initial specification permits at most one active helper reservation per node. The source retains its own packet until the destination acknowledges it.

3.3 Transmission opportunities and queue service

The parameter η is the probability of selecting the source FIFO when both ordinary FIFOs are nonempty; the relay FIFO is selected with probability 1 − η. When only one FIFO is nonempty, it receives the ordinary service attempt. Selection occurs before a node begins contention. Immediate forwarding in another node's reserved cooperative exchange is not delayed by this lottery.

For M ordinary service selections with both queues continuously backlogged, independent draws give

$$\mathbb{E}[N_s] = M\eta, \quad \mathbb{E}[N_r] = M(1-\eta) \tag{3}$$

These are expected selection counts, not successful deliveries or airtime fractions. Variable packet lengths, failed attempts and cooperative transfers may consume different durations. Positive η and 1 − η do not give a deterministic waiting-time bound. Moreover, η is not interpreted here as a probability of a cell-level source-to-relay or relay-to-destination encounter.

Table 2. Principal notation.

Symbol	Meaning
B; Bs; Br	Total, source and relay capacities (packet slots).
κ; η	Source-storage fraction; source-selection probability.
Qr,h; Zh; Fh	Relay occupancy, reservations and free slots at helper h.
ℓ; Rij	Payload bits; configured data rate from i to j (bit/s).
Cd; Ch; Td; Th	Non-payload time and calculated no-loss exchange time (s).
Ed; Eh	Total modeled active-radio energy of an exchange (J).
Eres,h; Emin,h	Helper's residual energy and minimum reserve (J).
δ; β	Required time-saving margin; exchange-energy multiplier.

4. PROPOSED COOPERATIVE MAC DESIGN

Figure 1 separates ordinary packet scheduling from helper nomination and feasibility assessment. The diagram is an original representation of the specification developed here; it is not an implementation trace or a reproduction of a published protocol figure.

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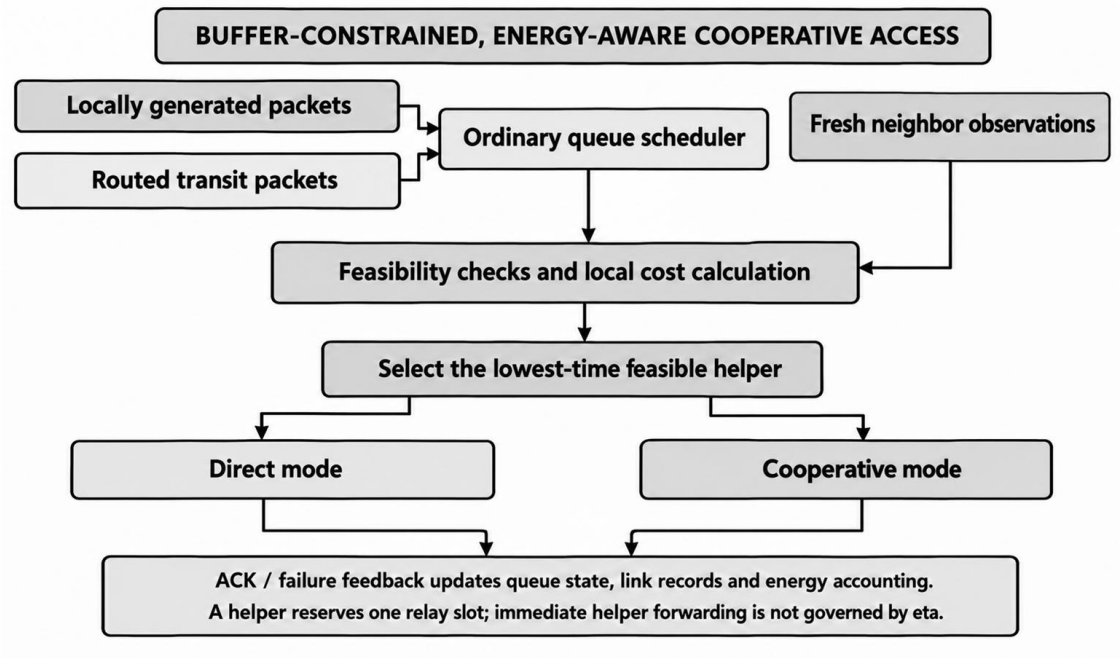

Figure 1. Proposed buffer-constrained and energy-aware MAC controller.

4.1 Link state and no-loss exchange time

The current node stores time-stamped estimates of direct and helper-link rates together with reported relay capacity and battery state. Stale entries, missing reverse-control connectivity and failed reservations invalidate a candidate. Link quality must be recorded separately from rate: an ETX-style measurement emphasizes that delivery probability and asymmetry matter [12]. No delivery probability is inferred merely from physical distance.

Let ℓ denote the payload length in bits. Cd and Ch contain the complete modeled non-payload time of direct and cooperative exchanges, respectively: headers, preambles, control frames and interframe gaps. They exclude queueing and the contention that preceded the reservation. Under successful transmissions without retries,

$$T_d = C_d + \frac{\ell}{R_{sd}} \tag{4}$$

$$T_h = C_h + \frac{\ell}{R_{sh}} + \frac{\ell}{R_{hd}} \tag{5}$$

The two forwarding phases are sequential, so their durations add. These expressions are local timing estimates; they are not mean end-to-end delays. An executed simulator must calculate overhead from its configured frame formats and PHY mode rather than assume the numerical constants used in Section 5.

4.2 Active-radio energy and reserve constraints

Let Ptx and Prx denote total electrical power in the corresponding radio state, including circuit consumption, rather than radiated RF power alone. With control-related energy Ec, the modeled active-participant costs are

$$E_d = (P_s^{\mathrm{tx}} + P_d^{\mathrm{rx}})\frac{\ell}{R_{sd}} + E_{c,d} \tag{6}$$

$$E_h = (P_s^{\mathrm{tx}} + P_h^{\mathrm{rx}})\frac{\ell}{R_{sh}} + (P_h^{\mathrm{tx}} + P_d^{\mathrm{rx}})\frac{\ell}{R_{hd}} + E_{c,h} \tag{7}$$

Idle listening, overhearing by nonparticipants, mobility-related control traffic and retransmission energy are not included in these simple expressions. They must be included in the network-level measurements. Configured powers are inputs; this proposal does not solve a continuous transmit-power optimization problem.

A helper must satisfy the configured time and energy limits

$$T_h \le (1-\delta)T_d, \qquad E_h \le \beta E_d \tag{8}$$

Here $0 \le \delta < 1$, while β specifies the tolerated exchange-energy ratio. The examples use δ = 0.10 and β = 1. These values are design choices, not settings established as optimal. For one successful helper reception and forwarding operation, its own energy requirement is

$$e_h = P_h^{\mathrm{rx}}\frac{\ell}{R_{sh}} + P_h^{\mathrm{tx}}\frac{\ell}{R_{hd}} + e_{c,h} \tag{9}$$

Before confirming the exchange, the helper reserves an upper bound eh,reserve for the radio activity and timeout duration it is agreeing to support. Acceptance requires

$$E_h^{\mathrm{res}} - e_h^{\mathrm{reserve}} \ge E_h^{\min} \tag{10}$$

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The source applies an analogous local reserve check. The destination must also be available to participate. A successful no-loss cost is not a worst-case reserve in a lossy execution: the actual reservation must cover the configured control, waiting and forwarding bounds. Each new source retry requires a fresh feasibility decision; helper energy cannot be promised repeatedly from a stale battery report.

4.3 Feasible helper selection

Let Hfeasible contain only fresh, reachable helpers that pass the buffer reservation, source/helper reserve and exchange-cost tests. The selected candidate is

$$h_{\mathrm{sel}} = \arg\min_{h \in \mathcal{H}_{\mathrm{feasible}}} T_h \qquad (11)$$

Ties are resolved by greater remaining helper energy after reservation, then by a stable node identifier. A single scan costs O(m) for m known candidates, excluding neighbor discovery. The minimum is only over the currently enumerated, feasible local helpers. It does not prove global throughput optimality, fairness or maximum network lifetime. An empty feasible set triggers direct transmission if the direct mode itself remains feasible; otherwise the node defers or drops under its documented retry policy.

4.4 Reservation, forwarding and failure handling

The source nominates one helper in an extended request-to-send (RTS) message. The helper atomically checks its slot and energy budgets and returns a helper-clear-to-send (H-CTS) response. The destination returns CTS only after the expected control sequence. Payload transfer then proceeds from S to H and from H to D, followed by a destination ACK that is receivable by S and H. Figure 2 shows the logical order; H-CTS is a proposed extension, not a standard frame claimed to exist in unmodified devices.

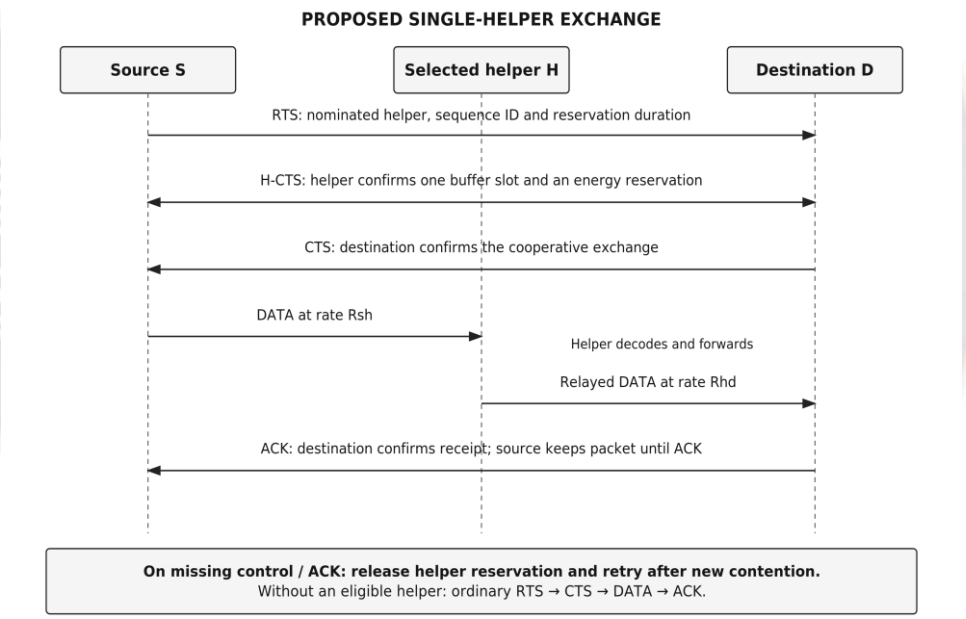

Figure 2. Logical cooperative exchange with one preselected helper.

Every participant validates the source identifier, destination, helper identifier and packet sequence number. The announced channel-reservation duration must cover the full selected exchange. Missing H-CTS, CTS or ACK ends the attempt; the helper releases its temporary slot after the appropriate timeout and the source retries only after a new contention procedure. The destination suppresses duplicate delivery while still acknowledging a successfully received duplicate. A helper does not retain an orphaned copy for later ordinary forwarding.

Direct fallback uses its own ordinary RTS–CTS–DATA–ACK transaction. It is not an unsignaled transmission inserted into a failed cooperative reservation. Control-message collisions, hidden terminals, inaccurate channel estimates and legacy-node interoperability still require explicit simulation and implementation checks. Merely naming a helper does not eliminate interference.

4.5 Decision procedure

Algorithm 1. Proposed local procedure; no executed implementation is claimed.

1 Admit arrivals only within their quotas.
2 Choose an ordinary queue using eta.
3 Read the head packet and its next hop.
4 Reject stale helper-state entries.

5 Calculate direct time and radio energy.6 For each reachable candidate helper:

check slot, link and energy feasibility;

calculate cooperative time and energy;

retain it only when all tests pass.

7 Choose the feasible minimum-time helper.

8 If none exists, use feasible direct mode.

9 Contend, reserve and recheck live state.

10 Keep source copy until destination ACK.

11 On failure, release; re-contend or drop.

The invariants are that occupied plus reserved slots never exceed a quota, the source retains a copy until ACK or a declared drop, and helper activity never extends beyond its reservation. Tests must include transit arrivals during an active helper reservation.

5. ANALYTICAL RESULTS UNDER STATED ASSUMPTIONS

5.1 Evidence status and numerical inputs

The supplied project contains a network-animation screenshot but no numerical performance series, simulator configuration, random seeds or raw packet traces. Consequently, the results below are deterministic calculations for constructed cases. They do not recover experimental evidence from that image or validate the original claims of improved network lifetime.

For the first example, assume a 1024-byte payload (ℓ = 8192 bits), Rsd = 2 Mbit/s, Cd = 0.30 ms and Ch = 0.50 ms. All active transmit and receive powers are set to 1.4 W and 0.9 W, respectively. Direct and cooperative control energy are 0.20 mJ and 0.40 mJ; the helper portion of cooperative control energy is 0.10 mJ. Links succeed without retries. These are illustrative inputs selected for arithmetic transparency, not hardware measurements.

The direct-mode equations give Td = 4.396 ms and Ed = 9.6208 mJ. The helper battery floor is 0.200 J. In this deterministic case only, the reserved helper energy equals its successful-exchange cost; a practical retry/timeout budget can only increase that reservation. Source and destination participation is assumed feasible for all rows.

Table 3. Calculated candidate comparison for the assumed loss-free 1024-byte transaction

Helper	Rates S–H / H–D (Mbit/s)	Free relay slots	Residual energy (J)	Time Th (ms)	Active energy Eh (mJ)	Feasibility decision
H1	11 / 11	0	0.800	1.989	3.826	Reject: no buffer slot
H2	5.5 / 11	8	0.800	2.734	5.539	Select: all tests pass
H3	2 / 11	15	0.900	5.341	11.534	Reject: time and energy
H4	11 / 11	8	0.201	1.989	3.826	Reject: battery floor

Time includes the assumed fixed overhead but excludes contention and queueing. Energy is limited to active participants and stated control costs; it is not whole-network energy.

5.2 Interpreting helper rejection

H1 is the fastest candidate alongside H4, yet cannot accept the packet because its relay quota is full. H4 has a free slot but would spend approximately 1.813 mJ, leaving 0.199187 J, below the specified floor. H3 is slower than direct mode and exceeds the active-radio energy limit. H2 is therefore selected even though it is not the fastest unconstrained candidate.

H2 requires 2.734 ms and 5.539 mJ in the stated no-loss model. Relative to the constructed direct case, the calculated reductions are 37.80% in exchange time and 42.43% in active-radio energy. These percentages apply only to this arithmetic example. They are not throughput gains, measured energy savings, lifetime extensions or comparative benchmark scores. H2 itself spends approximately 2.483 mJ, leaving 0.797517 J from its assumed 0.800 J battery state.

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5.3 Storage and transmission-share examples

Table 4 holds ordinary relay occupancy at 32 slots with no existing helper reservation, and varies the source-storage fraction. The last configuration is infeasible for that snapshot: allocating 20 relay slots cannot accommodate 32 already queued packets. A runtime reconfiguration would need an explicitly specified drain or migration procedure, which the present static-quota design does not provide.

Table 4. Arithmetic capacity examples for B = 100 and Qr = 32

κ	Bs	Br	Free relay slots / status
0.20	20	80	48
0.40	40	60	28
0.60	60	40	8
0.80	80	20	Infeasible: Qr > Br

The two allocation parameters control different resources. With both queues backlogged over M = 100 ordinary selections, η values of 0.3, 0.5 and 0.7 imply expected source/relay selections of 30/70, 50/50 and 70/30. They do not alter the memory split. The binomial standard deviation of the source count is $\sqrt{(M\eta(1-\eta))}$, giving approximately 4.58, 5.00 and 4.58 selections. A realized finite run need not match these means.

5.4 Payload length and cooperation overhead

For a positive denominator and Ch > Cd, cooperation is faster in the no-loss timing model precisely when

$$\ell > \frac{C_h - C_d}{1/R_{sd} - 1/R_{sh} - 1/R_{hd}} \quad (12)$$

For the H2 links, the break-even payload is 880 bits, or 110 bytes. The stricter δ-margin test requires, when its denominator is positive,

$$\ell \geq \frac{C_h - (1-\delta)C_d}{(1-\delta)/R_{sd} - 1/R_{sh} - 1/R_{hd}} \quad (13)$$

At δ = 0.10 the threshold is approximately 162.18 bytes, so integer-byte payloads must be at least 163 bytes under these assumptions. When the denominator is nonpositive and the numerator positive, this margin cannot be achieved by increasing the payload alone. This boundary exposes why relay eligibility cannot be decided from link rates without considering protocol overhead.

Table 5. Calculated time sensitivity with fixed assumed rates and overhead

Payload (bytes)	Direct (ms)	Via H2 (ms)	10% margin
128	0.812	0.779	Fail
256	1.324	1.059	Pass
512	2.348	1.617	Pass
1024	4.396	2.734	Pass
1500	6.300	3.773	Pass

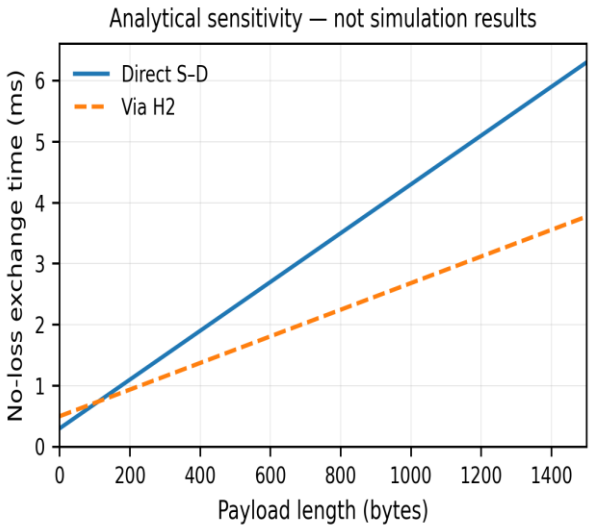

Figure 3. Deterministic payload-time curves from Equations (4) and (5), using the H2 rates.

The 128-byte case is slightly faster through H2 but saves only 4.03%, so the 10% guard rejects it. This is an intentional consequence of requiring a margin rather than selecting any positive predicted saving. If overhead, link rates or loss behavior change, the crossing points and admissible payloads must be recalculated.

6. PROPOSED SIMULATION AND VALIDATION PROTOCOL

6.1 Reproducible network scenarios

Evaluation should begin with static three-node cases that reproduce the arithmetic and control sequence, then progress to contending multihop mobile networks. A network simulator and exact version must be named once the protocol is implemented; none is claimed to have been run here. The PHY mode, packet headers, control rates, retry limit, energy-state model, propagation model and

link-estimation procedure must be reported together with the implementation changes.

AODV [13] may be held fixed as the routing baseline while the MAC changes. Comparing protocols with different routing, queue capacity or offered load would not isolate the MAC effect. Generated topology, mobility and traffic traces should be stored, not described only by a visual screenshot. Table 6 is a proposed starting matrix rather than a reconstruction of the source project's settings.

Random-waypoint initialization can bias a finite experiment if the mobility distribution is not handled carefully [14]. State the initial distribution, minimum speed, pause rule, settling criterion and measured observation interval. Static and mobile conditions should remain separate. Stop-time effects also require attention: packets left in queues at the end of observation cannot silently disappear from delivery accounting.

Table 6. Proposed evaluation matrix.

Factor	Planned values / control
Deployment	25, 50, 75 and 100 nodes in a 1000 m × 1000 m area.
Mobility	Static control; random waypoint with speeds 1–5, 1–10 and 1–15 m/s; initialization declared.
Payload	128, 256, 512, 1024 and 1500 bytes.
Traffic	Fixed source–destination pairs; UDP offered-load sweep; identical traces across MACs.
Packet storage	B = 50, 100 and 200 slots; feasible κ in {0.2, 0.4, 0.6, 0.8}.
Ordinary queue share	η in {0.3, 0.5, 0.7}; log actual service counts and airtime.
Selection guards	Initial δ = 0.10, β = 1; test δ sensitivity; declare energy floors.
Replication	At least 30 independent scenario seeds per fixed condition; paired traces for comparisons.

6.2 Baselines and ablations

The first comparison is direct IEEE 802.11 DCF without cooperative forwarding. A second implements a documented CoopMAC baseline [3] with the same routing, traffic and physical model. The proposed constrained policy is then compared with rate-only nomination, keeping physical memory limits and mandatory battery safety checks in force in every executable variant. A baseline must never be allowed to receive into nonexistent memory merely to create a favorable comparison.

Ablations should vary the buffer-aware nomination test, the exchange-energy guard and the additional time-saving margin one at a time. The κ and η grid is evaluated separately so that any benefit is not incorrectly attributed to helper selection. Parameter selection uses development scenarios; final comparisons use independent scenario seeds. A best setting on a finite grid is reported as such, not as an unrestricted optimal allocation.

6.3 Performance measures and units

Report application goodput and packet-delivery ratio using unique delivered payloads over a defined interval:

$$G = \frac{8B_{\text{delivered}}}{T_{\text{obs}}}, \qquad \text{PDR} = \frac{N_{\text{delivered}}}{N_{\text{generated}}} \tag{14}$$

Bdelivered is a payload-byte count and Tobs is measured in seconds, so G has units bit/s. Generated and delivered packet counts must refer to the same declared packet cohort. Aggregate throughput that includes retransmissions or helper copies is not application goodput. Report buffer-overflow, retry-limit, route-failure and end-of-run undelivered counts separately.

Mean end-to-end delay among delivered packets is

$$\overline{D} = \frac{\sum_{i=1}^{N_{\text{delivered}}} (t_i^{\text{recv}} - t_i^{\text{gen}})}{N_{\text{delivered}}} \tag{15}$$

Delay includes queueing, route discovery when applicable, contention and retransmissions. It is conditional on successful delivery, so it must be interpreted with delivery ratio and drop counts rather than in isolation. Report the median and a high percentile as well as the mean when the distribution is skewed.

Network energy per delivered payload bit and Jain's per-flow fairness index [15] are

$$E_{\text{bit}} = \frac{E_{\text{network}}}{8B_{\text{delivered}}}, \qquad J = \frac{\left(\sum_{f=1}^{m} g_f\right)^2}{m \sum_{f=1}^{m} g_f^2} \tag{16}$$

Enetwork must include transmit, receive, idle, overhearing and control energy of all modeled nodes, without double-counting radio states. The gf values are

per-flow goodputs for a fixed set of m offered flows, including zero-goodput flows. Undefined zero-denominator cases are reported explicitly. First-node exhaustion and loss of required source–destination connectivity are distinct lifetime endpoints; choose and state the endpoint before interpreting any lifetime comparison.

6.4 Statistical reporting and execution checks

Report individual replicate metrics, mean values, standard deviations and uncertainty intervals. For r independent replicate summaries z under a justified mean-interval approximation,

$$\overline{z} \pm t_{0.975,r-1}\frac{s_z}{\sqrt{r}} \quad (17)$$

Paired comparisons use per-seed differences from matching scenarios, not separate unpaired intervals. Packets within the same run are not treated as independent experimental replications. Random-number streams, confidence-interval assumptions and output processing should be documented; simulation credibility depends on both model specification and statistical treatment [16].

Unit tests should cover full buffers, stale candidates, helper refusal, missing ACKs, repeated sequence numbers, a source that reaches its energy floor, and zero feasible helpers. Additional system tests examine hidden terminals, bursty arrivals, asymmetric links, control loss and mobility during reservation. The implementation, configuration files and raw counters are required before the proposal can support empirical performance claims.

7. DISCUSSION AND LIMITATIONS

The feasibility rules make a local decision auditable, but their usefulness depends on the quality and cost of the information they consume. A large neighbor table may be expensive to maintain; a fresh buffer advertisement can become obsolete before the next RTS; and protecting a selected helper's energy does not guarantee balanced energy expenditure across the entire network. Candidate rejection, cooperation frequency and per-node helper workload should therefore accompany summary performance metrics.

The fixed source/relay partition can leave memory unused while another class drops traffic. Increasing κ may protect local bursts yet reduce the node's ability to carry transit traffic; increasing η may increase source-service attempts yet delay relayed traffic. The current proposal does not establish a stable queueing region, a delay bound or an adaptive allocation law. Such claims would require an appropriate traffic model and either a proof or supporting experiments.

The no-loss equations deliberately separate an arithmetic feasibility example from a complete performance model. They omit contention coupling, fading, interference, repeated control failure and most background energy consumption. A shorter modeled exchange can still yield worse application performance when failures or overhead dominate. Likewise, extending time to first battery exhaustion need not preserve end-to-end connectivity or an acceptable packet-delivery ratio.

The source project's general claims of improved throughput, energy and lifetime are not adopted as findings. This revision specifies a testable design and adds analytical examples without supplying the missing implementation evidence. Publication as an empirical article would require actual execution, verifiable records and a comparison appropriate to the target venue.

8. CONCLUSION

This paper has presented a buffer-constrained cooperative medium access control (MAC) design for mobile ad hoc networks (MANETs) that integrates source and relay storage allocation, queue-service scheduling, and energy-aware helper selection. The design distinguishes ordinary queue service from immediate MAC-layer cooperative forwarding. A candidate helper is selected only when sufficient relay-buffer capacity is available, the required energy reservation preserves a minimum residual battery level, and the estimated transaction provides a sufficient time-saving benefit within the specified active-radio energy limit. Direct transmission is retained when cooperation is unsuitable, while acknowledgements, timeout-based resource release, and duplicate suppression are incorporated into the protocol specification.

The analytical examples illustrate how buffer capacity, battery constraints, and cooperation overhead influence local transmission decisions under the stated assumptions. These examples establish the numerical consequences of the proposed model rather than measured improvements in network performance. Future work should implement the control exchange and resource-accounting mechanisms, verify the storage and energy-reservation invariants, and conduct paired baseline comparisons and ablation studies. The resulting simulation or testbed evidence will be needed to assess throughput, energy consumption, and network lifetime. The present study provides a resource-aware protocol specification and an analytical basis for evaluation without claiming global optimality or experimentally verified performance gains.

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