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ReCoMM: resource-aware cooperation modelling using Markov process for effective routing in mobile ad hoc networks

PRASANNAVENKATESAN THEERTHAGIRI

Department of Computer Science and Engineering, GITAM School of Technology, GITAM University, Bengaluru, India
e-mail: prasannait91@gmail.com

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Abstract. In Mobile Ad hoc Networks (MANETs), the most essential factor for successful routing is the cooperation of nodes. The node's non-cooperative behavior causes routing problems and lowers network performance. The non-cooperation is related to a mobile node's resource restriction characteristics. The battery energy is a significant restriction for a node since it runs out after a certain amount of time. The mobility of nodes, on the other hand, has an impact on routing performance. As a result, the focus of this research is on assessing a node's collaboration by exploring futuristic node mobility and energy of the node. This study proposes the Resource-aware Cooperation Modeling with Markov Process (ReCoMM) for assessing link stability of the node in order to design effective routing. Using a Markov process, the ReCoMM model investigates the factors that influence cooperation and node state change. The Markov process is used to modify node durability and connection stability. The Markov process aids in the determination of the higher and smaller limits of cooperation with the computation of the cooperation value. The proposed ReCoMM model has been simulated, and performances were assessed with various scenarios using the NS2 simulator. The results show that the suggested ReCoMM produces 13–21 percent of higher packet delivery ratio than the existing methods. In a higher mobility scenario, the nodes' remaining energy increases to 6–7 percent as compared to previous methods. Furthermore, it considerably outperforms previous models by average end-to-end latency and routing overhead.

Keywords. Cooperative routing; Markov process; resource-aware routing; ARIMA; MANET.

1. Introduction

Routing is most important for successful network activities in MANETs for establishing communication between mobile nodes [1–6]. One of a mobile node's primary resource limitations in MANET is battery energy. After discovering a routing path, a node's battery energy often runs out. It leads to failed or incomplete packet delivery. Because a node's energy is limited, routing is a difficult operation. Because there is no centralized administrative nodes in the MANET, the dynamic actions of a node causes network connection stability concerns [2–5]. The link disconnectivity because of fast node mobility causes packet loss and decreases network lifespan. Similarly, a node's change from a cooperative to a selfish state has a significant impact on the network's dependability [2–7]. Malicious assaults, communication connection failures, and other environmental effects are all threats to the network. These factors have an impact on network routing as well as neighbor node cooperation.

Many academics have focused their study efforts in the last decade on analyzing the amount of collaboration of a mobile node in various circumstances. The degree of neighbor node cooperation determines the degree of connection between the source and the destination. To save energy, the non-cooperative node does not participate in the routing. As a result, a node's partial cooperation or non-cooperation leads to packet delivery failure. Several extant research projects aim to use reputation values, game theory, or rewards for nodes in routing to encourage node cooperation. Several extant research papers focus on detecting, preventing, and mitigating intrusions, assaults, selfish behavior, and selfish node mitigation [6, 8, 9]. Many of the efforts focus on finding common performance measures such as the shortest way rather than enhancing the routing discovery process using node resources, including speed, energy, etc. [4, 5, 10, 11]. The proposed model in this study uses the energy-draining rate, residual energy, and speed of the node to assess a node's degree of cooperation. In order to provide reliable route discovery, this model takes into account the speed and energy of intermediary nodes. The proposed Markov process determines if the mobile node's state changes are cooperative, partial, or non-cooperative.

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The following are the main contributions and benefits of the proposed ReCoMM in improving routing:

- The proposed ReCoMM investigates node dependability based on the node's residual energy. It determines an effective routing path and facilitates resource-based routing by analyzing the topology and speed of nodes.
- It also uses a Markov method to analyze the node's future cooperation states.
- The ReCoMM combines energy and mobility measurements to provide an efficient MANET cooperative routing mechanism.
- It offers the advantage of lowering routing overhead by lowering the frequent routing discovery process due to reduced mobility nodes
- The suggested ReCoMM emphasizes combining both the mobility and energy of the node components to overcome the constraints of the current literature.

The remainder of the paper is structured in the following manner. Section 2 of MANET briefly addresses collaboration challenges and solutions from a variety of sources. The proposed forthcoming cooperation based on resources and node transitions in different states are described in section 3. Section 4 discusses ReCoMM's effects on node cooperation and assesses the simulation findings. It also includes a performance study of various situations based on the reliability of the mobile node and connection stability parameters. In the end, section 5 wraps up the study by discussing how this research may be improved in the future.

2. Related works

This section addresses current literature on cooperative routing in MANETs and its different advancements. Existing research helps to develop routing techniques, cooperative stimulation ways such as trust, reputation, and acknowledgment methods, or Quality of Service (QoS) concerns, as well as mitigating routing assaults such as malevolent or selfish attacks. This article looks at studies on resource constraints and develops a protocol based on affecting variables like energy, mobility, and trust values.

To tackle the energy of node concerns, the paper [8] developed an energy-aware routing. In a dynamic topology, it uses min-max formation to transfer packets and manages high mobility nodes. However, only connection breaks caused by a node' energy are considered in this work. The focus of this article is not on external malicious attacks or network security problems. It renders the mobile node completely anonymous. Rashid *et al* (2017) [9] proposed mobility and energy-aware routing to extend the network's lifetime. For routing, it chooses nodes with smaller mobility and greater remaining energy. It allows the node to exist for a longer length of time in order to complete the routing. For efficient node selection for routing, it should take into account the rate of energy consumption. However, the node's performance is not evaluated in this study, and the mobility characteristics are not discussed.

In addition, to tackle the network reliability optimization problem based on the nodes and connections of the interconnection, an artificial neural network-based approach has been developed. An energy function and stable states were used to create the artificial neural network. This steady-state is a solution to the problem of network dependability. The authors demonstrate that the suggested technique is more effective at optimizing network dependability through comparative reports. They claimed that using this technique enhances the dependability of fully linked nodes in networks while reducing the risk of nodes in the networks failing due to decreased connections [12]. Sengathir and Manoharan (2015) proposed a Model prediction model based on a futuristic trust coefficient to evaluate network survivability [13]. It uses the non-birth-death method. The network survivability is assessed using the lower and upper bounds of a Markov prediction model. However, this work does not investigate the impact of a node's fast mobility, which has a significant impact on node cooperation, nor does it assess a node's partial cooperating factor.

Jayalakshmi and Razak (2016) used fuzzy logic prediction in [14] to improve security and defend against vulnerabilities. The routing protocol takes higher trust and residual power levels into account. Routing history, trust record list, forwarding ratio weights, and time-aging factor are all used by each node to compute its trust value. This study, however, does not look at false positives and negatives when evaluating trust and energy levels. The mobility and load-aware routing proposed in [15] solves broadcast storm difficulties and reduces contention, redundancy, and collision concerns. This protocol seeks to limit flooding and message rebroadcasting. Instead, this protocol should compare with another algorithm using the fundamental Ad hoc On-demand Distance Vector (AODV) protocol. The energy and scalability of the nodes are not examined in this work. The paper [16] proposed a routing protocol that uses a linear programming optimum model to conserve energy and travel time. The viable solution was estimated using greedy bi-objective integer programming. For the development of this protocol, it evaluates energy, traffic load, and connection stability. On the other hand, it does not focus on node mobility. Manoharan and Sengathir (2016) [17] developed an Erlang coefficient-based conditional probabilistic model for MANET to isolate selfish nodes. The selfish nodes are isolated because of genuineness and non-cooperative causes. The Erlang distribution uses independent exponential random variables to predict the routing path's failure rate. This study, however, does not assess false positives and negatives.

To create a threshold-based routing algorithm, the study [18] investigates the energy level, connection, and degree of trust. It finds the quickest route and filters out harmful or selfish nodes. For packet forwarding, it uses the nodes' in-out ratio and prior forwarding history to calculate trust. Nonetheless, this document is not evaluated on the basis of trust. The study [19] describes a heuristic technique for routing that uses the node's minimum power.

The MQ-Routing is presented in the paper [20] to increase the battery lifespan in a dynamic network architecture. MQ-Routing assesses path availability and topological changes before modifying the reinforcement-learning Q-routing method. Artificial Neural Network (ANN) was used to forecast delays in the packet delivery of MANET [21]. The ANN-GRNN method outperforms the Radial Basis Function (RBF) model in terms of actual and projected latency. It does not, however, look at the GRNN's applicability in dynamic settings.

In MANET, the article [22] uses mobility prediction to decrease air interference between the node's radio transmissions. It creates mobility models by analyzing node location and movement trends in the past. Theoretical study shows that the Elman network outperforms traditional techniques in terms of location prediction. It does not, however, implement or analyze the suggested task. A link-stability prediction method based on signal strength was reported in [23]. For the implementation, it changes the traditional AODV protocol. For connection stability and mobility prediction, it accounts for variations in radio signal intensity. It simply assesses the results of the standard AODV protocol. It should be compared to improved versions of routing algorithms and other artificial intelligence-based routing algorithms that are currently existing. The analyses with different current methods are not included in this article. Using the sojourn time distribution, the article [21] uses the Markov renewal process to forecast link-state behavior and availability. It uses the Markov chain and Markov renewal process to analyze the prediction outcomes for three pairs of nodes. The results show that the Markov renewal process outperforms the Markov chain in terms of prediction accuracy. It does not, however, address the overheads spent in the forecasts, and it also falls short in terms of doing the suggested task in a mobile ad hoc setting.

Using the eye of coverage method in the MANET, the work in [24] forecasts the mobility and future placement of nodes. The [25] forecasts the resources availability like as energy and bandwidth and buffer-space. For future resource prediction, it uses the Wavelet Neural Network. It does not, however, address the prediction overheads, nor does it compare the suggested work to existing approaches.

The paper [26] presented the new AODV protocol for determining the best routing in a MANET based on the nodes' energy levels. The proposed approach is unclear, and it requires more control than AODV and DSR. Sengathir and Manoharan [27] presented a fault-tolerant system. It seeks to predict node mobility patterns in order to transmit clinical care data. According to the document, the mobility prediction model chooses paths with the least amount of interference and transmission power. It does not, however, identify or assess the cost of forecasts.

3. The ReCoMM model

The procedures concerned with the proposed ReCoMM model for the MANET are described in this section. It uses the Markov process to estimate the amount of cooperation and state transitions of nodes across distinct states. It also explains how to evaluate node and connection dependability and stability.

A Markov process is underlying the proposed ReCoMM model. The reliability factor is used to assess the mobile node's level of cooperation. The Markov model is a better fit for designing distinct node states in MANET. The characteristics of MANET nodes are easily modeled using the Markov process. It is possible for modulating the different behaviors of the mobile nodes into various states.

A node's cooperation level is classified into three categories based on its forwarding ability: extremely cooperative level, limited cooperative level, and non-cooperative level. Limited cooperative node has the ability to dynamically discard data, and it is not involved in the routing process. Although these nodes were not forwarding the packets, the non-cooperative node remains in the routing network. As a result, resource restrictions, malicious attacks, creating heavy load in the network, increased mobility, and quick energy-consuming may influence the features of partial/non-cooperation of nodes [20, 21]. The ReCoMM uses the following techniques to assess a node's level of cooperation in a MANET.

1. Using a Markov process to model transition states
2. Determining state characteristics
3. Calculating reliability of the node using energy
4. Estimating stability of the link using mobility
5. Manipulating the ReCoMM for dependable and cooperative routing

3.1 *Using a Markov process to model transition states*

Consider a MANET node's transition states as a stochastic process in a network. The mobile nodes' values are varying dynamically over a period in the stochastic process, which is called as a Markov process. As a result, each node is treated as a mathematical object, with its related properties treated as a random variable. Likewise, with MANETs, node properties like mobility and energy vary dynamically in a period. A stochastic process uses a node's current state and conditional probability distribution to forecast its transition states. As a result, a Markov process 'A_t' is determined by previous states and t (that is A_t: t), where 't' is the random variable. As a result, a Markov chain (A_n) is a Markov process in a sequence that predicts future behavior based on previous behaviors such as A_{n-1}, A_{n-2},..., A_0. Similarly, it assesses the node's current state based on its previous behavior The Markovian Decision Process (MDP) assesses the node's transition.

3.2 *Determining state characteristics*

Using a conditional probability and a Markov process, the contributing variables that cause the change of mobile node transition level from C to L to N are identified. The ReCoMM is a dispersed method for calculating mobile node stability and link connection reliability. Regardless of whether there is a central node, it estimates the cooperation factors and energy values for every mobile node in the mobile ad hoc network. The resultant collaboration factor measures the node's influence as a level of cooperation. The state transition Markov model using node behaviors for evaluating the cooperation of the node is depicted in figure 1. The three states of a node's transition are depicted in figure 1: According to the Markov process, the Completely cooperative (C) state, limited cooperative (L) state, and non-cooperative (N) state are the three options. This model ignores the non-cooperative to highly cooperative (N => C), partial cooperative (N => L), and non-cooperative to cooperative (L => C) transitions. The state values CL, CN, and LN designate the precise transition of states between distinct levels of cooperation. The following characteristics are used by the MDP to evaluate node states and transitions. The symbol definitions and parameters employed in this paper are listed in table 1.

1. When Z is the set of transition states that determines a node's cooperation level, the node in the MANET has primarily three states (i.e., Z = C, L, and N).
2. T = CL, CN, LN is a finite set of transitions for the states Z = C, L, N.
3. The transitions for the state C are C = CL, CN, and the transition for the state L is L = LN.

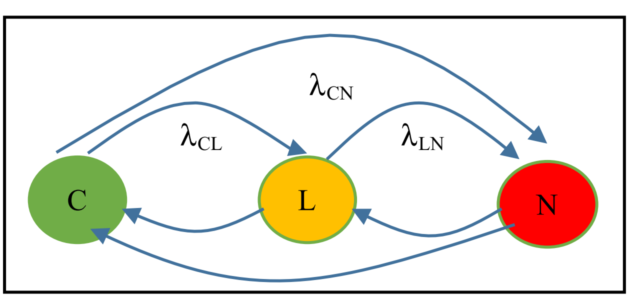


Figure 1. Transitions of the node's states.

Table 1. Nomenclature.

Symbol	Description
Eres	A node's residual energy
ET	The amount of energy necessary to send a packet
ER	The required energy to get a data packet
MS_t	At time 't,' the rate of mobility
N_p	Number of packets in total
λS	Link stability
λR	Node reliability
C	Node with high cooperation
L	Partial cooperative node
N	Node that refuses to cooperate
λ_{HP}	Transitioning from a complete cooperative to a limited cooperative node
λ_{PN}	Transitioning from a limited cooperative to a non-cooperative node
λ_{HN}	The switch from a complete cooperative to a non-cooperative node
V	Mobile node
E	Wireless links
G	Graph
Xt	Previous states "t"

4. The probability that transition CP in state C at time 't' will lead to state L at time t+1 is Pr(CL).

$$Pr(\lambda_{CL}) = Pr\{C_{t+1} = L|C_t = C, \lambda_t = \lambda_{CL}\}$$

5. The probability that transition CN in state C at time 't' will lead to state N at the time 't + 1' is Pr(CN).

$$Pr(\lambda_{CN}) = Pr\{C_{t+1} = N|C_t = C, \lambda_t = \lambda_{CN}\}$$

6. Similarly, Pr(LN) is the probability that transition LN from state L to state N at time t+1.

$$Pr(\lambda_{PN}) = Pr\{L_{t+1} = N|L_t = L, \lambda_t = \lambda_{LN}\}$$

3.3 *Calculating reliability of the node using energy*

The energy dissipation of a node is used to assess node dependability. During packet transmission, receiving, and overhearing operations, energy is dissipated. Let the network with 'G' as a weighted undirected graph with 'V' vertices (mobile nodes) and edges of 'E' (wireless links). Mobile nodes are vertices, and edges are the links, therefore G = (V, E). To assess a node's collaboration degree, this research takes into account the following essential variables. First, there's a node's residual energy, which is a crucial statistic for estimating the node's dependability. Energy necessitates to send and receive data from other mobiles nodes, and in the end, the pace at which a node's energy is depleted.

Meanwhile, these numbers are used to estimate the node's lifespan. The pseudo-code stages for estimating the node reliability (λR) are given in algorithm 1. To determine the reliability (λR) of node, it first calculates the node's remaining/ residual energy (Eres); if the Eres value is higher than one, it calculates the necessary energy for packet transmission (ET) and reception (ER. It calculates the node's node reliability (λR) value based on these variables.

The following equation is used to determine the energy necessary to transmit (ET) a packet from source to destination, where ET_1 is the required energy to transmit a data packet to the destination MANET node. Likewise, 'n' denotes the number of packets in ET_2. The total number of packets is represented by Np.

$$ET = \frac{ET_1 + ET_2 + \cdots + ET_n}{N_p}; \tag{1}$$

The required energy to receive a packet (ER) from any node is calculated using equation (2).

$$ER = \frac{ER_1 + ER_2 + \cdots + ER_n}{N_p}; \tag{2}$$

As a result, λR uses ET, ER, EO, and residual-energy (Eres) data to determine node reliability, where EO is the energy wasted owing to overhearing. The λR is written as follows: (3)

$$\lambda R = \frac{Eres}{Eres + (ET + ER) + EO} \tag{3}$$

Equation (3)'s node reliability (λR) value classifies each node's cooperativeness into C, L, or N. The node is characterized as highly cooperative if its dependability is more than 0.5, i.e., C = λR > 0.5 (50 percent) (C). Suppose the λR value goes below 0.5 (i.e., $\lambda R < 0.5$), as illustrated in figure 1, the transitions of states from C to L (CL). It determines the more transitions of state in the same way. If the dependability factor value of the node falls between 0.5 and 0.2, the ReCoMM classifies it as a partly cooperative (L) node. L = $0.2 < \lambda R < 0.5$. As shown in figure 1. Suppose the λR value falls below 0.2 (i.e., λ R < 0.2), the state transitions from L to N (LN). The node is thus classified into the non-cooperative node (N). When the node reliability (λR) value goes below 0.2 (i.e., $\lambda R < 0.2$), the state transitions from C to N (CN), as seen in figure 1 [18].

Algorithm 1: Node reliability (λR) Estimation

Begin

__For__ each mobile node N do

__While__ (Eres>0)

Compute the residual energy (Eres)

__If__ Eres ≥ 1 then

__For__ packet i = 1 to n do

Compute energy required for transmission

(ET) and reception (ER) of data

Calculate λR

3.4 *Estimating stability of the link using mobility*

The wireless connection between nodes is heavily influenced by a node's mobility. If a mobile node with high speed is selected for routing, link breakages between the nodes are likely to occur often. Because the node with high speed may migrate outside the source mobile node's overage region while routing is in operation. As a result, a mobile node with high speed must be excluded from the process of route discovery. It necessitates the search for a more durable mobile node. The lower mobile nodes may be able to decrease frequent connection breaks caused by fast mobility, lowering routing overhead. The connection stability factor is proposed in this work as a way to find low steady and mobile nodes [28]. The proposed ARIMA algorithm comprises three parameters, namely, (p, d, q) where 'p' specifies the time delays, 'd' denotes the speed, it has been subtracted from previous values, and 'q' is the moving average method order [29–32]. Consider the following time series of data: 'SV t;t>0'. Equation (4) yields the ARIMA (p,d,q) model:

$$\begin{aligned} &SV_t - \alpha_1 SV_{t-1} - \alpha_2 SV_{t-2} - \cdots - \alpha_{p'} SV_{t-p'} \\ &= \epsilon_t + \theta_1 \epsilon_{t-1} + \theta_2 \epsilon_{t-2} + \cdots + \theta_q \epsilon_{t-q} \end{aligned}$$

$$(i.e.)\, SV_t \left(1 - \sum_{i=1}^{p'} \alpha_i T^i\right) = \epsilon_t \left(1 + \sum_{i=1}^{q} \theta_i T^i\right) \tag{4}$$

The end result is as follows:

$$\left(1-\sum_{i=1}^{p'}\alpha_i T^i\right)=(1-T)^d\left(1-\sum_{i=1}^{p'-d}\varphi_i T^i\right)$$

The ARIMA (p, d, q) model will be formulated using the

drift rate 'δ', and the final model will be changed as follows: (5),

$$SV_t\left(1-\sum_{i=1}^{p}\varphi_i T^i\right)(1-T)^d=\delta+\epsilon_t\left(1+\sum_{i=1}^{q}\theta_i T^i\right) \quad (5)$$

The equation (5) estimates as well as predicts the future

Algorithm 2: Estimation of link stability (*λS*)

Begin

__For__ each mobile node 'N' do

Compute the future speed of node (MS) at different

time 'T'

using ARIMA

***If** MS≤ 30 then*

Calculate λS

***Else If** all node's*

mobile node speed with the ReCoMM model link stability measure. Consider the mobile ad hoc network as the weighted undirected network with nodes with specific weights (speeds) ranging from 1 to 50 m/s to evaluate link stability (λS). Based on the node's speed in different sessions, the ReCoMM model determines the link stability (λS) of a node. Let's have a look at 'T' as the maximum duration and as a disjoint set with 'n' various time values of 't' as shown in equation (6), and Ns as the number of speed samples. The value of 'n' should be smaller than the duration of the simulation. The link stability (λS) of a node is then calculated using equation (7).

$$T=\{t_1,t_2,t_3,\ldots,t_n\};n\le T \quad (6)$$

$$\lambda S=\frac{MS_{t1}+MS_{t2}+MS_{t3}+\cdots+MS_{tn}}{Ns};t_n\ge 1,n\le T$$

$$(i.e.)\ \lambda S=\sum_{tn=1}^{n}\frac{MS_{tn}}{Ns} \quad (7)$$

Using the ARIMA model, the equations (5) and (7) drive

the link stability (S) of a node. The pseudo-code stages for estimating a node's connection stability (λS) are provided in method 2. (1) Using ARIMA, compute each mobile node's forthcoming mobile speed values of (MS) in various time sessions (T) to assess link stability. (2) If the value of the MS is less than 30, it calculates the node's link stability (λS) value. (3) If all of the nodes' MS values are more than 30, the mobile node with the smallest possible MS value between 30 and 40 is chosen for the link stability computation. (4) In the most extreme scenario, if all of the nodes' MS values are more than 40, the node with the smallest MS value will be used for the λS computation.

The nodes are classified as regular mobility nodes or rapid mobility nodes based on their S values. As an example, let's say a node's threshold speed is 30 m/s. If a node's S value is less than 30 m/s, the ReCoMM model deems it to be a highly cooperative (H) node. If a node's MS value is between 30 and 40, it is called partly cooperative (P), whereas nodes with MS values over 40 are deemed non-cooperative (N). When the MS value of all nodes exceeds 30 m/s, the ReCoMM classifies them as nodes with higher mobility. Following that, it chooses the mobile node with low among all nodes for the shortest routing path to the destination node from the source node.

3.5 *Manipulate the ReCoMM model*

The Markov process was used to formulate the ReCoMM model, which is based on mobility speed and remaining energy. By using the link stability of the node and node reliability calculation from the derivations (3) and (7) classifies a node as complete/limited/non-cooperative. It makes use of ReCoMM to carry out the routing. By using the following criteria, the ReCoMM model finds the nodes that can execute reliable routing. (1) The mobile node could be highly cooperative in the sense that the node's reliability (R) is more than 50 and link stability (S) is less than 30 (i.e., $\lambda R > 50\,\&\&\,\lambda S \le 30$). (2) If the first criterion fails, the second criterion, $20<\lambda R<50\ \ \&\&\ \ 30<\lambda S<40$. Table 2 shows the ReCoMM's assumptions for classifying nodes as complete cooperative (C), limited cooperative (L), or non-cooperative (N). To assess the complete cooperative situation, figure 2 depicts the state changes depending on connection stability and node dependability of the mobile node.

Table 2. Cooperation evaluation.

Parameter	$\lambda R(\%)$	λS(m/s)
Complete cooperative (C)	≥ 50	≤ 30
Limited cooperative (L)	$20 < \lambda R < 50$	$30 < \lambda S < 40$
Non-cooperative (N)	< 20	> 40

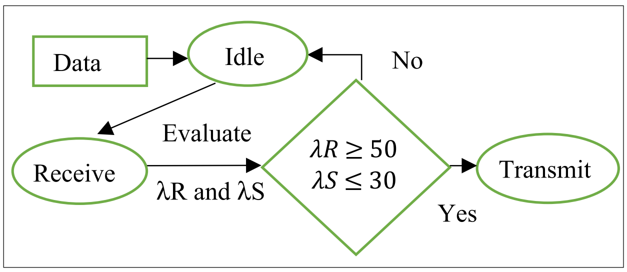


Figure 2. The node state transitions in ReCoMM.

As seen in figure 2, initially, a node is idle and expecting to collect data from broadcasting to the mobile destination node. The Markov process is then used to assess λR and λS values in order to determine if it has enough moderate mobility and energy to send the packet to its destination node. When a node's λR and λS values fulfil the ReCoMM criteria, the associated node is considered a highly cooperative node. When the node effectively receives a data packet to send to the destination, the status of the node switches from idle to active. Following that, packet transmission takes place using a fully cooperative node. When the node fails to meet the ReCoMM λR and λS criteria, the node returns to the idle state. As a result, it is not a cooperative mobile node.

4. Performance evaluation and analysis

This section describes the proposed ReCoMM in the MANET simulation environment, simulation settings, energy parameters, and simulated scenarios.

4.1 *Simulation environment*

The proposed effort builds a MANET simulation environment in order to deploy the ReCoMM and test a variety of situations. The following implementation scenarios create the routing protocol by combining the ReCoMM aspects and attributes of the proposed work, based on the characteristics of MANET, which is that it has no pre-existing infrastructure. The simulation model creates a dynamic network architecture with 50 randomly distributed nodes in a 1000×1000 m^2 region. With the Omni-directional antenna, each node in the network has a radio propagation range of 150 m and a channel capacity of two megabits per second. The Random Waypoint (RWP) mobility model facilitates movement between network nodes. The nodes in the RWP model travel in a zigzag pattern from one waypoint to the next. The waypoints were evenly dispersed throughout the simulation region. The mobile nodes travel at random based on criteria such as maximum/minimum speed, destination, and direction.

The nodes begin traveling to the destination location of the waypoint after stopping for a few seconds. After arriving at its target, the node pauses for a few seconds before selecting a new destination waypoint and moving towards it. Correspondingly, the movement of the node will continue until the simulation is completed. BonnMotion [33], a tool for creating and analyzing mobility scenarios, produces the motions for the RWP model. The mobile node travels corresponding to the RWP Model, with speeds ranging from zero to fifty, and its motions are assigned at random using the BonnMotion tool. For all of the tests reported in the study, the nodes' speed limitations are set to 0 m/s for least speed and 50 m/s for maximum speed; the pause period is 100 s. For the experiments, the maximum simulation time is 100 s. At pause time 0 s, the node begins to move, and at pause time 100 s, the node becomes immobile. The traffic of the network in the ReCoMM model is set with packet sizes of 64–1024 bytes is calculated using Constant Bit Rate (CBR). The proposed research examines its performance over time and with a growing amount of nodes. The ReCoMM analyses the nodes' cooperative performance at 10, 20, 30, 40, and 50 m/s, as well as the number of nodes at 10, 20, 30, 40, and 50.

4.2 *Implementation of the proposed ReCoMM model*

The Network Simulator (NS-2.35) tool [34] has been used for the implementation of the proposed ReCoMM algorithm in this phase. The proposed procedures and schemes are included in the ns2.35 simulator of different such as network layer and medium access layer. The AODV routing protocol first determines the nodes in the route path. Following that, the proposed ReCoMM predicts the routing mobile nodes and changes the routing node by discovering the path on a regular basis depending on the future availability of resources. For each experiment, table 3 lists the simulation settings and simulation environment. The energy model parameters and values used in the proposed study work are summarised in table 4. The simulation script's energy values are configured using the Tool Command Language (TCL). To implement the reliability and link stability methods, the suggested equations 1, 2, 3, 5, and 7 derive, develop, and interfere with the other NS2 modules using TCL scripts. It uses the routing table and

Table 3. Parameters of simulation.

S. No.	Parameter	Value
1	Number of nodes	0–50
2	Area size	1000 m × 1000m
3	Antenna Type	Omni-directional antenna
4	Transmission range	150 m
5	Packet size	128–1024 bytes
6	Channel capacity	2 Mbps
7	Traffic source	Constant Bit Rate (CBR)
8	MAC	Wireless LAN (802.11)
9	Queue type	Inter Face Queue (IFQ)

Table 4. Parameters for energy model.

S. No.	Parameter	Value
1	Initial energy (Eres)	50 J
2	Transition time	0.001 s
3	Sleep power	0.05 W
4	Transmission power (ET)	1.0 W
5	Idle power	0.1 W
6	Receiving power (ER)	1.0 W

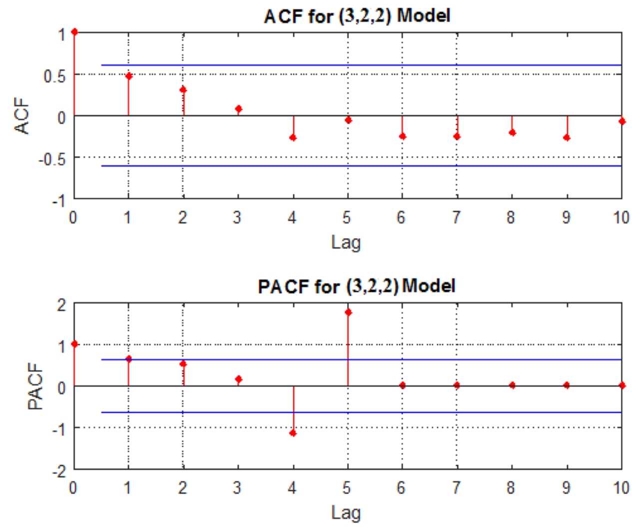


Figure 3. ACF and PACF of model (3, 2, 2).

routing history of the node as input. The output trace files are processed by the AWK [35] script. The AWK script formats the traces as needed.

Consider the challenge of predicting a node's future speed values as an autoregressive nonlinear problem. As previously stated, this study uses the ARIMA model to forecast the mobile node's forthcoming speed values using the time-series model [29]. Given 'd' previous values of 'x(t)', it predicts the series 'x(t)'. The target time series (input) is the node's speed values of 110–130 timestamps. It randomly splits the data matrix (timestamp speed) into two data matrices for training and testing. The network is regulated by the training dataset based on its error. The testing dataset assesses network performance before, during, and after training [18]. By varying the number of delays and channels, the ARIMA process evaluates the speed prediction model.

As a result, $x(t) = f(x(t-1), x(t-2),\ldots,x(t-5)$ is the ARIMA's definition of the problem. ARIMA trains the provided dataset and ends when the Mean Square Error (MSE) rises to a certain level [31]. As shown in table 5, it evaluates roughly 10 models for prediction: (1, 1, 2), (1, 2, 1), (1, 2, 2), (2, 1, 1), (2, 1, 2), (2, 1, 2), (2, 2, 1), (2, 3, 2), (2, 3, 3), (3, 2, 2), (3, 2, 2), (3, 2, 2), (3, 2, 2), (3, 2, 2), (3, 2, 2), (3, 2, 2), (3, 2, 2), (3, 2, 2), (3, 2, 2), (3, 2, 2) The lowest Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and Correlated Information Criterion (AICc) values in table 5 correspond to the dataset's stationary values. Table 5 uses boldface to highlight the lowest model, which is the (3, 2, 2) model. The Auto-Correlation Function (ACF) and Partial ACF (PACF) values for the stationary model (3, 2, 2) are shown in figure 3. The computation of the AIC, BIC, AICc, ACF, and PACF yields a stable and dependable quality dataset for future speed prediction. figure 4 compares RWP observed speed values to ARIMA projected speed values in a time-series (based on the highlighted (3, 2, 2) dataset presented in table 5). The lowest model, the (3, 2, 2), is shown in boldface in table 5. Figure 2 shows the values of the Auto-Correlation Function (ACF) and Partial ACF (PACF) for the stationary model (3, 2, 2). 3. The AIC, BIC, AICc, ACF, and PACF are used to create a consistent and reliable quality dataset for future speed prediction. In a time-series (based on the highlighted (3, 2, 2) dataset provided in

Table 5. Mobility prediction models based on ARIMA model.

(p, d, q)	(1, 1, 2)	(1, 2, 1)	(1, 2, 2)	(2, 1, 1)	(2, 1, 2)	(2, 2, 1)	(2, 3, 2)	(2, 3, 3)	(3, 2, 2)	(3, 2, 3)
AIC	348.139	171.423	147.323	136.456	265.287	161.5353	185.5752	154.5722	122.7527	190.366
BIC	350.256	174.352	146.448	137.562	266.277	162.235	186.7575	158.3285	124.5252	192.527
AICc	350.309	173.895	145.817	139.585	265.258	161.5287	186.5786	157.5282	126.8728	191.286

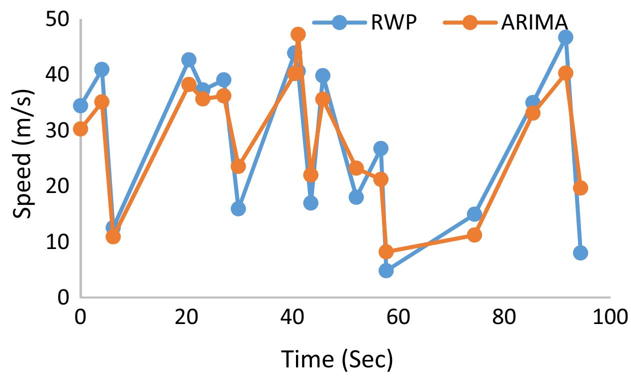


Figure 4. Comparison of ARIMA based redicted speed and observed RWP based speed.

table 5), 4 compares RWP observed speed values to ARIMA predicted speed values.

The ReCoMM's packet format is as follows.

Chart 1. Packet format.

Source ID	Destination ID	Hop count	DFS	λR	λS	FCS

The packet format of the proposed ReCoMM is depicted in Chart 1. The first two fields, source and destination node IDs, each carry two bytes. The hop count is the next parameter; it shows how many nodes are linked to a certain mobile node in their transmission range. It just contains one byte. The Data Forwarding Status (DFS) is the fourth field, and it takes up four bytes. We have included two more new fields, a 5th and 6th fields, to reflect the ReCoMM's R and S values. The fifth field (R) is used to store information regarding node dependability. The values of link stability are stored in the sixth field (S). For the discovery of complete cooperative, stable nodes for the routing process in which each mobile node must have the two fields with R and S values. The default FCS (Frame Check Sequence) is the last field, and it contains the error repair and detection settings [29].

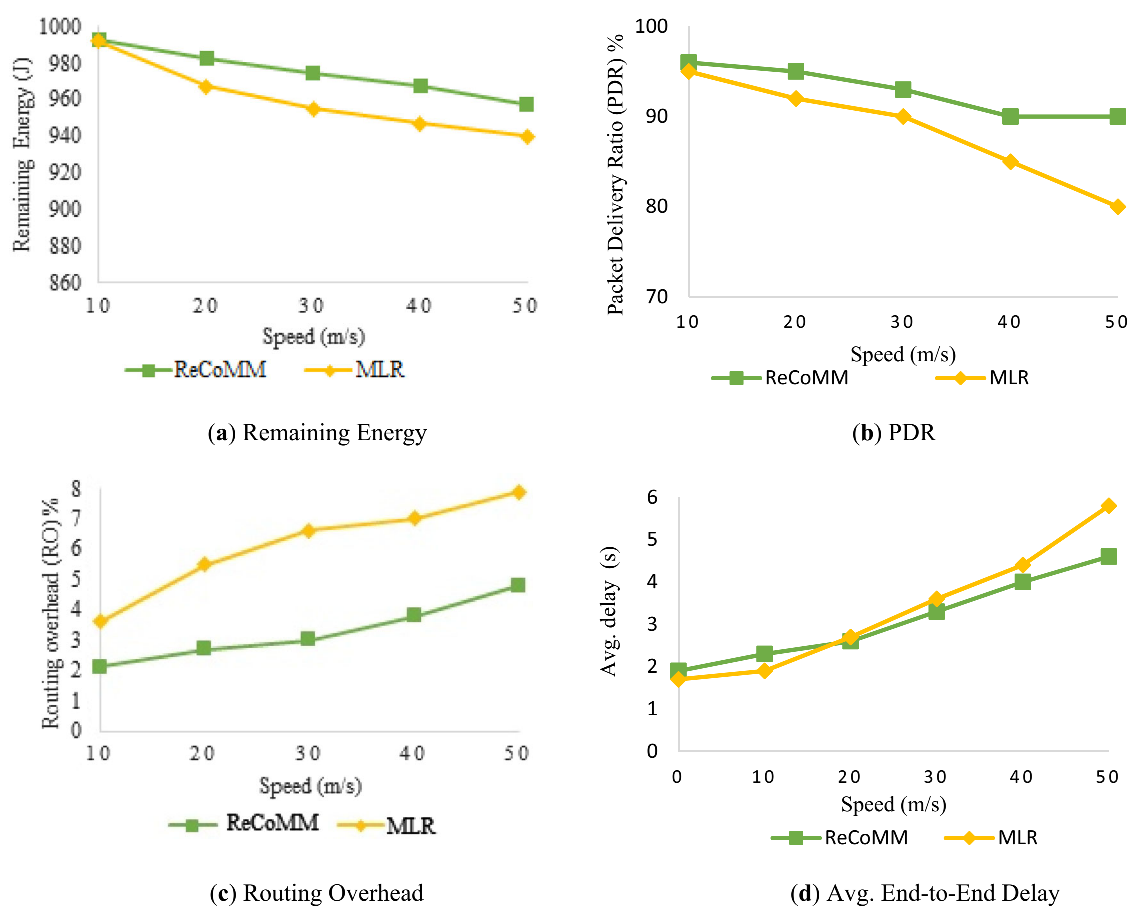
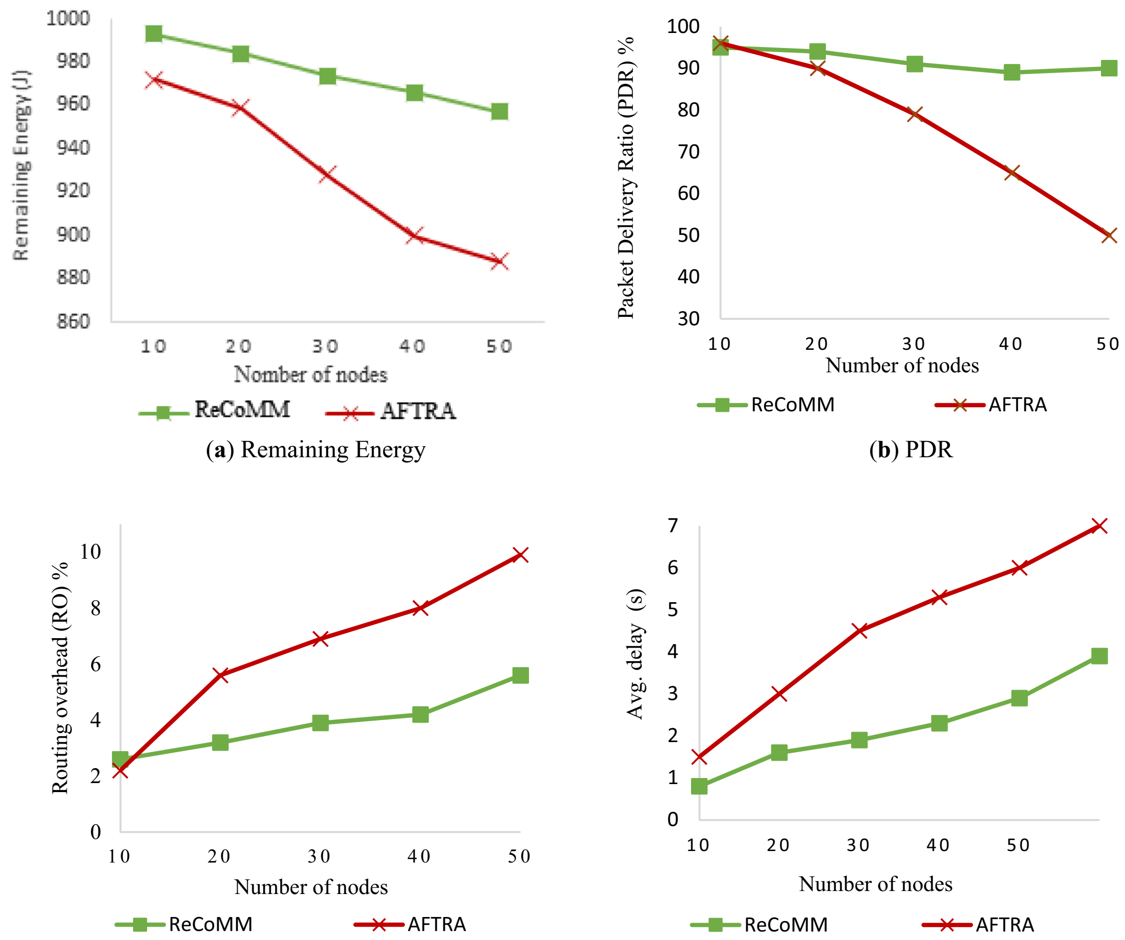


Figure 5. Evaluation of performance results by varying node speed.



(**a**) Remaining Energy (**b**) PDR

(**c**) Routing Overhead (**d**) Avg.End-to-End Delay

Figure 6. Evaluation of performance results by varying number of node.

4.3 *Performance evaluation*

The various implementation scenarios examine the proposed ReCoMM method, and results are compared to the performance of MLR [14], AFTRA [12], and FTP-DSR [13]. The suggested approach has a similar goal to the algorithms reported in [14, 17], and [8]. As a consequence, the suggested outcomes are compared using the AFTRA, FTP-DSR, and MLR algorithms. The MLR method uses MDP to handle mobility-aware routing. As a consequence, the ReCoMM uses an MLR routing algorithm to compare and analyze ReCoMM's algorithm speed prediction findings by modifying the speed (m/s) values. The simulation results of the ReCoMM and MLR algorithms are shown in figure 5. It demonstrates how changing node speed affects the output of several metrics. The AFTRA method uses fuzzy logic to offer an energy-aware routing. It examines energy measurements for routing in resource-constrained situations.

As a result, the ReCoMM model's node reliability (energy) findings are comparable to the AFTRA results. Changing the number of nodes in figure 6 shows how the outcomes of these two methods compare. In comparison to the MLR [14] and AFTRA [17] algorithms, the proposed ReCoMM analyses performance measures such as Packet Delivery Ratio (PDR), average energy consumption, average end-to-end latency, and Routing Overhead (RO). Table 6 gives the performance metrics of proposed ReCoMM.

4.3a *Evaluation of performances by varying speed of the mobile node* The maximum speed rises by ten m/s every 20 s in this scenario, as shown in figure 5, starting at 10, 20, 30, 40, and 50 m/s. It depicts the average remaining energy

Table 6. Performance metrics.

MSE	0.9636
RMSE	0.9816
MAE	0.7765
MARE	0.9642
RMSRE	2.4094

of nodes at various speeds of mobility. It shows the ReCoMM and MLR algorithms' residual energy behavior for speed values of 10, 20, 30, 40, and 50 m/s. The variations in the energy of the nodes are measured in joules (J). If the mobile node speed increases, the ReCoMM and MLR models progressively increase the average consumption of energy of the nodes, as shown in figure 5a. However, when compared to the MLR algorithm, the ReCoMM has more residual energy. The reduced mobility and greater energy nodes are discovered by the link stability (S) and reliability (R) factors; consequently, the suggested ReCoMM consumes less energy than MLR.

The ReCoMM's residual energy is comparable to MLR at a node speed of 10 m/s. At a speed is 20 m/s, ReCoMM and MLR have 983 and 967 (J) of residual energy, respectively. The residual energy of the nodes in the ReCoMM and MLR models at 30 m/s is 974 and 955 (J), respectively. The MLR technique consumes more energy than the ReCoMM method, as seen in figure 5a. It is because the Markov process selects complete cooperative nodes (C) for routing. When the speed is increased to 40 m/s, the ReCoMM and MLR have 967 and 947(J) residual energy, respectively. For routing, the ReCoMM algorithm avoids the greater-speed mobile nodes. As a result, it consumes less energy than other algorithms. In the very much dynamic mobile network, the ReCoMM model produces greater residual energy 957 (J) at the conclusion of the simulation than the MLR. At varying node speeds, the ReCoMM enhances residual energy by 14–19 J. As a result, the MANETs have more residual energy in the ReCoMM model. By selecting the complete cooperative (C) and limited mobile speed nodes for routing, the Morkov-ARIMA based ReCoMM enhances node remaining energy.

PDR performance results for ReCoMM and MLR are shown in figure 5b for changing node speeds. Using a predetermined amount of nodes and changing node's mobility speeds, the PDR of the proposed ReCoMM is compared to the PDR of the MLR algorithm. For effective routing, the PDR should be greater. At a node speed of 20 m/s, ReCoMM and the MLR algorithm have a PDR difference of 96 and 92 percent, respectively. When the node speed is increased to 40 m/s, the PDR of ReCoMM and MLR is 91 and 85 percent, respectively. The PDR of the ReCoMM is higher than that of the MLR; the ReCoMM chooses nodes for routing based on link stability (S) values. As a result, the PDR is greater, but the MLR method fails in this case. Because the MLR must reestimate the route-cache when the mobility speed of the node varies over time, it has a lower PDR. The PDR of the ReCoMM model is 10–13 percent higher than the MLR at 50 m/s, and the ReCoMM uses the Markov process in order to find complete cooperative nodes to facilitate effective routing.

For the ReCoMM, the routing overhead comprises the computation of dependability and connection stability. The RO of ReCoMM and MLR is shown in figure 5c. When compared to MLR, the ReCoMM has a lower RO for varied node speeds. The ReCoMM and MLR have 2.7 and 5.6 percent RO, respectively, at a node speed of 20 m/s. When node speeds reach 40 m/s, the MLR affects the overall performance of the network by creating a greater RO of 7.1 percent, but ReCoMM only creates 3.8 percent. The ReCoMM yields 4.8 percent RO at a node speed of 50 m/s, which is relatively low when compared to the MLR's RO of 7.9 percent. The suggested ReCoMM decreases the RO by 3–4 percent in dynamic mobile networks. Due to frequent connection failures, the MLR must retransmit packets; as a result, the MLR algorithm has a greater RO; however, the ReCoMM uses the link stability calculation to pick lower mobility nodes for routing. As a result, link stability and dependability decrease link failures and prevent packet flooding in the network.

The average end-to-end latency for packet transmission is shown in figure 5d. Because ReCoMM uses the Morkov-ARIMA procedure to compute the λR and λS values, the delay is initially longer than MLR. ReCoMM has a 2.4 s transmission delay at 10 m/s, while MLR only has a 1.9 s delay. Following that, the ReCoMM's delay tends to be shorter than the MLR's. ReCoMM and MLR have transmission delays of 3.6 and 5.6 s, respectively, at a node speed of 50 m/s. The reduced packet transmission delay for the ReCoMM is due to less roaming of data packets. The λS estimation is crucial in avoiding greater speed mobile nodes for routing and therefore lowering retransmission. In this paper, the proposed approach achieves this advancement by employing the Morkov-ARIMA method and ReCoMM conditions to create stable and low-speed nodes.

4.3b *Evaluation of performance by varying number of node* The nodes for this setting have a random mobile speed of up to 50 m/s. Figure 6 shows the performance of the ReCoMM and AFTRA models for various metrics when the number of nodes is varied from 10, 20, 30, 40, and 50. The suggested approach uses the BonnMotion mobility model to allocate RWP mobility for mobile nodes in this situation. The influence of the amount of mobile nodes on average remaining energy is seen in figure 6a. For both models, the residual energy consistently declines as the number of nodes rises. Faraway nodes often use more energy to transport data packets than their nearer neighbors. When there are ten nodes, the remaining energy for the ReCoMM and AFTRA algorithms is 993, 972 (J), respectively. Initially, a small number of nodes demand more energy to locate the network's destination node. Following that, the graph for the ReCoMM appears to be linear by the total number of nodes. The energy usage of the ReCoMM model is 20–25 (J) lower than that of the AFTRA model when the number of nodes is increased to 30.

In the ReCoMM, the Markov transition states find the lower mobile and higher energy nodes for routing. As a result, it has more energy. The lower energy usage of both models is due to the increased number of routing nodes accessible. The AFTRA model has somewhat less residual energy than the suggested ReCoMM model, as seen in figure 6a. The AFTRA model has a lower residual energy of 887 (J) when the number of nodes grows to 50, but the ReCoMM model has a greater remaining energy of 957 (J). It is evident that utilizing the S calculation, the ReCoMM steadily improves the stability of the node links. Compared to AFTRA, the S computation makes routing easier for lower mobile nodes.

PDR behavior is seen in figure 6b as the number of nodes increases. For both methods, the PDR reduces somewhat as the number of nodes grows. When compared to AFTRA, the PDR of the ReCoMM algorithm seems to be a straight line, indicating that the ReCoMM method has a considerably greater PDR than AFTRA. Because it eliminates frequent link breakages and energy-draining difficulties by picking higher energy and lower mobility nodes to forward packets using the Morkov-ARIMA method, the ReCoMM has 96 percent PDR when the number of nodes increases to 20. When the number of nodes reaches 40, ReCoMM has a PDR of 93 percent, but the AFTRA protocol only has a PDR of 65 percent. Over the AFTRA procedure, the ReCoMM improves the PDR by 18–28 percent. When the number of nodes is 50, the PDR offers a performance improvement of 31–40% when compared to the ReCoMM AFTRA algorithm. If the nodes in the network grow up, then the number of nodes accessible for routing grows as well. As a result, the ReCoMM picks nodes depending on R and S, thus increasing the PDR of routing.

Furthermore, the ReCoMM picks highly cooperative nodes for routing on the basis of different transitions of node states. Furthermore, the AFTRA often discovers nodes for routing, lowering the PDR. The RO is depicted in figure 6c as the number of nodes increases. When the number of nodes is increased to 30, the ReCoMM's RO drops to 3.4 percent, while the AFTRA yields a higher RO of 6.9 percent. When an error, namely retransmission and link breakages, happen during transmitting and receiving packets, the RO is increases. The MAC layer's overhead is increased by the routing mistake. When the number of nodes is 50, ReCoMM has a RO of 5.6 percent. The AFTRA algorithms, on the other hand, have 9.9% RO. Because found nodes have reduced mobility for routing, the ReCoMM does not have frequent retransmissions, lowering the RO. As a result, the ReCoMM has a decrease in RO of 4.3–5.3 percent.

The delay variance is seen in figure 6d as the number of nodes increases. When the number of nodes is 20, the AFTRA method has a greater latency of 4.5 s, but the ReCoMM algorithm has an average end-to-end delay of just 1.6 s. The AFTRA algorithm's packet delivery to the destination is delayed owing to the frequent route finding procedure caused by node mobility. When the number of nodes is 50, the ReCoMM method has a considerably shorter latency than the AFTRA algorithm. That is, for packet delivery to the destination, the ReCoMM has a reduced delay variance of 3.9 s.

Furthermore, the AFTRA has a 6.9 s delay. The ReCoMM and AFTRA algorithms have a 2–3.9 percent delay difference. As a result, it results in a quicker packet transfer. Using a Markov algorithm to forecast node transition states, higher-cooperative nodes can be predicted, which improves network stability and lowers packet transmission latency. Overall, the ReCoMM performs better in a variety of circumstances.

The identification of non-cooperative nodes is shown in figure 7, and the consumption of time in order to detect non-cooperation across the number of nodes is shown in figure 8 for the ReCoMM and FTP-DSR [13] protocols. It is evident that the ReCoMM outperforms the FTP-DSR in terms of performance. As seen in figure 7, ReCoMM's identification of non-cooperative nodes has improved over time as node density has increased, compared to FTP-DSR. The detection ratio for ReCoMM via FTP-DSR improves to 12–14 percent at 30 nodes. Similarly, as shown in figure 8, the time needed for determining the path with the

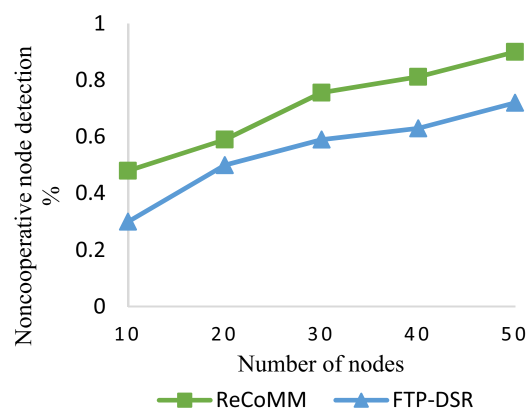


Figure 7. Detection of non-cooperative node.

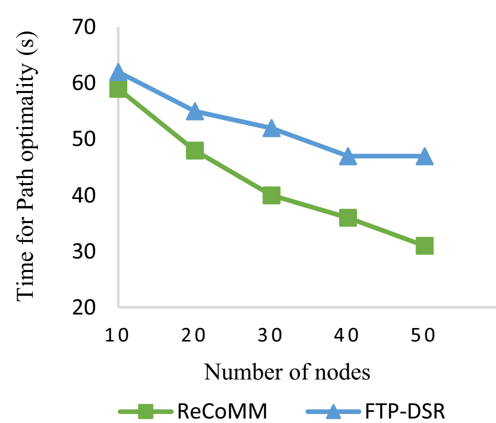


Figure 8. Time for path optimality.

Table 7. Performance of routing algorithms.

Authors		Manohar *et al* [37]	Khamayseh *et al* [15]	Gopal and Saravanan [18]	Gite [21]	Chaudhari and Biradar [26]	Senthil Kumar and Manikandan [36]	Proposed model
Method/Algorithm		SwarmFTCP	MLR	AFTRA	Link-stability prediction	WNN	NAODV	ReCoMM
Residual energy (J)	Nodes at 50	883	–	888	–	–	–	957
	Speed at 50	903	940	–	–	–	–	962
PDR (%)	Nodes at 50	42	–	50	55	84	81	92
	Speed at 50	44	77	–	–	–	–	93
RO (%)	Nodes at 50	–	–	9.9	–	–	7.8	5.7
	Speed at 50	–	7.9	–	–	–	–	4.9
Delay (s)	Nodes at 50	8.9	–	7	4.3	–	–	4.0
	Speed at 50	4.9	5.8	–	–	–	–	4.8

cooperative node for routing is longer for FTP-DSR than for ReCoMM. Because it uses the Morkov-ARIMA procedure, the ReCoMM takes less amount of time to discover the complete cooperative routing path than the FTP-DSR. It provides robust and dependable nodes for effective routing. When the number of nodes is 50, for example, the path discovery time for ReCoMM and FTP-DSR is 38 and 48 s, respectively. The ReCoMM uses node reliability (R) and link stability (S) modules to achieve quicker cooperative node discovery. As a result, the ReCoMM beats competing algorithms in most performance measures [13, 14, 17].

The proposed ReCoMM performance results are compared against SwarmFTCP, AFTRA, MLR, and a few current routing algorithms in table 7. It shows the numerical findings with a node speed of 50 m/s and a total of 50 nodes. The ReCoMM model has the largest residual energy (949 J) in table 7, whereas AFTRA and MLR have much lower energies (901 and 914 J, respectively). The ReCoMM has a 5–6 percent lower routing overhead than the competition; AFTRA and MLR, on the other hand, have greater routing overheads of 9.9% and 10.9 percent, respectively. Lower mobility nodes minimize the overhead of route discovery by reducing the frequency of control packet delivery. As a result, the ReCoMM method has a lower RO as compared to existing other algorithms. Likewise, the ReCoMM's delay and PDR measures outperform other algorithms by a substantial margin. It is because the nodes' dependability and link stability are computed, with the goal of providing efficient outcomes in all circumstances.

5. Conclusion and future work

The Morkov-ARIMA model is used in this article to develop resources such as mobility and energy-based cooperative protocol for MANET. When the ReCoMM's performance is compared to that of the AFTRA, MLR, and FTP-DSR algorithms, the ReCoMM outperforms them both in high-density network and dynamic mobile environments. The ReCoMM aims to offer mobile nodes with reliable and efficient cooperative routing process. For the various situations, the simulation results show that the ReCoMM delivers a higher node lifespan (6–7%) due to lower energy usage, improved PDR (13–21%), and shorter latency. The ReCoMM method improves PDR by 31–40% for various node densities and reduces RO by 4.3–5.3 percent when compared to the MLR and AFTRA algorithms. Hence, the proposed ReCoMM allows a steady routing path by employing the ARIMA and Markov processes to consider both the mobility and energy values of a mobile node. Furthermore, the ReCoMM locates cooperative neighbor nodes and generates effective QoS routing with improved performance. Future improvements to this work will take bandwidth and other affecting variables into account.

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