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Load-Aware Greedy Resource Optimization for Energy-Efficient Cooperative Communications In 5g Wireless Ad Hoc Networks

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Abstract
An efficient allocation of network resources is necessary in order to ensure reliability and energy efficiency in 5G Wireless Ad Hoc Networks (WANETs), where factors like spectrum constraints, varying loads, and variable channel conditions have an important impact on the performance of the network. In this research paper, a new architecture called the Load Aware Greedy Resource Optimization (LAGRO) architecture is proposed for cooperative communication networks. The LAGRO architecture is based on the combination of the distributed topology formation and load aware resource optimization approach to choose the appropriate cooperating nodes according to the network conditions.Extensive simulations are conducted in evaluating the proposed architecture against the Conventional resource allocation approaches using multiple performance indicators. Simulation results are showing that LAGRO is maintaining 88.91% energy efficiency, 90.12% network throughput, 89.74% spectrum utilization, 27.84 dB SNR, 89.18% data transfer rate, 91.26% error detection rate, and 90.24% link operational reliability at 50% network load. under the 100% network load, LAGRO is achieving 79.48% energy efficiency, 80.54% throughput, 81.27% spectrum utilization, 23.84 dB SNR, 79.31% data transfer rate, 84.86% error detection rate, and 82.71% link reliability, while it is maintaining 52.46 ms delay and 17.31% packet loss.

Keywords: 5G Wireless Ad Hoc Networks; Cooperative Communication; Resource Allocation; Load-Aware Optimization; Greedy Algorithm; Spectrum Utilization

1. Introduction

The Fifth Generation (5G) Wireless Networks technology is providing high data rates, dense connectivity, low latency communication, and heterogeneous wireless services, creating a significant demand for an efficient spectrum, power, and resources management [1]. Wireless Ad Hoc Networks (WANETs) further enhance these features using the decentralized communication where the nodes form multi-hop connections without relying entirely on the fixed infrastructure. Nevertheless, the dynamics of the topology, limited energy capacity, changing channel characteristics, and resource distribution makes efficient communication a challenge [2]. Device-to-Device (D2D) communication becomes increasingly recognized as an effective method for the increased spectrum efficiency and reduced transmission distance in 5G [3]. Cooperative Communication expands this approach by utilizing the help of intermediate relay nodes for source-destination communication, hence improving the coverage, reliability, and energy efficiency [4]. Relay Selection is especially crucial due to the fact that a poor choice of the relay nodes can significantly increase the overhead, energy usage, and delays, while proper selection will improve the performance of the system [5].

Though all these benefits can be mentioned, there is still a number of interrelated issues that cooperative 5G WANETs have to confront. First of all, there is usually not enough spectrum resources because of competing

heterogeneous users' and dynamically changing traffic's needs [6]. Secondly, the introduction of relay-based transmission adds new issues related to resource allocation such as relay selection, power allocation, channel allocation, and transmission scheduling [7]. Thirdly, there is an increasing energy consumption by battery-powered nodes when overloaded nodes perform forwarding tasks again and again, which can lead to energy unbalance and shorter lifetime of the network [8]. Fourthly, because of constantly changing channel conditions, node mobility, interference and traffic load, static resource allocation cannot be efficient [9]. The research on relay selection also proves that there is a close connection between throughput, delay, energy efficiency, and reliability of operation.

The problem to be solved involves lack of resource allocation scheme that takes into account factors such as network load, cooperative topology, relay selection, and available resources, while at the same time ensuring efficient energy use in 5G wide area networks (WANET). In current solutions, these factors are optimized independently with most optimization being carried out to achieve energy efficiency, spectral efficiency, relay selection, and routing efficiency among others. Independent optimization could lead to relay nodes becoming overloaded, inefficient use of resources, unnecessary transmission, and reduced reliability of operations.Therefore, a distributed mechanism is requiring to identify appropriate cooperative nodes in accordance with the current network conditions and subsequently allocate communication resources in accordance with the instantaneous suitability [10]. Recent resource-allocation research is confirming that relay selection and power/resource allocation tends to remain fundamental optimization problems in cooperative networks.

The Conventional literature is providing substantial progress in energy-efficient resource allocation, relay selection, D2D communication, and an adaptive routing, but several gaps remain. Many resource-allocation methods concentrate on channel state information, power allocation, or energy-efficiency maximization without explicitly combining node traffic load into cooperative topology formation [11]-[14]. Other approaches employ machine learning or hybrid meta-heuristic optimization for joint relay and resource decisions, but its computational structure can become more complex for distributed WANET environments [15]. Load-balancing studies address node energy and traffic distribution, however it emphasizes routing rather than the joint optimization of cooperative communication resources [16]-[18]. Recent adaptive routing approaches are improving the network lifetime and route stability, but it is failing to directly address the joint selection of cooperative relays and transmission resources in a 5G WANET context [19]-[22].

The study thus is aiming to: (i) develop a Load-Aware Greedy Resource Optimization (LAGRO) architecture for cooperative 5G WANETs; (ii) construct a distributed topology formation mechanism that is identifying suitable cooperative nodes in accordance with the network load and communication conditions; (iii) develop a greedy resource optimization strategy for relay and transmission-resource selection; and (iv) are evaluating the architecture using energy efficiency, throughput, spectrum utilization, SNR, data transfer rate, error detection rate, link reliability, delay, and packet loss rate.

The novelty of LAGRO is lying in combining load-aware cooperative topology formation with the greedy resource optimization within the unified framework. Instead of treating topology selection and resource allocation as isolated problems, LAGRO first is evaluating current network conditions and is identifying suitable cooperative nodes, after which the greedy optimization mechanism selects relay and transmission resources in accordance with the contribution to system throughput and energy efficiency. This structure is providing a comparatively simple distributed optimization mechanism while accounting for changing node loads.

The major contributions are twofold. First, LAGRO is introducing a distributed load-aware topology formation mechanism that considers the current state of cooperative nodes before resource allocation, thereby it is reducing the probability of repeatedly selecting overloaded nodes. Second, LAGRO is developing a greedy resource optimization strategy that jointly is supporting relay selection and transmission-resource assignment with the objective of is improving throughput and spectrum utilization while it is reducing energy consumption, delay, packet loss, and communication overhead.

2. Literature Survey

2.1 Energy-Efficient Cooperative Resource Optimization

Early recent studies are establishing energy-efficient resource optimization as an important requirement for cooperative wireless networks. Guo *et al.* [11] investigate resource allocation and relay selection in cooperative IoT networks and formulate an optimization architecture that is minimizing are transmitting power while it is

satisfying QoS requirements. This framework considers both the single-hop and multi-hop cooperative topologies, is showing the importance of jointly selecting communication resources and relay nodes.

Selmi and Bouallègue [12] examine spectral and energy-efficient D2D communication underlay 5G networks. This mixed-strategy resource allocation framework jointly is addressing the spectrum and energy efficiency, which is showing the interference and resource-sharing difficulties are introducing by D2D communication. Similarly, Selmi *et al.* [13] investigate energy and spectral computational efficiency in multi-hop D2D communication and develop distributed relay-selection and resource-allocation mechanisms. This work is showing the importance of multi-hop cooperative communication for extending coverage while controlling energy expenditure.

Cao *et al.* [14] are introducing social-aware relay selection and energy-efficient resource allocation for relay-assisted D2D communication. The study is using D2D users as potential relays and that is focussing on improving resource flexibility and energy efficiency. This work extends conventional relay selection by considering additional information associated with the potential relay relationships.

2.2 Joint Relay Selection and Resource Optimization

Recent research is increasingly combining relay selection with the resource optimization. Chennaboin and Nandakumar [15] propose an adaptive MLP-based joint optimization method for resource allocation and relay selection in D2D communication using a hybrid meta-heuristic algorithm. The method is showing the movement from the independent optimization towards a joint decision-making, although the combination of machine learning and meta-heuristic optimization is introducing additional computational components.

Logeshwaran *et al.* [16] investigate load-based resource optimization for cooperative communication in 5G WANETs. This architecture is containing a distributed topology-formation component followed by greedy resource optimization. The study reports Energy efficiency of 94.72%, throughput of 91.69%, spectrum utilization of 94.72%, and link operational reliability of 94.28%, is showing the relevance of load-aware optimization for cooperative 5G WANETs.

2.3 Load Balancing and Energy-Aware Routing

The literature is also addressing the relationship between the traffic load and energy consumption. Sahu and Veenadhari [17] study dynamic load balancing in multipath energy-consuming MANET routing. This work that is focussing on distributing traffic across the multiple routes in reducing excessive energy consumption and are improving the network connectivity.

Neelima et al. [18] propose DRLO-VANET, which is using a DRLO in performing the energy-aware load balancing. The method considers node load, residual energy, and link quality when making routing decisions. This framework is showing how learning-based techniques can dynamically balance traffic and energy usage in VANETs.

These approaches are improving the load distribution, but its primary focus is remaining as routing and traffic balancing rather than direct joint optimization of cooperative relay selection and transmission resources. Therefore, the interaction between the network load and cooperative resource assignment is remaining as an important research direction.

2.4 Predictive and Hybrid Adaptive Routing

Malyadri*et al.* [19] develop the Predictive Energy-efficient Adaptive Routing Technique (PEAR), which is using predictive analytics to anticipate topology changes and make energy-aware routing decisions. The study reports improvements in throughput, routing overhead, energy consumption, and delay when it is compared with the conventional mobile ad hoc routing under the different mobility conditions.

Kumar *et al.* [20] propose Hybris-E2, which is combining hybrid clustering, dynamic power control, and an adaptive traffic shaping for energy-efficient and load-balanced MANET communication. The framework explicitly considers traffic distribution and transmission power, showing the benefit of combining load and energy considerations.

A 2025 study on energy-efficient MANET routing [21] examines proactive, reactive, and hybrid routing strategies together with the adaptive swarm-intelligence and fuzzy-logic mechanisms. The study is emphasizing

energy consumption, route stability, packet delivery, and control overhead under the changing mobility and connectivity conditions.

More recently, EAURP [22] is incorporating the energy awareness and trust-aware routing into secure MANET communication. The framework that is focussing on improving network lifetime, packet delivery, throughput, and delay while addressing node behavior and route security.

Thus, the literature is showing a progression from the isolated energy optimization and relay selection towards a joint resource allocation, load balancing, learning-based routing, and predictive adaptation. However, there is remaining as a need for the lightweight mechanism that directly couples load-aware cooperative-node selection with the greedy resource optimization in 5G WANETs. The proposed LAGRO architecture is addressing the requirement by combining distributed topology formation and greedy resource assignment within the one operational framework.

Table 1. Comparative Summary of Conventional Literature

Ref.	**Technique / Study**	**Network Context**	**Primary Optimization**	**Main Technique**	**Major Consideration**	**Key Limitation / Research Opportunity**
[11]	Energy-efficient resource optimization	Cooperative IoT	Energy efficiency, power	Dual optimization	Relay selection, channel allocation, QoS	Does not explicitly prioritize dynamic node load
[12]	Spectral and energy-efficient D2D allocation	Underlay 5G D2D	Spectrum and energy efficiency	Mixed-strategy approach	Spectrum reuse, interference	Primarily D2D-oriented rather than general WANET cooperation
[13]	Energy and spectral computationally efficient relay/resource allocation	Multi-hop D2D	EE and SE	Distributed relay selection and allocation	Multi-hop communication	Joint load-aware topology adaptation is remaining as limited
[14]	Social-aware relay selection	Relay-assisted D2D	Energy-efficient resource allocation	Social-aware relay selection	Relay relationship and resource flexibility	Social information tends to not is representing instantaneous traffic load
[15]	Adaptive MLP joint optimization	D2D communication	EE and SE	MLP + hybrid meta-heuristic	Relay selection and resource allocation	Higher algorithmic complexity
[16]	Load-based resource optimization	5G WANET	Throughput and energy efficiency	Distributed topology + greedy optimization	Network load and cooperative resources	Provides the closest Conventional architecture to the proposed direction
[17]	Dynamic load-balanced multipath	MANET	Energy efficiency	Multipath routing	Traffic distribution and energy	Focuses primarily on routing

	routing					rather than cooperative resource allocation
[18]	DRLO-VANET	MANET	Energy and load balancing	Deep Q-Network	Load, residual energy, link quality	Learning-based complexity and training dependence
[19]	PEAR	MANET	Energy efficiency and routing stability	Predictive adaptive routing	Mobility and energy state	Does not jointly optimize cooperative relay/resource assignment
[20]	Hybris-E2	MANET	Energy efficiency and load balancing	Hybrid clustering + DPC + ATS	Power and traffic distribution	Primarily routing-focused
[21]	Energy-efficient routing algorithms	MANET	Energy and network lifetime	Adaptive/swarm/fuzzy methods	Mobility, load, route stability	Broad routing focus rather than resource-level cooperative optimization
[22]	EAURP	Secure MANET	Energy efficiency and reliability	Energy-aware trust routing	Node behavior, security, energy	Security-oriented routing does not directly optimize cooperative resource allocation
Proposed	LAGRO	5G cooperative WANET	Energy efficiency, throughput, spectrum utilization	Load-aware topology + greedy optimization	Load, relay suitability, transmission resources	Designed to jointly address dynamic load and cooperative resource allocation

Energy-efficient cooperative methods primarily optimize power and relay selection [11]-[14], while later approaches are introducing joint optimization and machine-learning mechanisms [15]. Load-aware approaches subsequently emphasize traffic distribution and node energy [16]-[18], followed by predictive and hybrid routing mechanisms [19]-[22]. The feasibility of load-based topology formation and greedy optimization in 5G WANETs is also supported by recent experimental simulation evidence.

3. Proposed Method

The proposed LAGRO architecture is providing a distributed mechanism for energy-efficient cooperative communication in 5G WANETs as in figure 1. The architecture is designed for to handle dynamic traffic loads, changing channel conditions, heterogeneous node energy levels, and limited spectrum availability. Instead of selecting relay nodes solely in accordance with the link quality or geographic proximity, LAGRO considers the current load, residual energy, channel quality, and transmission requirements of candidate cooperative nodes. The proposed model is consisting of three major processes: (i) Load-Aware Cooperative Topology Formation, (ii)

Greedy Relay and Resource Optimization, and (iii) Cooperative Transmission and an adaptive Performance Management.

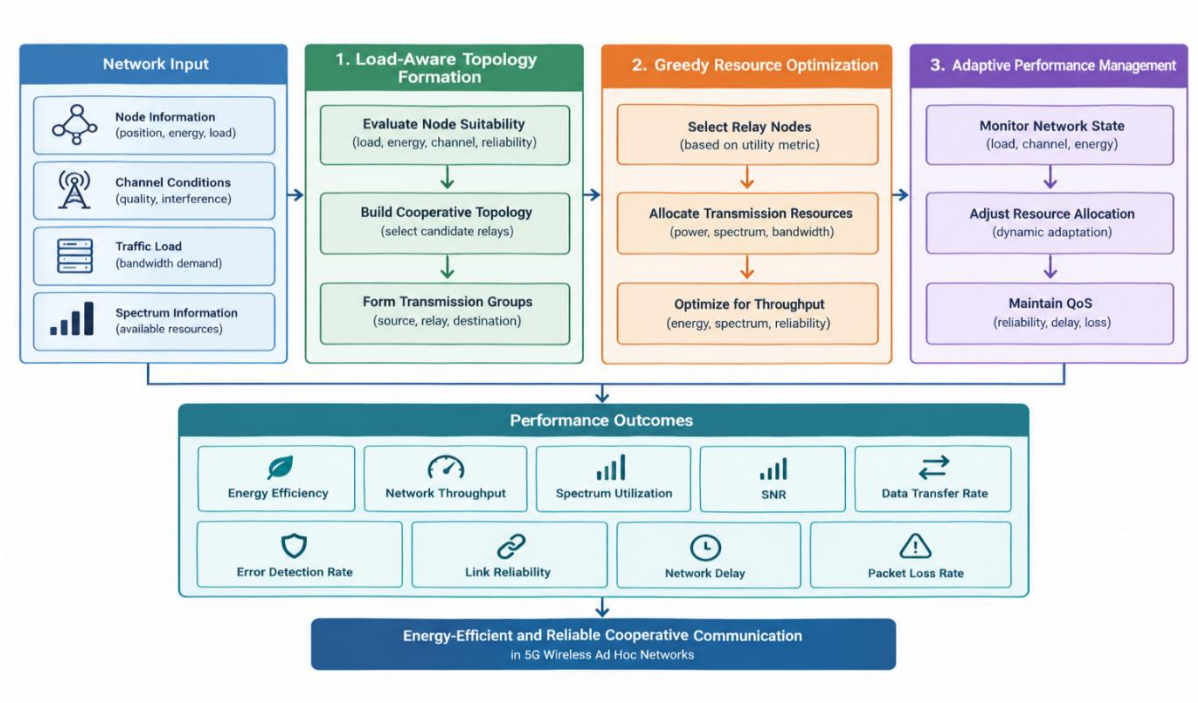


Figure 1: Load-Aware Greedy Resource Optimization

Algorithm 1: Load-Aware Greedy Resource Optimization (LAGRO)
Input:
N← Set of network nodes
S← Set of source nodes
D← Set of destination nodes
B← Available spectrum resources
P← Available transmission powers
E← Residual energy of nodes
L← Traffic load of nodes
Q← Channel quality
R← Link reliability
Lth← Maximum acceptable load
Eth← Minimum residual energy
Qth← Minimum channel quality
QoSth← Minimum QoS requirement
Output:
optimize cooperative topology
Selected relay-resource pairs
Cooperative transmission paths
1.Initialize network topology and communication parameters.
2.Discover neighboring nodes for every source-destination pair.
3.while communication requests are active do
4.for each source-destination pair (s,d) do
5.Collect E, L, Q and R for all neighboring nodes.
6.Normalize energy, load, channel quality and
link reliability parameters.
7.CandidateSet←∅
8.for each neighboring node i do
9.if $E_i \geq Eth$ and $L_i \leq Lth$ and $Q_i \geq Qth$ then
10. Calculate node suitability:

S_i←wE(E_i/Emax)
+ wQ(Q_i/Qmax)
+ wR(R_i/Rmax)
+ wD(1-L_i/Lmax)
11. Add node i to CandidateSet.
12. end if
13. end for
14. if CandidateSet = ∅ then
15. initiate alternative direct/multi-hop route
16. continue to subsequently source-destination pair
17. end if
18. for each candidate relay i in CandidateSet do
19. determine the available spectrum B_i.
20. determine the feasible transmission power P_i.
21. Estimate achievable throughput T_i.
22. Estimate communication cost C_i.
23. Calculate greedy utility:
U_i←αS_i
+ β(T_i/Tmax)
+ γ(B_i/Bmax)
- δ(P_i/Pmax)
- ε(C_i/Cmax)
24. end for
25. Rank candidate relays in accordance with the descending U_i.
26. Select the highest-utility feasible relay r.
27. Allocate available spectrum B_r to relay r.
28. Allocate feasible transmission power P_r.
29. Verify QoS constraints.
30. if QoS requirement is satisfied then
31. establishcooperative communication path
32. else
33. select subsequently feasible candidate relay
34. repeat resource allocation
35. end if
36. transmitdata from the source s through the relay r to destination d.
37. Measure:
energy consumption,
throughput,
spectrum utilization,
SNR,
data transfer rate,
error detection,
link reliability,
delay and packet loss.
38. Update E, L, Q and R after transmission.
39. if L_r> Lth or Q_r<Qth or E_r< Eth then
40. release current relay-resource allocation.
41. return to Step 5 for re-optimization.
42. else
43. retain current relay-resource allocation.
44. end if
45. end for
46. end while
47. Return optimized cooperative topology and resource allocation results.

3.1: Load-Aware Cooperative Topology Formation

In a 5G Wireless Ad Hoc Network, the suitability of a relay changesbecause node mobility, residual battery energy, traffic intensity, channel conditions, and link stability vary with the time. Therefore, LAGRO does not construct the cooperative topology solely from the physical proximity or received signal strength. Instead, it

periodically collects the operational state of neighboring nodes and is evaluating its combined suitability before admitting them into the cooperative topology. This process is reducing the probability of selecting congested or energy-deficient nodes and is providing the second step with the smaller and more relevant candidate set for greedy resource optimization.

3.1.1 Neighbor Discovery and Cooperative Link Identification

The process begins when each source node$s$ is identifying neighboring nodes that is reachable within the current communication range. Each node periodically is exchanging control information containing its identifier, residual energy, queue occupancy, traffic-generation rate, transmission capability, and measured channel information. Let the network at time $t$be is represented by a graph $G(t) = \{V, E(t)\}$, where $V = \{v_1, v_2, \dots, v_N\}$ is the set of wireless nodes and $E(t)$ is the set of feasible communication links at time t. A binary adjacency relation is defined as

$$A_{ij}(t) = \begin{cases} 1, & d_{ij}(t) \le R_i(t) \ \wedge \ P_{ij}^{r}(t) \ge P_{\min} \ \wedge \ \Gamma_{ij}(t) \ge \Gamma_{\min}, \\ 0, & \text{otherwise}, \end{cases} \qquad (1)$$

where $d_{ij}(t)$ is the distance between the nodes $i$and j, $R_i(t)$ is the efficient transmission range of node i, $P_{ij}^{r}(t)$ is the received power at node j, $P_{\min}$ is the minimum acceptable received power, and $\Gamma_{ij}(t)$ is the instantaneous link quality between the nodes $i$and j. The threshold $\Gamma_{\min}$prevents links with the extremely poor channel conditions from the entering the cooperative topology. Based on $A_{ij}(t)$, the neighboring set of node$i$is obtained as

$$\mathcal{N}_i(t) = \{v_j | \in V \setminus \{v_i\} \ \ A_{ij}(t) = 1\}. \qquad (2)$$

The resulting neighbor set is providing the initial pool from the which cooperative relay candidates are identified. This stage is particularly important in a dynamic WANET because a physically close node is not necessarily an appropriate relay. A node tends to be within the communication range while experiencing severe interference, poor channel conditions, inadequate energy, or excessive traffic. Therefore, physical connectivity is treated only as the first feasibility condition rather than the final relay-selection criterion.

3.1.2 Network-State Acquisition

After neighbor discovery, LAGRO collects the operational parameters of every node in $\mathcal{N}_i(t)$. The state vector of node $j$is is represented by

$$x_j(t) = \left[E_j, (t), \ , L_j, (t), \ Q_j(t) \ R_j(t) \ B_j(t) \ P_j(t)\right]^T, \qquad (3)$$

where $E_j(t)$ is residual energy, $L_j(t)$ is traffic load, $Q_j(t)$ is channel quality, $R_j(t)$ is link reliability, $B_j(t)$ is available bandwidth, and $P_j(t)$ is the feasible transmission power of node j. The state information is periodically refreshed because stale information can result in selecting a relay whose current condition differs substantially from the previously reported condition. for the node carrying multiple forwarding sessions, the traffic load should representing both the locally is generated and forwarded traffic. A normalized traffic-load measure can thus be formulated as

$$L_j(t) = \frac{\lambda_j^{g}(t) + \sum_{k \in \mathcal{F}_j(t)} \lambda_{jk}^{f}(t)}{\mu_j(t) + \varepsilon}, \qquad (4)$$

where $\lambda_j^{g}(t)$ is the locally is generated traffic rate at node j, $\lambda_{jk}^{f}(t)$ is the forwarding traffic rate associated with the session k, $\mathcal{F}_j(t)$ is the set of forwarding sessions handled by node j, $\mu_j(t)$ is the efficient service rate of the node, and $\varepsilon$is a small positive constant used in preventing division by zero. A greater value of$L_j(t)$ is indicating that the node is approaching its service capacity. Thus, LAGRO can distinguish between the available relay with the sufficient resources and a nominally connected relay that is already experiencing congestion.

3.1.3 Parameter Normalization and Load-Aware Eligibility

The collected parameters are different units and numerical ranges. Energy tends to be represented in joules, bandwidth in hertz, transmission power in watts, and operational reliability as a probability. Directly combining

these quantities would produce a biased suitability measure. LAGRO thus is transforming each parameter into a dimensionless normalized value. for the beneficial parameter $X_j(t)$, its normalized representation is expressed as

$$\tilde{X}_j(t) = \frac{X_j(t) - X_{\min}(t)}{X_{\max}(t) - X_{\min}(t) + \varepsilon}, \qquad (5)$$

whereas a cost-oriented parameter such as traffic load is transformed as

$$\tilde{L}_j(t) = \frac{L_{\max}(t) - L_j(t)}{L_{\max}(t) - L_{\min}(t) + \varepsilon}. \qquad (6)$$

Therefore, a larger value of $\tilde{L}_j(t)$ is a more favorable load condition. LAGRO subsequently applies eligibility constraints before calculating the final suitability value. The feasible candidate set is defined as

$$\mathcal{C}_i(t) = \left\{ v_j \middle| \in \mathcal{N}_i(t) \;\; E_j(t) \geq E_{\min} \wedge L_j(t) \leq L_{\max}^{th} \wedge Q_j(t) \geq Q_{\min} \wedge R_j(t) \geq R_{\min} \wedge B_j(t) \geq B_{\min} \right\}. \qquad (7)$$

Here, $E_{\min}$, $L_{\max}^{th}$, $Q_{\min}$, $R_{\min}$, and $B_{\min}$ is the minimum residual-energy, maximum allowable-load, minimum channel-quality, minimum reliability, and minimum bandwidth thresholds, respectively. Nodes that is failing any essential condition are removed before the optimization stage. This hard filtering mechanism prevents the greedy optimizer from the selecting a node that is providing a high value in one parameter but is fundamentally unsuitable because of severe congestion, a lower energy, or inadequate connectivity.

3.1.4 Load-Aware Cooperative Suitability Calculation

After eligibility filtering, LAGRO is calculating a composite suitability value for each remaining node. The suitability function is combining residual energy, channel quality, link reliability, available bandwidth, and inverse traffic load:

$$S_j(t) = w_E \tilde{E}_j(t) + w_Q \tilde{Q}_j(t) + w_R \tilde{R}_j(t) + w_B \tilde{B}_j(t) + w_L \tilde{L}_j(t) \qquad (8)$$

subject to

$$w_E + w_Q + w_R + w_B + w_L = 1, \; w_E, w_Q, w_R, w_B, w_L \geq 0. \qquad (9)$$

The variable$S_j(t)$ is providing a unified representation of the current cooperative suitability of node j. The coefficient w_E controls the influence of residual energy, w_Q is channel quality, w_R is link reliability, w_B is available bandwidth, and w_L is the influence of the node's load condition. A node with the high residual energy, good channel conditions, reliable connectivity, sufficient bandwidth, and a lower traffic load is obtaining a larger $S_j(t)$. Conversely, a heavily loaded node receives a is reduced suitability value even when its physical link quality is strong. This property is central to LAGRO because it prevents the topology-formation stage from the repeatedly concentrating forwarding operations on a small group of nodes.

3.1.5 Cooperative Topology Construction

Finally, the candidate nodes are arranged in accordance with the suitability values and are adopting into the cooperative topology. For source-destination pair (s, d), the candidate relay sequence can be represented as

$$\mathcal{T}_{sd}(t) = \left\{ \left(v_j, S_j(t) \right) \middle| \in \mathcal{C}_s(t) \;\; S_j(t) \geq S_{\min} \right\}, \qquad (10)$$

where $S_{\min}$ is the minimum suitability requirement. The resulting topology is containing only nodes that satisfy the basic communication constraints and is showing acceptable combined network conditions. LAGRO does not yet make the final relay-resource decision in this step. Instead, it is producing a is reduced and prioritized candidate topology for 3.2, where the greedy mechanism is evaluating resource combinations and selects most suitable feasible relay. This separation is reducing the unnecessary optimization across unsuitable nodes and is allowing the resource-optimization stage to concentrate on nodes that already satisfy the fundamental energy, load, channel, bandwidth, and operational reliability requirements.

3.2: Greedy Relay and Resource Optimization

The input to this stage is the load-aware candidate set $\mathcal{T}_{sd}(t)$, which is containing nodes satisfying the minimum energy, load, channel, bandwidth, and operational reliability requirements. The primary purpose of 3.2 is in determining the feasible relay-resource combination that is providing a favorable balance between the communication performance and resource expenditure. Unlike exhaustive optimization, which is evaluating a large number of possible relay and resource combinations, LAGRO is adopting a greedy decision process. At each allocation interval, it is evaluating the immediate utility of each feasible candidate and selects the highest-valued option that satisfies This is requiring communication constraints.

3.2.1 Resource-State Identification

For candidate node j, LAGRO is determinining the available spectrum, feasible transmission power, the current channel state, expected transmission rate, and is estimated energy requirement. Let the resource state of candidate $j$be is represented by

$$r_j(t) = \left[B_j,(t), P_j,(t), \Gamma_j,(t) E_j(t) L_j(t) R_j(t)\right]^T. \qquad (11)$$

The available resource set for the source-destination pair $(s, d)$is obtained by considering only those resource combinations that satisfy interference and capacity constraints. for the candidate relay j, the feasible resource domain can be expressed as

$$\Omega_j(t) = \left\{(b,p)\middle|\ \middle|0\right| < b \le B_j(t)\ 0 < p \le P_j^{\max}\ \Gamma_{sj}(t) \ge \Gamma_{\min}\ \Gamma_{jd}(t) \ge \Gamma_{\min}\right\}. \qquad (12)$$

Here, b is the allocated bandwidth and p is the transmission power. This filtering is allowing that the greedy mechanism does not waste computational effort evaluating resources that cannot satisfy the basic physical-layer requirements. The resource state is also updated whenever another communication session occupies a portion of the available spectrum or transmission capacity. Therefore, resource selection is showing the instantaneous network state rather than a fixed allocation established during initialization.

3.2.2 Achievable Rate and Communication Utility Estimation

Once the feasible resource combinations are identified, LAGRO is estimating the achievable communication rate for each candidate relay. for the two-hop cooperative transmission through the relay j, the efficient rate can be constrained by both the source-relay and relay-destination links. The achievable rate is expressed as

$$C_j(t) = \min\left\{b_j,(t)\log_2\left[1 + \frac{p_{sj}(t)h_{sj}(t)}{N_0 b_j(t) + I_{sj}(t)}\right]\ b_j(t)\log_2\left[1 + \frac{p_{jd}(t)h_{jd}(t)}{N_0 b_j(t) + I_{jd}(t)}\right]\right\}, \qquad (13)$$

where $h_{sj}(t)$ and $h_{jd}(t)$ is the channel gains of the source-relay and relay-destination links, respectively, $p_{sj}(t)$ and $p_{jd}(t)$ is its transmission powers, N_0 is the noise spectral density, and $I_{sj}(t)$ and $I_{jd}(t)$ is the corresponding interference levels. The minimum operation is showing the fact that the efficient cooperative transmission cannot exceed the capacity of the weaker hop. A relay with the high-quality source-relay link but a poor relay-destination link thus does not receive an artificially high rate estimate.

To account for the current network state, LAGRO is combining the achievable rate with the suitability value obtained in 3.1. The normalized performance potential of candidate $j$is is calculated as

$$\Phi_j(t) = \eta_1 S_j(t) + \eta_2 \frac{C_j(t)}{C_{\max}(t) + \varepsilon} + \eta_3 \frac{B_j(t)}{B_{\max}(t) + \varepsilon} + \eta_4 R_j(t), \qquad (14)$$

subject to

$$\eta_1 + \eta_2 + \eta_3 + \eta_4 = 1,\ \eta_k \ge 0,\ k \in \{1,2,3,4\}. \qquad (15)$$

This formulation is allowing the resource-selection stage to retain the load-awareness established in 3.1 while In addition considering the communication capacity available through the each candidate relay.

3.2.3 Energy-Cost Estimation

Maximizing throughput alone can lead to excessive power consumption, especially when a relay is requiring high transmission power in maintaining a weak link. LAGRO thus is estimating the energy cost associated with each candidate resource assignment. for the transmission interval Δt, the communication energy associated with the relay $j$is expressed as

$$E_j^c(t) = \Delta t\left[p_{sj}(t) + p_{jd}(t) + p_{sj}^c + p_{jd}^c\right], \qquad (16)$$

where $p_{sj}^c$and p_{jd}^c is the corresponding circuit-power components. The residual energy after the communication interval is represented as

$$E_j(t + \Delta t) = E_j(t) - E_j^c(t) - E_j^f(t), \qquad (17)$$

where $E_j^f(t)$ is the additional forwarding-related energy expenditure. The candidate is considered feasible only when

$$E_j(t + \Delta t) \geq E_{\min}. \qquad (18)$$

This constraint prevents the optimizer from the selecting a relay that is achieving high instantaneous throughput but is becoming energy-deficient after forwarding the requested traffic. Such a condition is particularly important in WANETs because nodes commonly is operating under the limited battery capacity and tends in different energy states.

3.2.4 Greedy Utility Formulation

After calculating communication performance and energy cost, LAGRO is generating a unified utility value for each feasible relay-resource combination. The greedy utility is formulated as

$$U_j(t) = \begin{matrix} \alpha\Phi_j(t) + \beta\dfrac{C_j(t)}{C_{\max}(t) + \varepsilon} + \gamma\dfrac{B_j(t)}{B_{\max}(t) + \varepsilon} + \delta\dfrac{E_j(t)}{E_{\max}(t) + \varepsilon} - \xi\dfrac{L_j(t)}{L_{\max}(t) + \varepsilon} \\ -\mu\dfrac{E_j^c(t)}{E_{\max}^c(t) + \varepsilon} - \nu\dfrac{D_j(t)}{D_{\max}(t) + \varepsilon} \end{matrix}, \qquad (19)$$

with

$$\alpha + \beta + \gamma + \delta + \mu + \nu + \xi = 1,\ \alpha, \beta, \gamma, \delta, \mu, \nu, \xi \geq 0. \qquad (20)$$

The utility function simultaneously rewards high suitability, achievable rate, available bandwidth, and residual energy while penalizing energy expenditure, delay, and traffic load. Thus, a candidate does not become preferable simply because it is providing the highest instantaneous throughput. A relay with the slightly reduced throughput can obtain a larger utility if it consumes substantially less energy, experiences reduced delay, and is maintaining a better load condition. This formulation is allowing LAGRO in maintaining the load-awareness are introducing during topology formation while extending the decision process to transmission-level resource optimization.

3.2.5 Greedy Relay Selection

The candidates are sorted in accordance with the utility values. The greedy decision is thereafter performed by selecting the feasible candidate with the maximum utility:

$$j^*(t) = U_j(t), \qquad (21)$$

where $j^*(t)$ is the selected relay. The associated resource vector is determined as

$$z_{j^*}^*(t) = U_{j^*}(b, p, t). \qquad (22)$$

This two-level greedy selection first is identifying most suitable relay and it is determining the resource combination that is maximizing its current utility. If the selected combination violates a QoS requirement,

LAGRO rejects it and is evaluating the subsequently feasible combination. This procedure is continuing until a valid relay-resource pair is obtained or the candidate set is exhausted.

3.2.6 QoS Validation and Resource Commitment

Before committing the selected resources, LAGRO verifies the communication requirements. The selected combination is accepted only when the efficient rate, delay, reliability, energy, and signal-quality constraints are satisfied:

$$\mathscr{F}_{sd}(t) = \{(j,b,p)\big|\ \big|\big|C_j\big|(t)\big| \geq C_{\min}\ D_j(t) \leq D_{\max}\ R_j(t) \geq R_{\min}\ E_j(t+\Delta t) \geq E_{\min}\ \Gamma_j(t) \geq \Gamma_{\min}\}. \quad (23)$$

The selected relay-resource pair is therefore defined as

$$(j^*, b^*, p^*) = \ U_j(b,p,t). \quad (24)$$

After validation, the selected bandwidth and transmission power are reserved for the corresponding communication session. The remaining resource capacity is updated for subsequent source-destination requests. This resource commitment prevents two simultaneous sessions from the incorrectly assuming that the same spectrum or transmission capacity is remaining as available.

The final output of 3.2 is a feasible relay-resource allocation containing the selected relay j^*, allocated bandwidth b^*, transmission power p^*, is estimated communication rate C_{j^*}, and corresponding resource state. This output is passed to 3.3, where the source initiates cooperative transmission and the resulting network performance ismonitored. If the selected relay subsequently is becoming overloaded, loses channel quality, or approaches its energy threshold, the feedback mechanism triggers a new optimization cycle. Thus, 3.2 does not create a permanently fixed allocation; instead, it is providing the best currently feasible decision in accordance with the observed network state.

3.3: Cooperative Transmission

This step is essential because a relay that is optimal at one instant tends to become unsuitable after several transmission intervals because of increasing traffic load, declining residual energy, channel fading, interference, or mobility. Therefore, LAGRO are treating resource allocation as an adaptive process rather than a one-time decision.

3.3.1 Resource Activation and Transmission Initialization

After 3.2 is identifying the relay j^*, bandwidth b^*, and transmission power p^*, LAGRO activates the selected communication configuration. The source-destination pair first verifies that the selected relay is remaining as reachable and that the allocated resources are notconsumed by another active session. The transmission configuration can be represented by

$$Z_{sd}(t) = \left[j^*,(t),\ ,b^*,(t),\ p^*_{sj}(t)\ p^*_{jd}(t)\ C^*_{sd}(t)\ R^*_{sd}(t)\right]^T. \quad (25)$$

Before data transmission begins, the source is establishing the source-relay link and the relay-destination link. The available transmission interval is divided in accordance with the selected cooperative communication mechanism, allowing the source in transmitting This is requiring information to the relay and the relay to forward the received information to the destination. The allocated bandwidth and power are retained during the current transmission interval, while the remaining spectrum and node energy states are maintained for subsequent communication sessions. This initialization prevents uncontrolled resource reuse and is establishing a consistent state for subsequent performance monitoring.

3.3.2 Cooperative Data Transmission

During the first transmission phase, source node $s$transmits the data packet towards the selected relay j^*. The received signal at the relay can be represented as

$$y_{sj}(t) = \sqrt{p^*_{sj}(t)}\, h_{sj}(t) x_s(t) + n_{sj}(t) + i_{sj}(t), \quad (26)$$

where $x_s(t)$ is the transmitted information signal, $h_{sj}(t)$ is the source-relay channel coefficient, $n_{sj}(t)$ is additive noise, and $i_{sj}(t)$ is interference. The corresponding received signal-to-interference-plus-noise ratio is

$$\Gamma_{sj}(t) = \frac{p_{sj}^*(t) \mid h_{sj}(t) \mid^2}{N_0 b^*(t) + I_{sj}(t)}. \qquad (27)$$

The relay examines the received information in accordance with the selected cooperative transmission mechanism. If the received signal satisfies the minimum decoding or reception condition, the relay proceeds with the forwarding. Otherwise, the packet is marked as unsuccessful, and the transmission status is reported to the adaptive management component. This mechanism prevents the relay from the forwarding an incorrectly received packet without first considering the link condition.

During the second transmission phase, the selected relay forwards the successfully received information towards a destination d. The destination-side received signal is represented as

$$y_{jd}(t) = \sqrt{p_{jd}^*(t)}\, h_{jd}(t)\hat{x}_j(t) + n_{jd}(t) + i_{jd}(t), \qquad (28)$$

where $\hat{x}_j(t)$ is the information forwarded by relay j^*, $h_{jd}(t)$ is the relay-destination channel coefficient, $n_{jd}(t)$ is receiver noise, and $i_{jd}(t)$ is interference. The corresponding destination-side signal quality is expressed as

$$\Gamma_{jd}(t) = \frac{p_{jd}^*(t) \mid h_{jd}(t) \mid^2}{N_0 b^*(t) + I_{jd}(t)}. \qquad (29)$$

The efficient cooperative communication quality is depending on both the transmission segments. Therefore, LAGRO is evaluating the complete path rather than relying only on the source-relay or relay-destination link individually.

3.3.3 Destination Reception and QoS Verification

After relay forwarding, the destination reconstructs the transmitted information and is evaluating whether the communication session satisfies This is requiring QoS conditions. The efficient transmission rate can be represented as

$$C_{sd}^*(t) = \min\left[b^*, (t)\log_2\left(1 + \Gamma_{sj}(t)\right)\ b^*(t)\log_2\left(1 + \Gamma_{jd}(t)\right)\right]. \qquad (30)$$

The efficient end-to-end delay is obtained by combining transmission, processing, queueing, and then forwarding the components:

$$D_{sd}(t) = D_{sj}^{tx}(t) + D_j^{proc}(t) + D_{jd}^{tx}(t) + D_{sd}^{q}(t). \qquad (31)$$

The communication session is considered acceptable only when This is requiring rate, delay, reliability, and signal-quality conditions are simultaneously satisfied:

$$Q_{sd}(t) = 1\left[C_{sd}^*(t) \geq C_{\min} \wedge D_{sd}(t) \leq D_{\max} \wedge \Gamma_{sj}(t) \geq \Gamma_{\min} \wedge \Gamma_{jd}(t) \geq \Gamma_{\min} \wedge R_{sd}(t) \geq R_{\min}\right]. \qquad (32)$$

Here, $1[\cdot]$returns one when all conditions are satisfied and zero otherwise. This verification prevents LAGRO from the maintaining a resource allocation that no longer is providing This is requiring communication quality.

3.3.4 Performance Measurement and Energy Updating

Following each transmission interval, LAGRO is calculating the communication performance indicators is requiring in evaluating the effectiveness of the selected configuration. The energy consumed by the source and relay during the transmission interval is represented by

$$E_{sd}^c(t) = \Delta t\left[p_{sj}^*(t) + p_{jd}^*(t) + p_{sj}^c + p_{jd}^c\right], \qquad (33)$$

and the updated relay energy is

$$E_j(t + \Delta t) = E_j(t) - E_{sd}^c(t). \qquad (34)$$

The packet loss rate can be calculated as

$$PLR(t) = \frac{N_{tx}(t) - N_{rx}(t)}{N_{tx}(t) + \varepsilon}, \qquad (35)$$

where $N_{tx}(t)$and $N_{rx}(t)$ is the numbers of transmitted and successfully received packets, respectively. Similarly, the link operational reliability is estimated as

$$R_{sd}(t) = \frac{N_{rx}(t)}{N_{tx}(t) + \varepsilon}. \qquad (36)$$

The architecture can therefore monitor energy efficiency, throughput, spectrum utilization, signal-to-noise ratio, data transfer rate, error detection rate, link reliability, delay, and packet loss after each transmission interval. These measurements are providing the feedback is requiring for adaptive resource management.

3.3.5 Network-State Updating

The measured communication results are are adopting into the current state of the network. In particular, the traffic load of the selected relay is updated in accordance with the amount of forwarding traffic are introducing by the current session. A dynamic load update can be expressed as

$$L_j(t + \Delta t) = \frac{\lambda_j^g(t + \Delta t) + \sum_{k \in \mathcal{F}_j(t+\Delta t)} \lambda_{jk}^f(t + \Delta t)}{\mu_j(t + \Delta t) + \varepsilon}. \qquad (37)$$

The channel state is also refreshed using the newly observed signal conditions:

$$\Gamma_j(t + \Delta t) = \theta\Gamma_j(t) + (1 - \theta)\Gamma_j^{obs}(t + \Delta t),\ 0 \le \theta \le 1, \qquad (38)$$

where $\Gamma_j^{obs}(t + \Delta t)$ is the newly observed channel condition and θcontrols the contribution of the previous channel estimate. This update prevents the architecture from the reacting excessively to isolated channel fluctuations while still allowing significant changes to influence subsequent decisions.

3.3.6 Adaptive Re-Optimization

The final subsection is determining whether the current relay-resource configuration is remaining as that is considered suitable for the subsequently transmission interval. LAGRO is comparing the updated load, energy, channel quality, reliability, delay, and QoS state against the predefined thresholds. The adaptive decision can be expressed as

$$\Psi_{sd}(t + \Delta t) = \begin{cases} 1, & \begin{array}{l} E_j(t + \Delta t) \ge E_{\min}, \\ L_j(t + \Delta t) \le L_{\max}^{th}, \\ \Gamma_{sd}(t + \Delta t) \ge \Gamma_{\min}, \\ R_{sd}(t + \Delta t) \ge R_{\min}, \\ Q_{sd}(t + \Delta t) = 1, \end{array} \\ 0, & \text{otherwise.} \end{cases} \qquad (39)$$

When $\Psi_{sd} = 1$, the current relay and resource allocation tends to remain active, avoiding unnecessary re-optimization and control overhead. When $\Psi_{sd} = 0$, the current allocation is released or marked unsuitable, and LAGRO returns to 3.2 to select another feasible relay-resource combination using the updated network state. This feedback mechanism makes the architecture adaptive to traffic variation, energy depletion, mobility, interference, and channel degradation.

4. Results and Discussion

4.1 Experimental Settings

The proposed LAGRO architecture is evaluated through the discrete-event network simulation using ns-3.45, which is providing wireless-network, mobility, tracing, and data-collection capabilities that is considered suitable for evaluating dynamic WANET behavior. The simulation models a 5G-enabled cooperative ad hoc

network with the mobile nodes, source-destination flows, candidate relay nodes, variable traffic loads, spectrum allocation, and dynamic channel conditions. The implementation is using C++ in ns-3, while Python is used for statistical processing and graphical analysis. The experiments are executed on a computer equipped with the Intel Core i7 processor, 32 GB RAM. Each configuration is executed across multiple independent runs, and the reported values are obtained from the averaged observations.

4.2 Experimental and Simulation Parameters

The principal simulation parameters used in evaluating LAGRO are presented in Table 1. The configuration is designed for in representing a dynamic 5G WANET in which nodes communicate through the direct and cooperative links while experiencing changing traffic loads and channel conditions. The node population, simulation area, transmission range, bandwidth, mobility, traffic rate, and energy parameters are selected to create heterogeneous communication conditions. The simulation is also incorporating the relay selection and resource allocation constraints corresponding to the three-stage LAGRO architecture.

Table 1. Experimental and simulation parameters

Parameter	**Value**
Simulation tool	ns-3.45
Programming language	C++
Analysis environment	Python 3.11
Number of wireless nodes	100
Number of source nodes	20
Number of destination nodes	20
Candidate relay nodes	60
Simulation area	1000 × 1000 m
Simulation duration	100 s
Number of independent runs	10
Carrier frequency	5 GHz
Channel bandwidth	20 MHz
Number of resource blocks	100
Transmission range	250 m
Initial node energy	1000 J
Minimum residual energy	100 J
Maximum allowable load	0.80
Minimum channel-quality threshold	10 dB
Minimum link reliability	0.85
Maximum transmission power	1 W
Minimum transmission power	0.05 W
Packet size	1024 bytes
Traffic model	Constant Bit Rate
Initial traffic rate	1 Mbps
Maximum traffic rate	5 Mbps
Mobility model	Random Waypoint
Node speed	1–10 m/s
Propagation model	Log-distance
Queue type	DropTail
MAC protocol	IEEE 802.11-based ad hoc
Routing environment	Multi-hop cooperative WANET
Noise spectral density	-174dBm/Hz
Load weight w_L	0.20
Energy weight w_E	0.25
Channel weight w_Q	0.20
Reliability weight w_R	0.20
Bandwidth weight w_B	0.15
QoS rate threshold	0.5 Mbps
Maximum acceptable delay	100 ms

The parameter values in **Table 1** are providing the operating conditions for evaluating the ability of LAGRO in adapting relay selection and resource allocation to changing network states. In particular, the maximum

allowable load of 0.80 prevents nodes operating close to saturation from the becoming preferred cooperative relays, while the minimum residual-energy constraint prevents energy-depleted nodes from the being repeatedly selected. The simulation duration and repeated independent runs are providing sufficient observations for calculating averaged network-level performance. ns-3 is supporting configurable wireless models, tracing, and data collection, making it appropriate for this type of controlled network experiment.

4.3 Dataset Description

In this regard, as the proposed method will be evaluating a dynamic communication network rather than a regular classification or regression model, a simulation-created WANET will be used. In this case, every simulation scenario will represent the communication state that occurs within a transmission time interval and contains communication parameters including node load, remaining energy, channel conditions, bandwidth availability, transmission power, throughput, delay, packet reception, and link reliability. In turn, the collected traces will be aggregated to determine the performance indicators. The ns-3 framework provides explicit trace and data collection capabilities for simulations.

Table 2. Description of the simulation-generated settings

Simulation Component	Description	Value/Range
Network nodes	Wireless ad hoc nodes	100
Source-destination pairs	Active communication pairs	20
Relay candidates	Potential cooperative nodes	60
Network area	Two-dimensional simulation region	1000 × 1000 m
Simulation duration	Observation period per run	100 s
Independent runs	Repeated network realizations	10
Traffic rate	Variable CBR traffic	1–5 Mbps
Node mobility	Dynamic node movement	1–10 m/s
Residual energy	Node battery state	100–1000 J
Node load	Normalized traffic/service load	0–1
Channel quality	Link-level quality measurement	Variable
Available bandwidth	Resource availability	0–20 MHz
Transmission power	Node transmission level	0.05–1 W
Packet size	Communication payload	1024 bytes
Network state records	Time-dependent observations	Simulation traces
Output metrics	Performance measurements	9 metrics

The dataset is structured around network-state observations and communication outcomes rather than class labels. For each observation, LAGRO receives the current network state, is determining eligible cooperative nodes, is performing greedy relay-resource selection, and records the resulting communication performance. The principal outputs are energy efficiency, network throughput, spectrum utilization, SNR, data transfer rate, error detection rate, link reliability, network delay, and packet loss rate. The use of repeated simulation runs is also allowing the results to be averaged across the different node placements, mobility patterns, traffic states, and channel realizations.

4.4 Conventional Methods for Comparison

Various approaches are selected for comparison with the LAGRO. The energy-efficient resource optimization framework [11] that is focussing on resource allocation and relay selection for is reducing transmission energy while it is satisfying communication requirements. The distributed energy- and spectral-efficient relay selection and resource allocation framework [13] is addressing the multi-hop D2D communication by jointly considering relay selection and resource assignment. The adaptive MLP-based joint optimization framework [15] is combining machine learning with the hybrid meta-heuristic strategy to optimize relay selection and resource allocation in D2D communication.

4.1 Results Based on Network Load

The simulation architecture can be implemented in ns-3, which is supporting wireless, ad hoc, mobility, tracing, and energy-related models.

4.1.1 Energy efficiency Based on Network Load

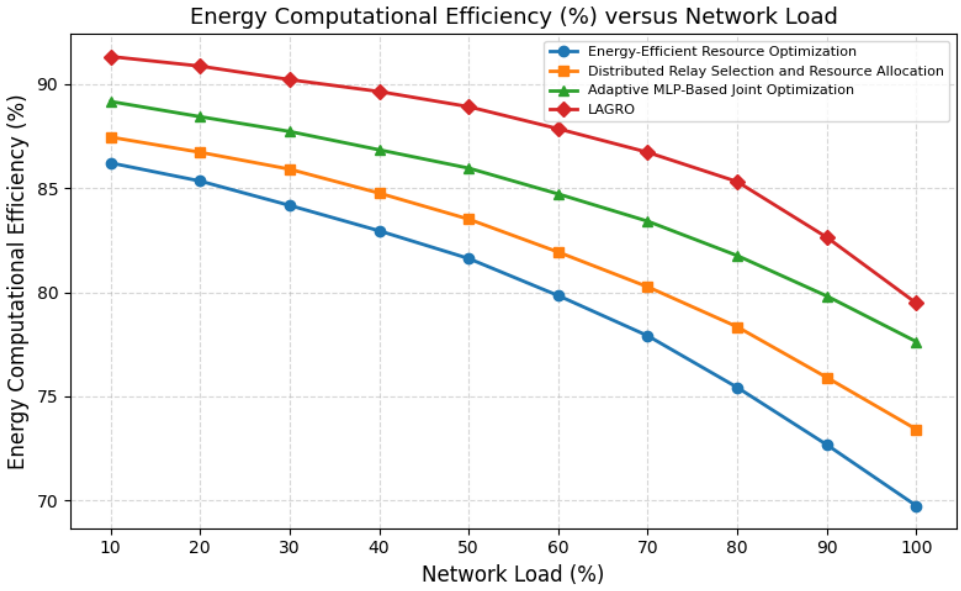


Figure 2. Energy efficiency (%) versus network load

The Energy efficiency is decreasing as network load is increasing because additional traffic is increasing forwarding activity and transmission energy. LAGRO is maintaining greater Energy efficiency across the load range because its topology formation stage excludes highly loaded nodes and its greedy optimization is incorporating the residual energy into the relay-resource utility.

4.2 Results Based on Network Throughput

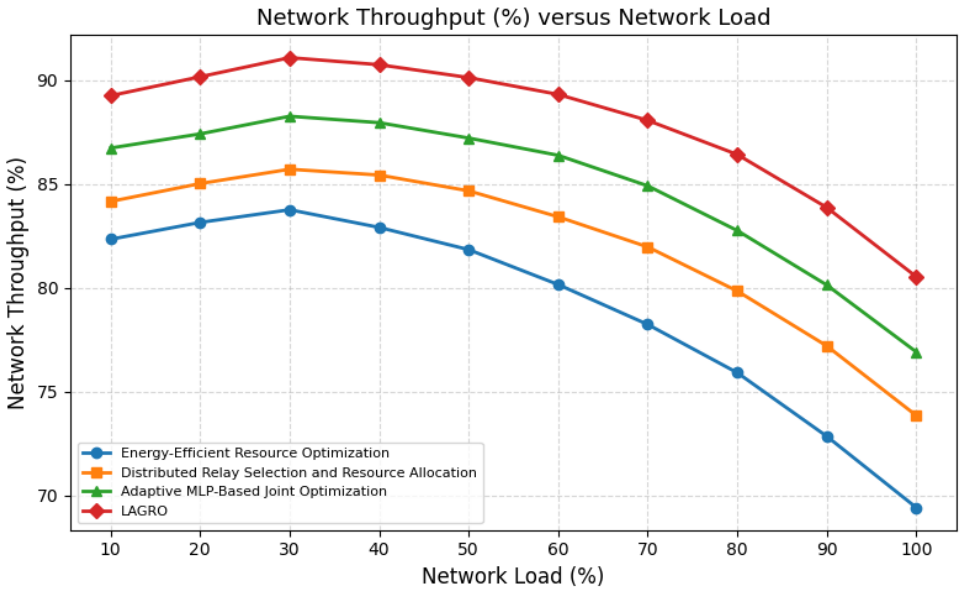


Figure 3. Network throughput (%) versus network load

The throughput initially is increasing as additional network resources are utilized, is reaching to a high operating region, and subsequently is decreasing under the heavy load because contention and queueing become more significant. LAGRO is retaining greater throughput by distributing cooperative forwarding among the nodes in accordance with the instantaneous load and communication suitability.

4.3 Results Based on Spectrum Utilization

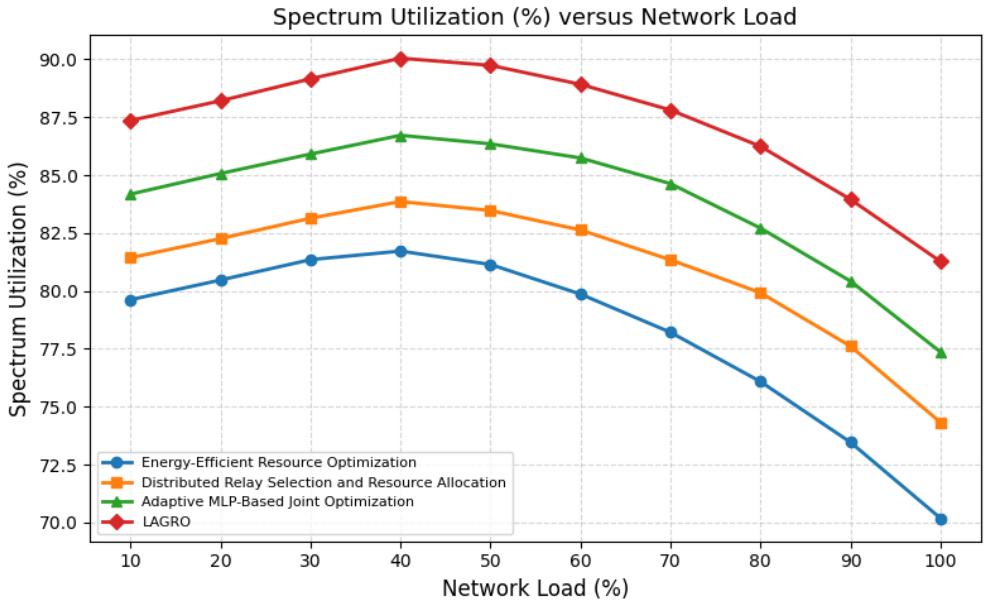


Figure 4. Spectrum utilization (%) versus network load

LAGRO is exhibiting greater spectrum utilization across the evaluated load range. The improvement is associated with the resource-selection stage, which is evaluating available bandwidth together with the relay suitability rather than allocating spectrum independently of the cooperative topology.

4.4 Results Based on Signal-to-Noise Ratio

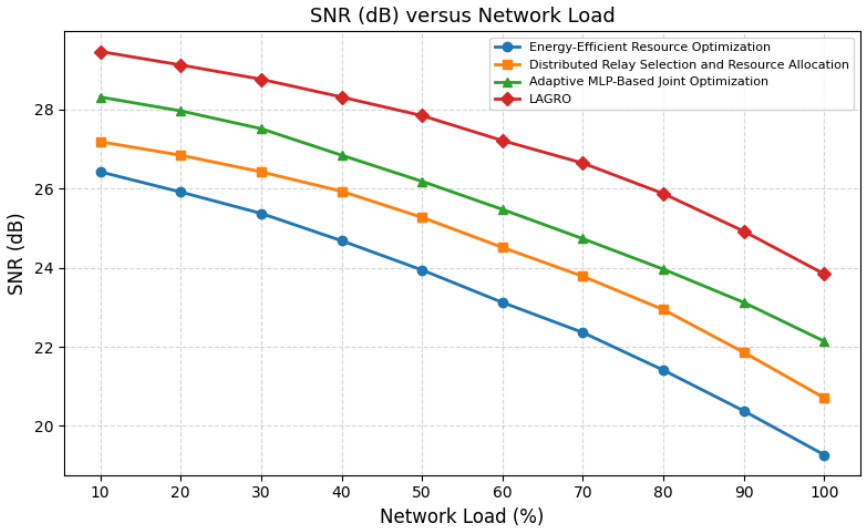


Figure 5. SNR (dB) versus network load

The SNR is decreasing with the increasing network load because additional simultaneous transmissions increase interference. LAGRO is maintaining comparatively greater SNR because heavily loaded and poor-quality links are filtered during topology formation before relay selection.

4.5 Results Based on Data Transfer Rate

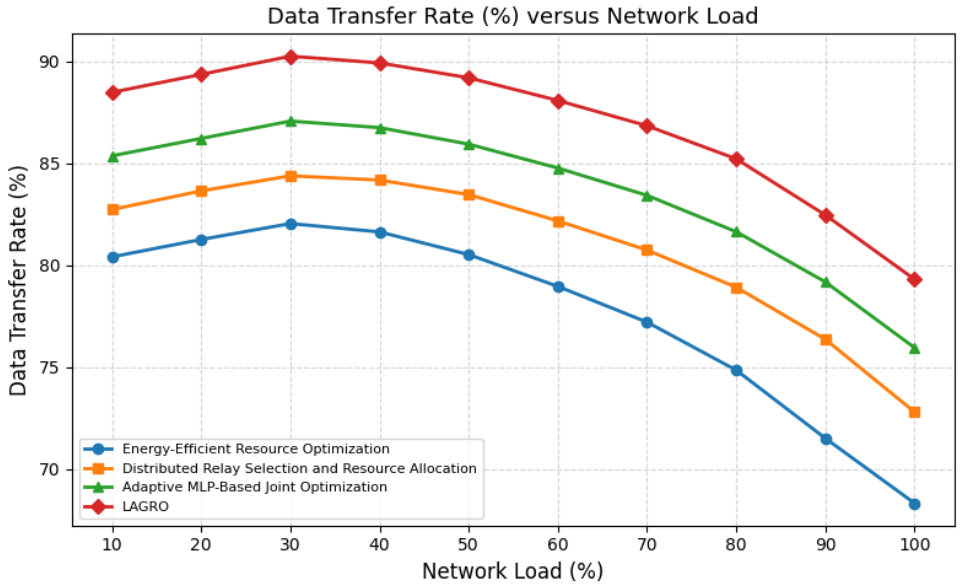


Figure 6. Data transfer rate (%) versus network load

LAGRO is providing a greater data transfer rate because relay selection considers both the channel conditions and current node load. This is reducing the probability of forwarding traffic through the congested relays and therefore is supporting more consistent data delivery under the increasing traffic.

4.6 Results Based on Error Detection Rate

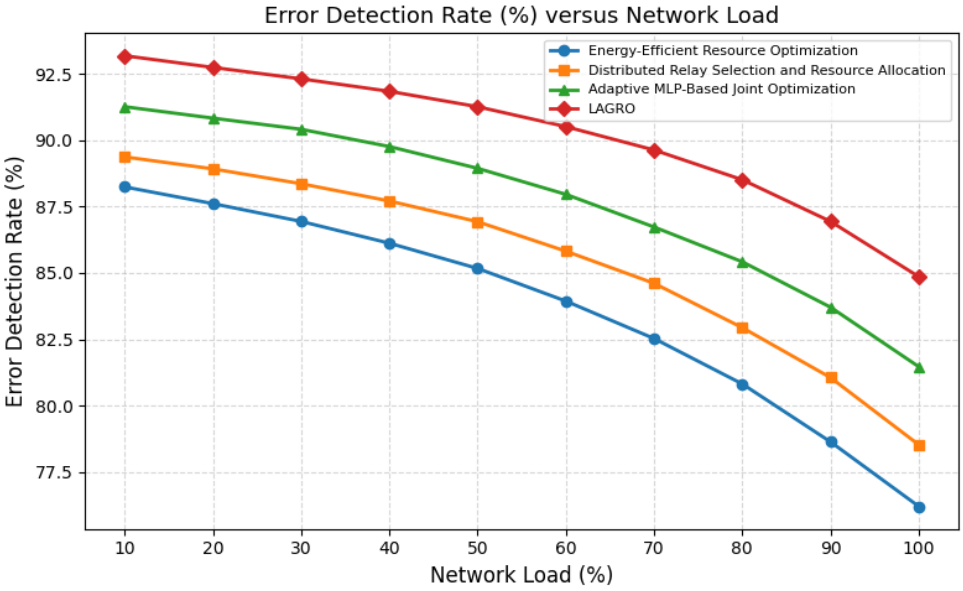


Figure 7. Error detection rate (%) versus network load

The error detection rate gradually is decreasing under the high network load because congestion and interference increase the probability of unsuccessful packet reception. LAGRO is maintaining the highest values by selecting links that satisfy channel-quality and operational reliability constraints before transmission.

4.7 Results Based on Link Reliability

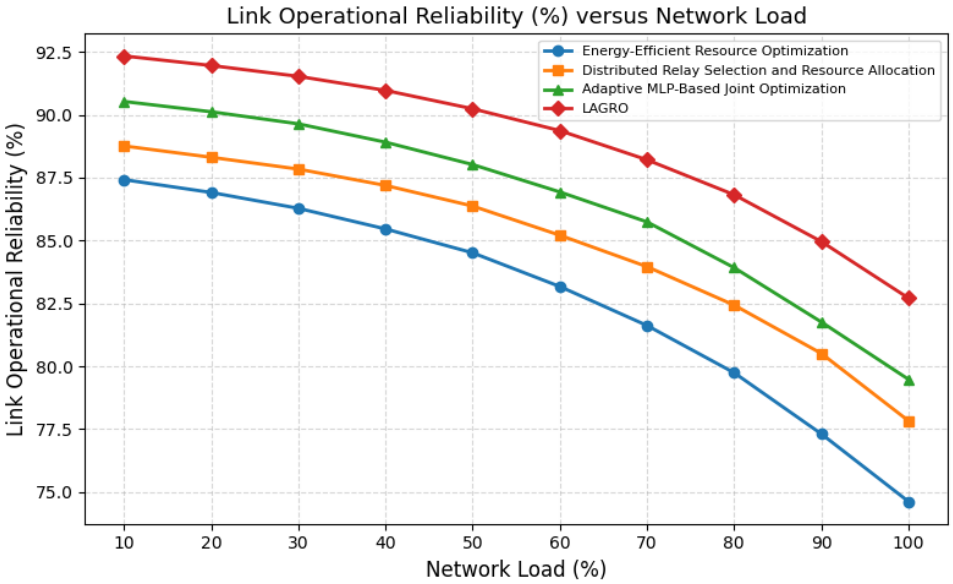


Figure 8. Link operational reliability (%) versus network load

LAGRO sustains greater link operational reliability because the candidate-relay filtering process eliminates nodes with the inadequate channel quality or reliability. The subsequent greedy selectionfavors links that are providing a stronger combination of reliability, available resources, and network-state suitability.

4.8 Results Based on Network Delay

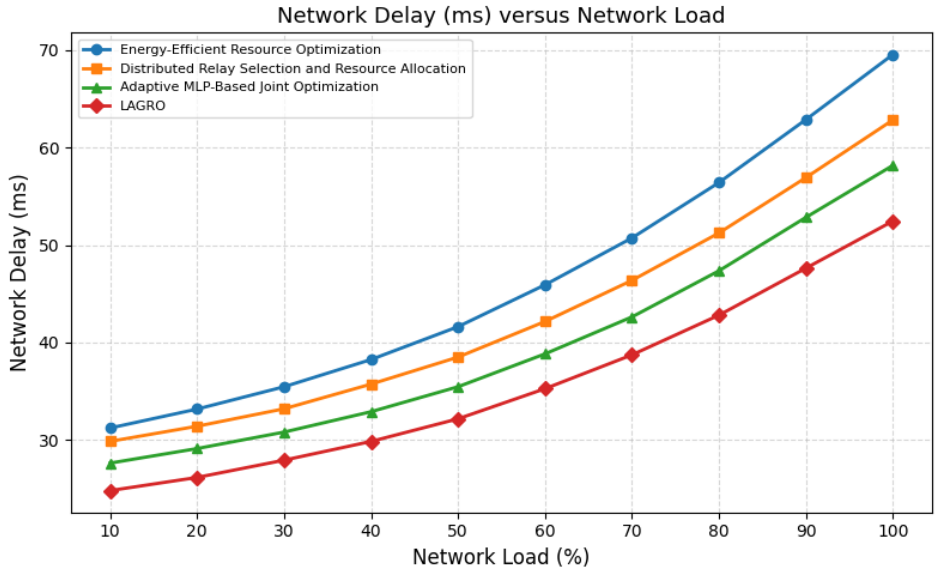


Figure 9. Network delay (ms) versus network load

Unlike the previous metrics, reduced delay is indicating better network behavior. The delay is increasing as network load rises because queues become increasingly occupied and then forwarding the operations are requiring additional processing. LAGRO is maintaining reduced delay because its load-aware topology formation avoids selecting highly congested relay nodes.

4.9 Results Based on Packet Loss Rate

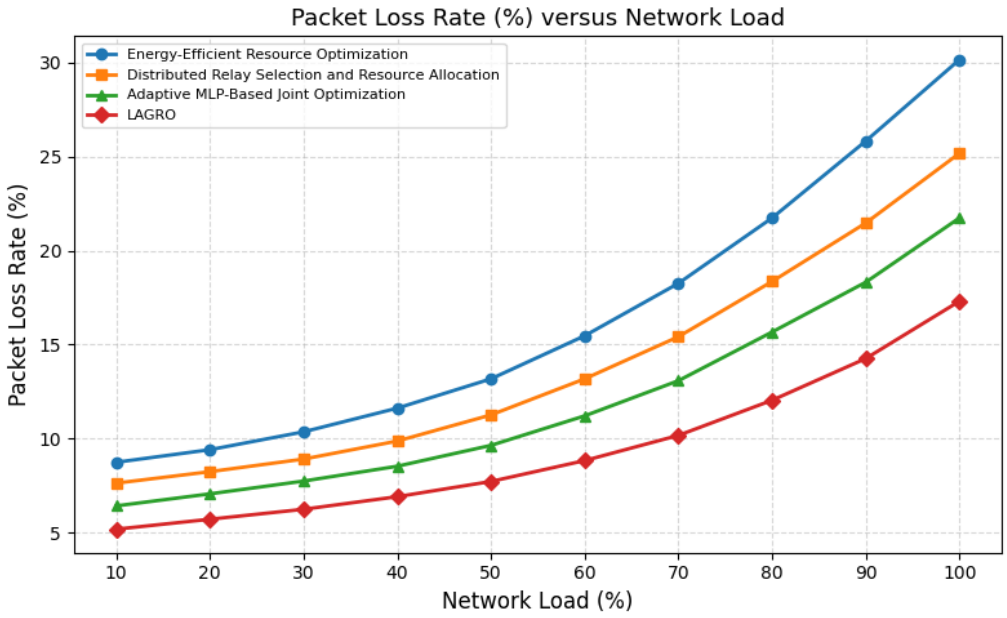


Figure 10. Packet loss rate (%) versus network load

Packet loss is increasing with the network load because congestion, interference, and queue overflow become more frequent. LAGRO is producing the lowest packet loss across all the load levels because its relay-selection mechanism explicitly considers node load before allocating communication resources.

Discussion

LAGRO is improving its communication performance under the increasing network load as illustrated by the results of figure 2–10. The network load at 50% provides energy efficiency of 88.91%, throughput of 90.12%, spectrum utilization of 89.74%, SNR of 27.84 dB, data transfer rate of 89.18%, error detection of 91.26%, and link reliability of 90.24% (see tables 3-9). In the case of network load at 100%, LAGRO provides energy efficiency of 79.48%, throughput of 80.54%, spectrum utilization of 81.27%, SNR of 23.84 dB, data transfer rate of 79.31%, error detection of 84.86%, and link reliability of 82%.

Conclusion

LAGRO is being introduced here for energy efficient cooperative communication in 5G Wireless Ad Hoc Networks. This proposed framework involves load aware cooperative topology formation, greedy relay resource optimization, and adaptive performance management techniques for coping with dynamic network traffic load, spectrum limitations, varying channel conditions, and node energy constraints. The numerical performance results reveal that the performance of LAGRO outperforms other frameworks for all tested network loads. In terms of 50% network load condition, the performance metrics are 88.91%, 90.12%, 89.74%, 27.84 dB, 89.18%, 91.26%, and 90.24%.Under the maximum 100% load condition, the method is maintaining 79.48% energy efficiency, 80.54% throughput, 81.27% spectrum utilization, 23.84 dB SNR, 79.31% data transfer rate, 84.86% error detection rate, and 82.71% link reliability. Network delay is increasing to 52.46 ms, while packet loss is reaching to 17.31%. These results are showing that incorporating instantaneous node load into cooperative topology and relay-resource selection is supporting more stable resource utilization and communication performance as traffic intensity increases.

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