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Statistical Markov Model Based Natural Inspired Glowworm Swarm Multi-Objective Optimization for Energy Efficient Data Delivery in MANET

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Mobile Ad Hoc Network (MANET) is an infra-structure less multi-hop network where the mobile nodes are moved randomly. An interference and collision is a significant problem to be solved in MANET. Handling both interference and collision on route path remained open issues which increases the energy usage and reduces the throughput of MANET. In order to overcome such limitations, Statistical Markov Model Based Natural Inspired Glowworm Multi-objective Optimization (SMM-NIGMO) technique is proposed. The SMM-NIGMO technique at first proposes a Statistical Markov Model to determine the interference level of each mobile node in MANET at the time t and reduces the interference level. After that, SMM-NIGMO Technique designs a Natural Inspired Glowworm Swarm Multi-Objective Optimization (NIGSMO) algorithm to carry out the optimal

node selection process in MANET. Then, Request-To-Send (RTS) and Clear-To-Send (CTS) mechanism are used in SMM-NIGMO technique for selecting route path and minimizing the collision during the data transmission. With the reduction of interference and collision on the route path, SMM-NIGMO technique enhances the throughput and also lessens the energy as compared to existing works. The performance of the proposed technique validated using following parameters such as energy consumption, throughput, End-to-End delay, Packet delivery ratio and Packet loss rate. The simulation result depicts that the SMM-NIGMO Technique is able to improve the throughput and also reduces the energy consumption, End-to-End delay of data transmission in MANET as compared to state-of-the-art works.

KEYWORDS: Collision, Interference, MANET, Natural Inspired Glowworm Swarm Multi-Objective Optimization Algorithm, Statistical Markov Model.

1. Introduction

A Mobile Ad Hoc Network (MANET) includes a set of mobile nodes that move freely and self-configure without an infrastructure. When two nodes in the network try to broadcast data packet at the exact same time on the communication node, collision is occurred in MANET. The collisions process results in lower throughput, higher network load, higher delay and high data drop rate in MANET. In addition to that, dealing with interference when routing the data gets prodigious significance for efficient communication in MANET and also lessens the energy consumption. A lot of research works have been designed in existing works to attain energy efficient data delivery. However, interference and collision minimization during data delivery were not solved. In order to overcome the above said existing drawbacks, Statistical Markov Model Based Natural Inspired Glowworm Multi-objective Optimization (SMM-NIGMO) technique is introduced.

A Localized Delay-constrained Bellman-Ford (LDBF) algorithm was introduced in [20] to minimize interference while considering the delay constraint. However, collision reduction during data routing remained an open issue. Artificial bee colony algorithm (ABCA) was designed in [23] to reduce the data collision and to increase data transmission performance in the ad-hoc network. However, the amount of energy utilized for data delivery was more.

Position-based stable routing protocol was designed in [1] to attain connection stability in communication interference. This approach is based on different strategies, namely the selection of next hop nodes that have the fewest neighbors, or the selection of nodes that have participated the least in previously constructed paths within the limited area. Due to the

dynamic nature of MANET'S channels and the movement of the mobile nodes, the packet loss rate of this protocol was higher. A Hybrid Interference-Aware Multi-path Routing protocol (HIA-MPOLSR) was presented in [12] to minimize End-to-End delay, and routing overhead in MANET. Each node that creates TC (Topology Control) messages adds the carrier sensing range, the neighbor information and the position of it, in MPR selector set to TC messages. When the nodes in the network receive a TC message, they save the information in the message to calculate the interference level of links. However, collision avoidance was not solved. The above two existing methods not consider any algorithm for collision avoidance. To solve these drawbacks, SMM-NIGMO technique is introduced in this work.

A novel technique was developed in [22] to resolve the issues of physical interference constraints. However, the delay time of this technique was more. An interference-based topology control algorithm was employed in [18] for addressing the interference and the delay problem in MANET. However, the throughput of this algorithm was lower. The probabilistic broadcast schemes were introduced in [8] to examine the effects of thermal noise and co-channel interference during the route discovery in MANET. However, energy usage during transmission was remained unaddressed. A novel mechanism was presented in [9] to lessen the probability of DATA packet collisions due to the masked nodes in an ad hoc network. But, the time utilized for efficient data delivery was very higher.

Packets Collision Control based Multipath Secure Routing method was intended in [13]. Although, interference on the route path was not solved. A fault-tol-

erance-and-interference-aware topology control (FICTC) algorithm was introduced in [19] to get enhanced throughput and minimal delay. However, data loss due to the collision was not addressed.

In order to resolve the above mentioned existing problems in MANET, SMM-NIGMO technique is designed. The main contributions of SMM-NIGMO technique are explained in below.

- To improve the performance of energy efficient data delivery via an interference and collision reduction in MANET as compared to conventional works, SMM-NIGMO technique is developed. The SMM-NIGMO technique is introduced by integrating the Statistical Markov Model and Natural Inspired Glowworm Swarm Multi-Objective Optimization (NIGSMO) algorithm and Request-To-Send (RTS) and Clear-To-Send (CTS) mechanism.
- To minimize the interference level on route path through finding the optimal mobile nodes in MANET and thereby increasing throughput and reducing energy usage as compared to existing works, Statistical Markov Model and Natural Inspired Glowworm Swarm Multi-Objective Optimization (NIGSMO) algorithm are designed in SMM-NIGMO technique.
- To reduce the occurrence of collision during data transmission and thereby minimizing the packet loss rate and an End-to-End delay as compared to state-of-the-art works, Request-To-Send (RTS) and Clear-To-Send (CTS) mechanism is employed in SMM-NIGMO technique.

The rest of the paper is formulated as follows. In Section 2, the reviews related to energy efficient routing in MANET are explained. Section 3 describes the proposed SMM-NIGMO technique with the help of the architecture diagram. Section 4 shows simulation settings. Section 5 discusses the comparative result analysis and finally, Section 6 depicts the conclusion of the paper.

2. Related Works

A dynamic energy ad-hoc on-demand distance vector routing protocol (DE-AODV) was presented in [10] to lessen the energy utilization. A review of different collision avoidance techniques was analyzed in [17] to increase throughput and fairness in ad-hoc network.

Spatial Interference control was performed in [11] for multi-antenna mobile ad hoc networks.

The interference problem in mobile random networks was resolved in [21] to reduce the bursts of transmission failures. Collision Aware MAC Protocol was introduced in [2] to attain higher throughput in MANET. An Enhanced MACAW Protocol was presented in [14] to accomplish packet transmission to any node without any collision.

The cross-layer design approach for Power control (CLPC) was intended in [5] to discover the best route between the source and the destination with minimum energy. However, collision avoidance and interference control remained an open issue. Multi-Criteria Decision Making (MCDM) technique was designed in [15] to obtain energy-aware routing. An Energy Comprehensive Index (RECI) was employed in [6] to prolong the network lifetime and to lessen the average end-to-end delay in MANET. Dynamic fuzzy logic and reinforcement learning was developed in [16] for performing routing with minimal energy in MANET. Passive online wireless LAN health monitoring from a single measurement point in [7] to develop a scalable approach that relies on measurements collected by a single monitor for WLAN health monitoring. An Effective Wireless Media Access Controls Architecture for Content Delivery Networks in [3] for reducing delays and overcrowding in networks. Implementation of MANETs routing protocols in WLANs environment: Issues and prospects in [4] for cost maintaining, low throughput and delay.

More precisely, although methods presented above can attain good performance, difficulties such as higher interference level, low throughput, higher energy consumption and Collision. Our Proposed Statistical Markov Model Based Natural Inspired Glowworm Multi-objective Optimization (SMM-NIGMO) techniques provides a different approach for deliberately selecting optimal node selection for finding route path and attain energy efficient data transmission in MANET. Experimental results prove the effectiveness of the proposed algorithm.

3. Motivation

In Mobile Ad Hoc Network, different sensor nodes in the network collect the information and transmit the information to the destination node. Different routing

processes and route path discovery are introduced in network for broadcasting the data packets among nodes. During the transmission of data packets, data delivery ratio is most essential to obtain optimal data transmission in network. In addition, energy consumption and routing overhead are most important for efficient data communication and improves the better data delivery ratio. Energy consumption is the most significant factors because it directly affects the lifetime of the network. Several techniques have been developed in MANET to improve the performance of routing but it has a few problems such as interference and collision. This increases the energy consumption and reduces the throughput. In order to overcome these issues Statistical Markov Model Based Natural Inspired Glowworm Multi-objective Optimization (SMM-NIGMO) technique is introduced to reduce the energy consumption and increase the throughput. In the proposed SMM-NIGMO technique, Statistical Markov Model (SMM) is used to determine the interference level with minimum time. With Natural Inspired Glowworm Swarm Multi-Objective Optimization (NIGSMO) algorithm is designed to select the optimal node based on the luciferin value. Request-To-Send (RTS) and Clear-To-Send (CTS) mechanism employed to reduce collision during data transmission. Therefore, the proposed SMM-NIGMO technique minimizes the level of interference and energy consumption by reducing collision.

4. Statistical Markov Model Based Natural Inspired Glowworm Optimization Technique

The Statistical Markov Model Based Natural Inspired Glowworm Multi-objective Optimization (SMM-NIGMO) technique is designed with the objective of attaining energy efficient data delivery through an interference and collision minimization in MANET. The SMM-NIGMO technique is proposed by combining the Statistical Markov Model and Natural Inspired Glowworm Swarm Multi-Objective Optimization (NIGSMO) algorithm and Request-To-Send (RTS) and Clear-To-Send (CTS) mechanism. On the contrary to state-of-the-art works, SMM-NIGMO technique employs Statistical Markov Model to ac-

curately predict interference of the nodes in MANET with a minimal amount of time.

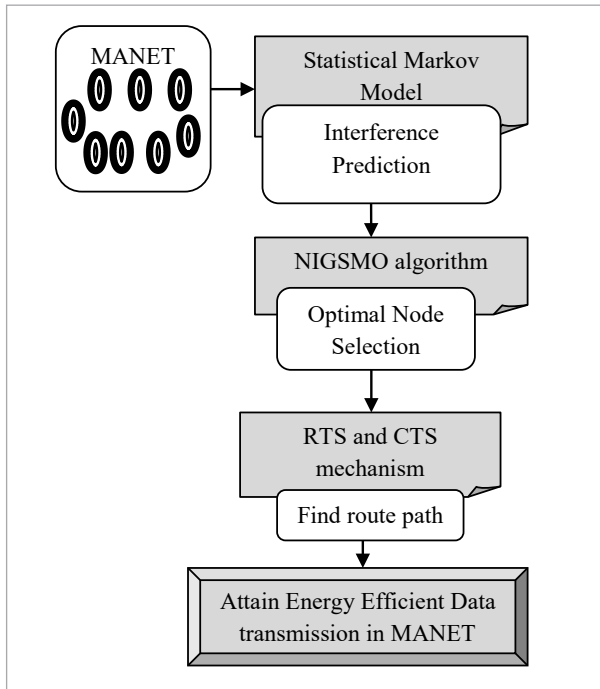
In addition to, a Natural Inspired Glowworm Swarm Multi-Objective Optimization (NIGSMO) algorithm is designed in SMM-NIGMO technique to select the optimal nodes to deliver the data packets to the destination node. The NIGSMO algorithm computes the luciferin value for each glowworm (i.e. mobile nodes) in the network by considering multi-objectives on the contrary to conventional work. The luciferin value of all the glowworms is changed with respect to current positions. This helps for SMM-NIGMO technique to significantly measure the interference, residual energy level of mobile nodes in a dynamic environment. This supports for NIGSMO algorithm to provide an optimal solution for discovering best mobile nodes with minimal interference, higher residual energy in MANET. Thus, SMM-NIGMO technique significantly minimizes the level of interference during data delivery and also enhances the network performance with lower energy consumption.

In addition to that, the Request-To-Send (RTS) and Clear-To-Send (CTS) mechanism are applied in SMM-NIGMO technique in order to minimize the collision during the data transmission process in MANET. With the reduction of interference and collision on the route path, SMM-NIGMO technique enhances the throughput and also lessens the energy as compared to existing works. The overall architecture diagram of SMM-NIGMO technique is depicted in Figure 1.

Figure 1 presents the overall processes of SMM-NIGMO Technique to obtain reliable data transmission with higher throughput and lower energy utilization. As shown in the above figure, SMM-NIGMO Technique includes three main processes namely interference prediction, optimal node selection, and route path identification. In order to increase the performance of interference prediction of mobile nodes in a dynamic environment; SMM-NIGMO technique designs Statistical Markov Model. After that, SMM-NIGMO Technique enhances the optimal node selection process performed in MANET with help of NIGSMO algorithm. Finally, SMM-NIGMO Technique improves the route path identification performance as compared to state-of-the-art works with the application of RTS and CTS mechanism. Thus, SMM-NIGMO

Figure 1

Architecture Diagram of SMM-NIGMO Technique for Energy Efficient Data Delivery



Technique gets the Energy Efficient Data delivery in MANET. The elaborate process of SMM-NIGMO Technique is described in below subsections.

4.1. Interference Prediction

The SMM-NIGMO Technique utilizes the Statistical Markov Model in order to determine interference of the mobile nodes on the network. In Statistical Markov Model, the states and transitions are hidden and output is obtained through symbols. Here, ‘ α ’ is the set of hidden states and ‘ β ’ is the set of observation states which is expressed mathematically as

$$\alpha = (\alpha_1, \alpha_2, \dots, \alpha_n) \tag{1}$$

$$\beta = (\beta_1, \beta_2, \dots, \beta_m) \tag{2}$$

In SMM-NIGMO Technique, hidden states ‘ α ’ indicates the interference value of mobile nodes in MANET and observation state ‘ β ’ point out the signal to interference plus noise ratio (SINR). Let ‘ α ’ is the set of the hidden states (i.e. interference value) which mathematically defined as

$$\alpha = (\rho_1, \rho_2, \dots, \rho_n) \tag{3}$$

Let ‘ \mathcal{N} ’ is a fixed state sequence of length ‘ L ’ which mathematically expressed as

$$\mathcal{N} = (n_1, n_2, \dots, n_L) \tag{4}$$

Let ‘ β ’ be the corresponding observations which mathematically represented as below

$$\beta = (\varphi_1, \varphi_2, \dots, \varphi_L) \tag{5}$$

Thus, Statistical Markov Model is mathematically expressed as

$$\lambda = (U, V, \pi) \tag{6}$$

From Equation (6), ‘ U ’ refers to the transition array, ‘ V ’ denotes an array of observation and ‘ π ’ represents the initial state probability. The transition array ‘ U ’ contains the probability of interference state ‘ y ’ following interference state ‘ x ’ which obtained using below

$$U = [u_{xy}] \tag{7}$$

$$u_{xy} = P(n_t = \rho_y | n_{t-1} = \rho_x) \tag{8}$$

From Equation (8), ‘ t ’ denotes the current time and ‘ $t-1$ ’ refers to the previous state time. Here, ‘ ρ_x ’ and ‘ ρ_y ’ represent the interference value of mobile the node at the state ‘ x ’ and ‘ y ’ respectively. The array of observation ‘ V ’ stores the probability of observation ‘ k ’ which is generated from the state ‘ y ’ which formulated as

$$V = [v_i(k)] \tag{9}$$

$$v_i(k) = P(n_t = \rho_y | n_{t-1} = \rho_x) \tag{10}$$

Then, the initial state probability is mathematically expressed as follows

$$\pi = [\pi_i] \tag{11}$$

$$\pi_i = P(n_t | \rho_x) \tag{12}$$

In SMM-NIGMO Technique, Statistical Markov Model measures the interference of mobile node based on signal to interference plus noise ratio. During the data broadcasting from a source node to

its neighbor node, signal to interference plus noise ratio (SINR) is mathematically determined using below

$$SINR = \frac{zd^{-e}}{\sigma + \sum_i zd_i^{-e}} \tag{13}$$

From Equation (13), ‘z’ denote a data transmitted with constant power, ‘d’ refers to the distance between the nodes. Here, ‘σ’ represents the channel noise whereas ‘e’ indicates the path loss attenuation factor i.e. ‘σ>2’. From that, observation(β) probability for a given sequence ‘N’ is mathematically evaluated as,

$$P(\beta | N, \lambda) = \prod_{i=1}^n P(\varphi_i | n_i, \lambda) = v_{n_1}(\varphi_1) \times v_{n_2}(\varphi_2) \dots v_{n_L}(\varphi_T) \tag{14}$$

Then, the probability of the state sequence is mathematically estimated as the following,

$$P(N | \lambda) = \pi_{n_1} u_{n_1}, \pi_{n_2} u_{n_2}, \dots \pi_{n_T} u_{n_T} \tag{15}$$

By using the Equation (14) and (15), Statistical Markov Model easily estimate the probability of observations using below,

$$P(\beta | \lambda) = \sum_N P(\beta | N, \lambda) P(N | \lambda) \tag{16}$$

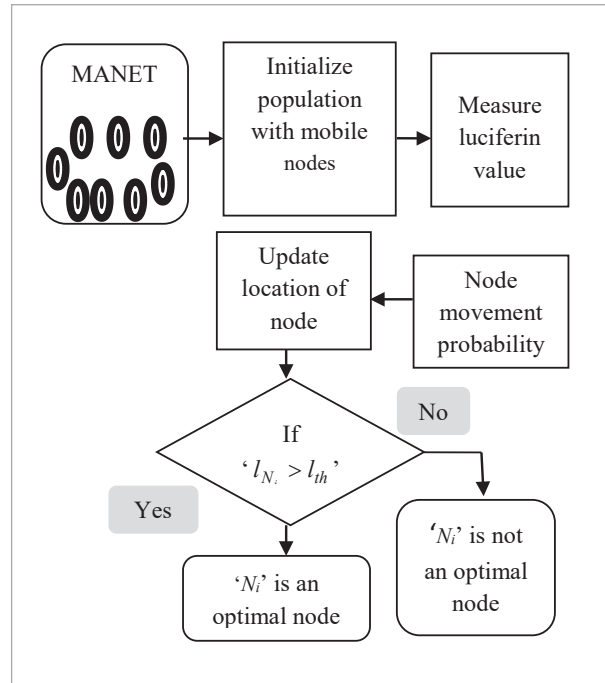
$$P(\beta | \lambda) = \sum_{n_1, n_2, \dots, n_T} \pi_{n_1} v_{n_1}(\varphi_1), \pi_{n_2} v_{n_2}(\varphi_2) \dots \pi_{n_T} v_{n_T}(\varphi_T) \tag{17}$$

From Equation (16) and (17), SMM-NIGMO Technique determines the interference value for each mobile node ‘φ_i’ in the network. After measuring the interference level, SMM-NIGMO Technique chooses the best nodes in MANET to effectively transmit the data packets using NIGSMO algorithm.

4.2. Optimal Node Selection

On the contrary to existing works, NIGSMO algorithm considers the multi-objectives such as interference level and residual energy of the mobile node during the optimal node selection process. This helps for NIGSMO algorithm to perform interference-aware routing and also lessens the energy used for reliable data delivery in MANET. The process involved in NIGSMO algorithm is shown in below Figure 2 to choose the best mobile nodes for data routing in mobile networks.

Figure 2
Flow process of NIGSMO algorithm



As presented in the above figure, NIGSMO algorithm initializes population with a swarm of glowworms (i.e. mobile nodes). Each glowworm contains luminescence capacity called luciferin. The NIGSMO algorithm measures the luciferin value by considering the multi-objectives such as residual energy and interference value of mobile nodes in MANET. The NIGSMO algorithm is designed in SMM-NIGMO Technique based on the behavior of glowworms (i.e. fireflies or lightning bugs) where the glowworm with less lighting behaviors is attracted to the brighter one. After that, NIGSMO algorithm determines the probability of node movement and consequently updates the location of glow worms. If the luciferin value of the mobile node is lesser than the predefined threshold value, then the node is considered as a best for routing the data in MANET. Otherwise, the mobile node is considered as not an optimal node. In NIGSMO algorithm, the energy consumption of the mobile node is measured as follows

$$\epsilon_{N_i} = pow * t \tag{18}$$

From Equation (18), ‘ε_{N_i}’ indicates an energy level of

mobile node. Here, 'pow' represents and 't' is a time. The energy level of node is determined in terms of a joule '(J)', the power is estimated in the unit of watt '(W)', and the time is evaluated in second '(s)'. Then, the residual energy of mobile node is evaluated as differentiation between the initial energy and utilized energy for data transmission. From that, residual energy of node 'Re_{N_i}' is computed as

$$Re_{N_i} = \epsilon_I - \epsilon_U \tag{19}$$

From Equation (19), 'ε_i' indicates an initial energy and 'ε_U' refers an energy used by a node to broadcast particular size of data the packet to neighbor node in the network. Followed by, interference level of a mobile node is computed using the Statistical Markov Model. Thus, the luciferin value of node is mathematically obtained as

$$I_{N_i} = \{\epsilon_{N_i}, \varphi_i\}. \tag{20}$$

From Equation (20), luciferin value 'I_{N_i}' for each mobile node in network is computed. In NIGSMO algorithm, the glowworm with less luciferin value is attracted towards to higher one. Let us assume the mobile node 'N₂' with less luciferin value move towards to the other brighter mobile node 'N₁' with higher luciferin value. Hence, the moving probability is mathematically estimated as follows

$$Pr = \frac{I_{N_2}(t) - I_{N_1}(t)}{\sum I_{N_n}(t) - L_{N_1}(t)}. \tag{21}$$

From Equation (21), 'Pr' indicates a probability of node movement, 'I_{N₂}(t)' point outs a luciferin value of the glowworm 'N₂' at the time 't'. Here, 'I_{N₁}(t)' represents the luciferin value of the glowworm 'N₁' at the time 't' and I_{N_n}(t) signifies a luciferin value of the glowworm 'n' at the time 't'. After the movement, the location of mobile nodes in network is changed. Therefore, the location of mobile node is mathematically updated using below

$$w_{N_{i(t+1)}} = w_{N_i(t)} + S(\frac{w_{N_2}(t) - w_{N_1}(t)}{D_{N_2N_1}}). \tag{22}$$

From Equation (22), 'w_{N_i(t+1)}' designates an updated location of the node 'N₁' at time 't+1'. Here, 'x_{N₁(t)}'

represents a location of glowworm 'a' at time 't' and 'S' indicates a step-size. Informal, 'W_{N₂(t)}' refers the location of glowworm 'N₂' at time 't' and 'D_{ba}' is a distance between the two mobile nodes 'N₁' and 'N₂'. The luciferin value of glowworm is gets varied along with their position. Hence, updated luciferin value is mathematically evaluated as

$$l_{(t+1)} = (1 - C) * l_{(t-1)} + \alpha(\epsilon_{N_i}(t)). \tag{23}$$

From Equation (23), 'l_(t+1)' refers to the updated luciferin value, 'C' is a luciferin decay constant '(0 < C < 1)'. Here, 'ε_{N_i}(t)' represents an initial energy level of node at a time 't' and 'l_(t-1)' indicates a prior luciferin value of the node at a time 't-1' and 'α' is a luciferin enhancement constant. Then, NIGSMO algorithm defines threshold luciferin value to compare the energy and interference level of the each mobile node in MANET. From that, NIGSMO algorithm choose the best node for routing using below mathematical expression,

$$\gamma = \begin{cases} \{N_i > l_{th}, N_i \text{ is an optimal mobile node} \\ I_{N_i} < l_{th}, N_i \text{ is not an optimal mobile node} \end{cases} \tag{24}$$

From Equation (24), 'γ' signifies a final output of the NIGSMO algorithm, 'I_{N_i}' is a luciferin value of the mobile node. Here, 'N_i' indicates an 'ith' node in dynamic environment whereas 'lth' refers a threshold luciferin value. If the luciferin value of nodes is higher than the threshold, then that mobile nodes are picked as a best node to perform data transmission in MANET. The mobile nodes with less luciferin values than a predefined threshold is considered as not best nodes in network for routing the data packets. With the help of discovered best mobile nodes, SMM-NIGMO technique reduces the interference level in mobile network. With the minimization of interferences, SMM-NIGMO technique also minimizes number of collisions and retransmissions and consequently lowers the amount of energy consumed for efficient data delivery in MANET.

4.3. Route Path Identification

After finding the best mobile nodes, SMM-NIGMO Technique discovers route path to send the data packets to the destination from the source node. The SMM-NIGMO technique used Request-To-Send

(RTS) and Clear-To-Send (CTS) mechanism in order to reduce packet collisions and increase throughput in MANET. In SMM-NIGMO Technique, the source node transmits RTS message to all neighboring node for the channel request. When the channel is free, the receiving node quickly replies to source node with CTS message before the timer expires. If the communication completes before the expiration of the timer set by CTS message, the source node selects that neighbor node to route the data packets to a destination node in MANET. This way SMM-NIGMO Technique minimizes the data packets collision with minimal time and solves delay problem in MANET. The algorithmic processes of SMM-NIGMO Technique are explained in below.

Algorithm 1

Statistical Markov Model Based Natural Inspired
Glowworm Multi-objective Optimization

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//Statistical Markov Model Based Natural Inspired
Glowworm Multi-objective Optimization Algorithm
Input: Number of Mobile Nodes ' $N_i=N_1, N_2, N_3, \dots, N_n$ ', data
packets ' $DP_i = DP_1, DP_2, \dots, DP_n$ ', Source Mobile Node ' $SN$ ',
Destination Mobile Node ' $DN$ ', Neighbor mobile node ' $NN_i$ ',
Output : Energy Efficient Data delivery in MANET
Step 1: Begin
// Interference Prediction
Step 2:For each ' $N_i$ ' in dynamic network
Step 3:Definestatistical Markov model using (6)
Step 4:Measure ' $SINR$ ' using (13)
Step5:Compute observation probability ' $P(b | N, l)$ ' using
(14)
Step 6:Probability of the state sequence ' $P(N|l)$ ' using (15)
Step 7:Determine interference value ' $j_i$ ' using (17)
Step 8:End For
// Optimal Node Selection
Step 9:Initialize the population with help of number of
mobile nodes ' $N_i$ '
Step 10: For each ' $N_i$ '
Step 11: Evaluate ' $l_{N_i}$ ' using (19)
Step 12:Measuremoving probability ' $Pr$ ' using (20)
Step 13:Update location ' $w_{N_i}(t+1)$ ' using (21)
Step 14: Update luciferin value ' $l_{(t+1)}$ ' (22)
Step 15:If ' $l_{N_i} > l_{th}$ ', then
Step 16:' $N_i$ ' is an optimal mobile node
Step 17:else
Step 18:' $N_i$ ' is not an optimal mobile node
Step 19:End If
Step 20:End For

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// Route Path Identification

```

Step 21:For each discovered best ' $N_i$ '
Step 22:SN broadcast the RTS message to  $NN_i$ 
Step 23: If the channel is free, then
Step 24: $NN_i$  reply to SN with CTS message before the
timer expires
Step 25:End If
Step 26: SN select ' $NN_i$ ' and transmit ' $DP_i$ '
Step 27: End For
Step 28: End

```

Algorithm 1 depicts the step by step processes of SMM-NIGMO Technique to obtain energy-efficient data delivery in MANET. As explained in above algorithmic process, SMM-NIGMO technique at first performs the interference prediction process where it finds the interference value of each mobile node at a time ' t ' in dynamic environment with aid of statistical markov model. Then, SMM-NIGMO Technique performs the optimal node selection process where it identifies the best mobile nodes in MANET based on the luciferin value, thus it helps to determine residual energy and interference value by using the NIGSMO algorithm. Luciferin value of the mobile node is greater than the threshold luciferin value then the node is selected as best for routing the data in MANET. Otherwise, mobile node does not selected for routing the data. The discovered optimal mobile nodes help for SMM-NIGMO Technique to achieve interference aware data routing with minimal energy utilization. Finally, SMM-NIGMO Technique carried out the route path discovery process where it employs the Request-To-Send (RTS) and Clear-To-Send (CTS) mechanism to choose the mobile node to broadcast the data packets to the destination node in MANET without any collisions. In this process source node sends the RTS message to neighboring node then the receiving node quickly replies to source node with CTS message before the timer expires. If the process completes before timer expires the source node selects the neighboring node for route path discovery. Thus, SMM-NIGMO Technique enhances the performance of interference and collision aware routing to attain higher throughput and minimal energy consumption in MANET as compared to state-of-the-art works.

5. Simulation Settings

In order to measure the performance, SMM-NIGMO Technique is implemented in NS-2 simulator with 1250m × 1250m network area using 500 mobile nodes. The simulation parameter used for performing experimental work is shown below.

Table 1

Simulation parameters

Simulation parameters	Values
Number of mobile nodes	50 – 500
Simulation area	1250m × 1250m
Simulation time	500sec
Simulation iteration	10
Initial energy	500J
Packet size	512bytes
Number of data packets	25, 50, 75, 100, 125, 150, 175, 200, 225, 250
Transmission range of nodes	20m to 200m
Movement	Random way point
Maximum speed	25m/s

The simulation result of SMM-NIGMO technique is compared against two existing works, namely, Localized Delay-constrained Bellman-Ford (LDBF) algorithm [20] and Artificial Bee Colony Algorithm (ABCA) [23]. The simulation processes of SMM-NIGMO Technique is conducted for many factors such as throughput, energy consumption, data loss rate and an End-to-End delay with respect to a diverse number of mobile nodes and data packets.

6. Result and Discussions

In this section, the performance result analysis of SMM-NIGMO Technique is discussed. The efficiency of SMM-NIGMO Technique is compared with conventional Localized Delay-constrained Bellman-Ford (LDBF) algorithm [1] and Artificial Bee Colony Algorithm (ABCA) [2]. The performance analysis of proposed technique using metrics such as throughput, energy consumption, data loss rate and End-to-End delay.

6.1. Performance Measure of Throughput

Throughput ‘ T ’ estimates the ratio of a number of data packets that are successfully distributed to destination mobile node in MANET at specific amount of time. The mathematical formula for determining the throughput is shown in below

$$T = \frac{N_{SD}}{t} . \quad (25)$$

From Equation (25), the throughput in MANET is evaluated. Here, ‘ N_{SD} ’ indicates the number of data packets successfully broadcasted to the destination at time ‘ t ’. The throughput is estimated in terms of packets per second (pps).

In order to evaluate the throughput, SMM-NIGMO Technique is implemented in NS-2 simulator by considering different number of data packets in the range of 25-250. When taking the 100 data packets to conduct the simulation work, SMM-NIGMO Technique gets 91 pps throughput whereas state-of-the-art works LDBF algorithm [20] and ABCA [23] obtains 82 pps and 84 pps respectively. From the above-obtained results, it is expressive that the throughput using SMM-NIGMO Technique is enhanced than other existing works. The performance result analysis of throughput is demonstrated below.

Table 2

Tabulation for Throughput

Number of Data Packets	Throughput (pps)		
	LDBF	ABCA	SMM-NIGMO
25	13	15	21
50	37	39	45
75	62	65	69
100	82	84	91
125	105	108	90
150	129	131	138
175	127	129	161
200	173	180	188
225	205	207	215
250	230	232	239

Table 2 depicts the simulation result analysis of throughput versus a varied number of data packets using three techniques namely LDBF algorithm [20] and ABCA [23] and proposed SMM-NIGMO Technique. As illustrated in the above tabulation, SMM-NIGMO Technique provides improved throughput as compared to the LDBF algorithm [20] and ABCA [23], respectively. In the existing LDBF algorithm does not consider RTS and CTS algorithm. Therefore, collision reduction during data transmission remained open issues. In existing ABCA algorithm used to reduce the data collision and to increase data transmission performance in the ad-hoc network. The existing ABCA process does not consider any algorithm for energy efficiency. Therefore, the amount of energy utilized for data delivery was more. In order to overcome above mentioned issues the Statistical Markov Model Based Natural Inspired Glowworm Multi-objective Optimization (SMM-NIGMO) technique is used for efficient data delivery in MANET. This is due to the application of a Natural Inspired Glowworm Swarm Multi-Objective Optimization (NIGSMO) algorithm in SMM-NIGMO technique for the optimal node chosen process. In SMM-NIGMO technique, NIGSMO algorithm measures the luciferin value for all glowworm (i.e. mobile nodes) in the network. With the support of estimated luciferin values, then SMM-NIGMO technique finds the optimal mobile nodes in a dynamic environment to successfully broadcast data packets to destination without any interference. This helps for SMM-NIGMO technique to increase the ratio of a number of data packets that are successfully delivered to destination mobile node in MANET as compared to other conventional works. As a result, SMM-NIGMO technique enhances the throughput by 17 % and 11 % as compared to state-of-the-art works LDBF algorithm [20] and ABCA [23] respectively.

6.2. Performance Measure of Energy Consumption

The Energy Consumption ‘(EC)’ estimates the amount of energy utilized to successfully delivery data packets to the destination from the source node in MANET. The energy consumption is mathematically computed as

$$EC = n * \varepsilon_U(SD). \quad (25)$$

From Equation (26), energy used during the data transmission in MANET is measured with respect to a varied number of mobile nodes. Here, ‘n’ point outs the total number of mobile nodes considering for performing

experimental evaluation in which ‘ $\varepsilon_U(SD)$ ’ denoted the energy consumed by a single mobile node to broadcast data packets to the neighboring node in MANET. The energy consumption is evaluated in terms of Joules (J).

The SMM-NIGMO Technique is implemented in NS-2 simulator by considering various numbers of mobile nodes in the range of 50-500 to determine the energy usage during efficient data delivery in MANET. When using the 350 mobile nodes to carry out the simulation evaluation, SMM-NIGMO Technique consumes 9 J to data transmission in MANET whereas the conventional LDBF algorithm [20] and ABCA [23] take 18 J and 21 J respectively. From that, it is clear that the energy utilization using SMM-NIGMO Technique is decreased than other existing works. The comparative result analysis of energy consumption is presented.

Table 3

Tabulation for Energy consumption

Number of Mobile Nodes	Energy Consumption (J)		
	LDBF	ABCA	SMM-NIGMO
50	4	5	2.5
100	5	6	3
150	10	11	5
200	11	13	7
250	15	18	8
300	14	17	8
350	18	21	9
400	18	22	10
450	25	29	11
500	27	32	12

SMM-NIGMO technique achieves lower amount of energy utilization for successful data transmission in MANET as compared to LDBF algorithm [20] and ABCA [23], respectively. This is because of the application of a Natural Inspired Glowworm Swarm Multi-Objective Optimization (NIGSMO) algorithm in SMM-NIGMO technique. With the algorithmic processes of NIGSMO algorithm, SMM-NIGMO technique decreases the interference level during data delivery process in MANET. With the reduction of interferences on the route path, SMM-NIGMO technique reduces the number of collisions and retransmissions. This supports for SMM-NIGMO technique to use lowers the amount of energy for reliable data packets broadcasting in MANET as compared to oth-

er state-of-the-art works. Thus, SMM-NIGMO technique minimizes the energy consumption by 46 % and 55 % as compared to the existing LDBF algorithm [20] and ABCA [23], respectively.

6.3. Performance Measure of Packet Loss Rate

Packet Loss Rate '(PLR)' determined as the ratio of number of packets lost to the total number of data packets transmitted. The packet loss rate is mathematically evaluated as

$$PLR = \frac{n_d}{n_t} * 100. \quad (27)$$

From Equation (27), loss rate during data transmission in MANET is estimated with respect to a diverse number of data packets. Here, ' n_d ' indicate the number of dropped packets during transmission and ' n_t ' represents a number of transmitted packets. The packet loss rate is evaluated in terms of percentage (%).

For measuring the packet loss rate during the transmission process in MANET, SMM-NIGMO Technique is implemented in NS-2 simulator with various numbers of data packets in the range of 25-250. When employing the 225 data packets to accomplish the simulation process, SMM-NIGMO Technique obtains 4 % packet loss rate whereas existing LDBF algorithm [20] and ABCA [23] acquires 9 % and 8 % respectively. Accordingly, it is significant that the packet loss rate using SMM-NIGMO Technique is very lower than other existing works. The experimental result analysis of the packet loss rate is depicted in below.

Table 4

Tabulation for Packet Loss Rate

Number of Data Packets	Packet Loss Rate (%)		
	LDBF	ABCA	SMM-NIGMO
25	48	40	12
50	32	24	14
75	17	13	9
100	18	16	15
125	40	36	34
150	14	13	8
175	27	26	8
200	14	10	6
225	9	8	4
250	8	7	4

Table 3 shows the impact of packet loss rate versus a varied number of data packets using three techniques namely LDBF algorithm [20] and ABCA [23] and proposed SMM-NIGMO Technique. As demonstrated in the above tabulation, SMM-NIGMO Technique attains minimal packet loss rate in MANET when compared to LDBF algorithm [20] and ABCA [23], respectively. This is owing to the application of a NIGSMO algorithm and RTS and CTS mechanism in SMM-NIGMO technique on the contrary to existing works. By using the concepts of NIGSMO algorithm, SMM-NIGMO technique lessens the interference on the discovered route path by selection a mobile node which has a minimal interferences level and higher residual energy as optimal in MANET. Thus, the data loss due to the interferences on the route path is lower in SMM-NIGMO technique as compared to conventional works. Moreover, with the application of RTS and CTS mechanism, SMM-NIGMO technique decreases the packet loss due to a collision on route path as compared to existing works. This assists for SMM-NIGMO technique to reduce the ratio of a number of packets dropped in MANET as compared to state-of-the-art works. Hence, SMM-NIGMO technique minimizes the packet loss rate by 49 % and 39 % as compared to existing LDBF algorithm [20] and ABCA [23], respectively.

6.4. Performance Measure of End-to-End Delay

End-to-End Delay '(EED)' computes the time taken for delivering data packets to destination from source the rce node in MANET. Thus, End-to-End delay is estimated as the difference between the data packet arrival time and data packet sending time. The End-to-End delay is mathematically formulated as

$$EED = ar_t - se_t. \quad (28)$$

From Equation (28), delay time involved during the data transmission process is determined with respect to a different number of data packets '(n)'. Here, ' ar_t ' refers arrival time of a data packet and ' se_t ' represents the sending time of a data packet in MANET. The End-to-End delay is determined in terms of milliseconds (ms).

To estimate the End-to-End delay during reliable data delivery process in MANET, SMM-NIGMO Technique is implemented in NS-2 simulator with the help of varied numbers of data packets in the range of 25-250.

When utilizing the 150 data packets to perform the simulation process, SMM-NIGMO technique gets 71 ms End-to-End delay whereas the conventional LDBF algorithm [20] and ABCA [23] gains 85 ms and 78 ms respectively. Therefore, it is considered that the End-to-End delay using SMM-NIGMO Technique is very minimal than other existing works. The simulation result analysis of End-to-End delay is shown in below.

Table 5

Tabulation for End-to-End delay

Number of Packets	End-to-End Delay (ms)		
	LDBF	ABCA	SMM-NIGMO
25	42	33	28
50	49	39	32
75	60	55	50
100	68	65	48
125	79	69	64
150	85	78	71
175	94	84	79
200	100	92	85
225	106	98	93
250	115	105	98

SMM-NIGMO technique gets lower End-to-End delay during data transmission from source to destination node in MANET as compared to LDBF algorithm [20] and ABCA [23] respectively. This is due to the application of a NIGSMO algorithm and RTS and CTS mechanism in SMM-NIGMO technique on the contrary to state-of-the-art works. The SMM-NIGMO technique avoids the retransmission of data packets due to loss through interference minimization in MANET using NIGSMO algorithm. Therefore, the transmitted data quickly reached at destination node without any information loss. In addition, SMM-NIGMO technique finds the collision-free route path in order to route the data packets to destination nodes with minimal time using RTS and CTS mechanism. This helps for SMM-NIGMO technique to reduce the time taken for delivering data packets as compared to state-of-the-art works. Therefore, SMM-NIGMO technique decreases the End-to-End delay by 21 % and 11 % as compared to existing LDBF algorithm [20] and ABCA [23], respectively.

6.5. Performance Measure of Data Packet Delivery Ratio

The measure of ratio of number of data packets delivered from source node at the destination node with respect to total number of data packets sent is defined as data packet delivery ratio. It is measured in terms of percentage (%) and mathematically formulated as follows

$$PLR = \frac{n_d}{n_t} * 100. \quad (29)$$

Data packet delivery ratio 'DPDR' is estimated.

Table 6

Tabulation for Data packet delivery ratio

Number of data packets	Data packet delivery ratio (%)		
	LDBF	ABCA	Proposed SMM-NIGMO technique
25	64	72	84
50	66	72	80
75	76	78	83
100	77	80	85
125	76	78	88
150	73	75	81
175	80	83	93
200	81	82	92
225	85	88	93
250	80	83	88

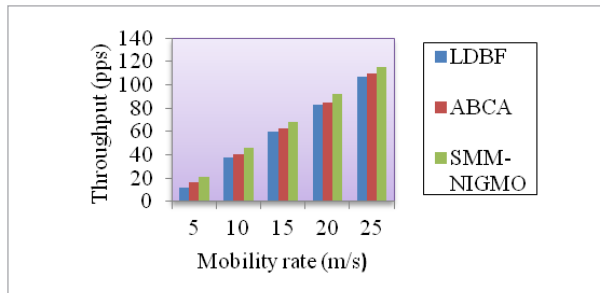
Above Table 6 shows the result analysis of data packet delivery ratio with respect to the number of data packets ranging from 25 to 250 data. The proposed SMM-NIGMO technique with different data packet from source node is taken for experimental purpose. The performance of proposed RGQKA technique is compared with existing two methods, namely, LDBF and ABCA. From the table value, it is illustrative that the packet delivery ratio using proposed SMM-NIGMO technique is increased when compared to the other existing methods.

6.6. Performance Measure of Mobility Strategies

Figure 3 describes performance analysis of throughput vs mobility rate. The maximum speed of the pack-

Figure 3

Performance analysis of throughput vs mobility rate



et delivery is 25 m/s. If the mobility rate is increased the throughput also increased and it achieves efficient packet delivery between source to destination node. When the mobility rate is 25 m/s the proposed SMM-NIGMO technique gets 115 (pps) throughput whereas conventional LDBF algorithm [20] and ABCA [23] acquires 107 (pps) and 110 (pps), respectively.

Figure 4

Performance analysis of energy consumption vs mobility rate

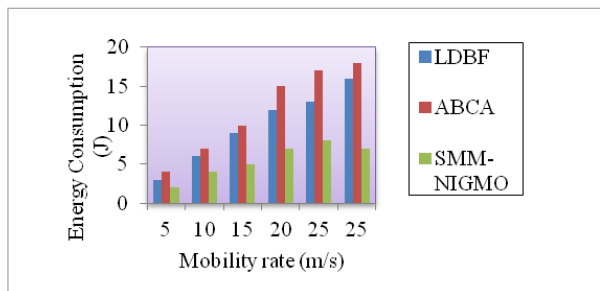
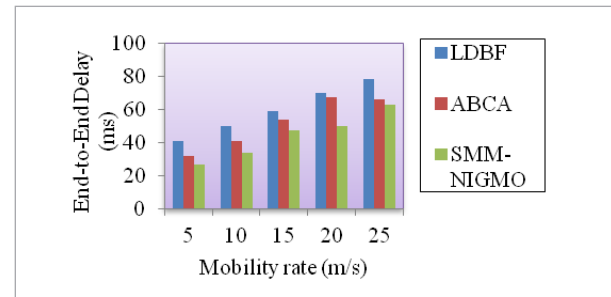


Figure 4 describes the performance analysis of energy consumption vs mobility rate. The initial energy of each node is 500J. If the mobility rate is increases the rate of energy consumption is reduced. When the mobility rate is 25 m/s the proposed SMM-NIGMO technique gets 7J energy consumption whereas conventional LDBF algorithm [20] and ABCA [23] acquires 16J and 18J, respectively.

Figure 5 describes the performance analysis of End-to-End delay vs Mobility rate. If the mobility rate increases, the end-to-end delay is reduced. When the mobility rate is 25 m/s, the proposed SMM-NIGMO technique gets 63 ms end-to-end delay whereas conventional LDBF algorithm [20] and ABCA [23] acquires 78 ms and 66 ms, respectively.

Figure 5

Performance analysis of End-to-End delay vs Mobility rate



7. Conclusion

An effective SMM-NIGMO technique is developed with the goal of obtaining energy efficient data delivery in MANET by means of interference and collision reduction. The goal of SMM-NIGMO technique is achieved with the aid of Statistical Markov Model and NIGSMO algorithm and RTS and CTS mechanism. The Statistical Markov Model supports for SMM-NIGMO technique to effectively predict the interference of mobile node in a dynamic environment. Furthermore, the NIGSMO algorithm helps for SMM-NIGMO technique to attain energy and inference aware routing in MANET through an optimal node selection. Informal, RTS and CTS mechanism assists for SMM-NIGMO technique to identify the collision free route path for routing the data packets to destination nodes in MANET. The SMM-NIGMO technique attains reliable data delivery with the minimal amount of energy usage through minimization of interference and collision on route path.

The effectiveness of SMM-NIGMO technique is estimated in terms of throughput, energy consumption, data loss rate and an End-to-End delay with respect to various numbers of mobile nodes and data packets and compared with existing works. SMM-NIGMO technique increases 14 % throughput, 16 % End-to-End delay and reduces the 50 % energy consumption, 44 % packet loss rate compared to existing work. The simulation result shows that SMM-NIGMO technique provides better performance with an improvement of throughput and reduction of energy for efficient data delivery as compared to state-of-the-art works.

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