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Firefly Optimized Resource Control and Routing Stability in MANET †

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Abstract: A mobile adhoc network (MANET) is a network that comprises mobile devices positioned in various places functioning without any central administration. Routing in MANET plays a vital role when the data packet (DP) is sent from source to destination. In order to improve the routing stability in MANET, resource utilization (i.e., energy and bandwidth) has to be controlled. An effective firefly resource-optimized routing (FFROR) technique controls resource utilization and improves routing stability during data packet (DP) transmission in MANET. Initially, in FFROR, the firefly resource optimization (FFRO) algorithm generates the population of fireflies (i.e., mobile nodes). It calculates the light intensity of every firefly based on objective functions (i.e., minimum energy consumption and minimum bandwidth utilization). The FFRO algorithm ranks fireflies according to the light intensity and finds the best resource-optimized mobile node (MN) to send the DP to the destination. This, in turn, helps in finding the resource-optimized mobile nodes and choosing the route path for sending the DP to the destination. The proposed FFROR technique uses the FFRO algorithm to increase routing stability and throughput. The simulation is carried out to analyze the performance of proposed FFROR techniques with parameters such as energy consumption, bandwidth availability, routing stability, and throughput.

Keywords: mobile ad hoc network; firefly resource-optimized routing; objective functions; routing stability; resource-optimized mobile nodes

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1. Introduction

Many mobile nodes (MN) with dynamic autonomous networks form a MANET. In [1], the authors introduced an energy-aware and error resilient (EAER) routing protocol to improve MANET network lifetime with low energy. A recovery method minimizes network control overhead and enhances dependability [1]. Discovering the shortest path required improving throughput. A stability-based multicast routing protocol (SMR) [2] identifies stable routes and adapts to network topology changes. The SMR procedure's energy consumption was high.

The zone-based routing with parallel collision-guided broadcasting protocol (ZCG) was introduced in [3] for parallel and distributed broadcasting to reduce duplicate broadcasting and energy waste. Despite this, route stability was not addressed. The basic communication strategy, minimal energy consumption with optimized routing (MECOR),uses mobile node mathematical and signaling features [4] and ant colony optimization [5]. The bandwidth consumption rate was larger.

The fuzzy-based approach in [6,7] increases an ad hoc on-demand distance vector (AODV) reactive routing protocol and identifies trusted nodes between the sender and recipient. Energy use was low. Energy-efficient routing was introduced in [8,9] with QoS monitoring agents that measured link dependability. Robust broadcast propagation(RBP) protects network energy. The energy-efficient routing method was not able to minimize bandwidth usage. Node movement stability, channel congestion, and link/route expiration time mobility are energy-efficient concepts in the mobility and quality of service aware anycast routing system (MQAR) [10]. Routing consumed a lot of energy.

In [11], the authors presented temporally ordered routing algorithm (TORA) routing protocol energy-aware features using a binary particle swarm optimization algorithm(BPSO). The route length and energy level were used to select routes. The weight function of route length and energy level was raised using BPSO route selection. The throughput was not boosted by BPSO. An energy-efficient bandwidth-aware MANET routing protocol was introduced in [12,13]. The source determines the data forwarding route due to limited energy and bandwidth for on-demand various disconnected pathways. ZRP [14] combined proactive and reactive MANET routing protocols. ZRP relies on hop-described zones. The energy use did not decrease.

Research contributions are characterized as follows: firefly resource-optimized routing (FFROR) cuts MN resource use and improves MANET routing stability; the proposed firefly resource optimization (FFRO) algorithm can find the resource-optimized way of sending the DP using FFROR; DP is sent to the destination node through the selected path, improving routing stability.

2. Related Works

For routing stability in MANET, much research has been carried out, and different methods have been proposed to establish efficient protocol methods for MANET. An on-demand bandwidth and stability-based unicast routing scheme (OBSUR) [15] has been implemented for reliable communication. A time division multiplexed access (TDMA)-based distributed system using fuzzy energy state-based AODV was introduced [16]. The Mamdani fuzzy logic system uses Route REQuests (RREQs). In AOMDV [17], link accessibility, queuing latency, node mobility, and bit error rate were used for MANET. With the help of persistent links, stable link route identification was conducted in [18] but suffers from the bandwidth in video streaming. In [19], an adaptive, self-configurable routing for video streams was discussed. In [20], an optimization rerouting model was introduced to reduce the energy. RECI [21] chose the path with the fewest hops. Throughput was not addressed in the optimization routing model. A routing metric helped nodes choose stable routes in [22], boosting route stability. Ref. [23] explored bandwidth-satisfied route evaluation and eradicating the hidden route problem for data rate selection using a cross-layer scheme from PHY and MAC to network layers. Particle swarm optimization prediction [24] determined MANET node and link lifespans. The prediction method minimizes data loss but not bandwidth use. Energy-efficient and stable multipath routing (EESMR) was described in [25] as finding stable paths. The optimized energy-efficient route assignment (OEERA) scheme [26] identified similar nodes in the network to find more reliable routes. The authors of [27] introduced the ant adhoc on-demand distance vector (AODV) to find the best network path. A new opportunistic routing strategy with gradient forwarding in MANET detected valid routes in [28]. Particle swarm optimization prediction [24] determined MANET node and link lifespans. In [29], efficient and robust geographic routing techniques were created to forward data packets with minimal resources. A unique particle swarm optimization was reported in [30] for energy-efficient MANET routing. A robust and energy-efficient routing technique was introduced [31] to reduce network node delay and energy consumption. Lowest-mobility high-power dynamic routing [32] sends route discovery signals to all its neighbors to find the path. Biogeographic-based optimization was used to find stable network nodes [33]. However, energy consumption did not decrease sufficiently. An efficient firefly resource-optimized routing (FFROR) technique is suggested to reduce resource use and improve routing stability. A FFROR reduces resource use to improve MANET routing reliability.

3. Design of Firefly Resource-Optimized Routing (FFROR) Technique

The FFROR technique is introduced for effective transmission of DPs with minimum resource utilization and improved routing stability. The FFROR technique uses a firefly resource optimization algorithm for finding the resource-optimized route path. With the resource-optimized route path, the proposed FFROR technique sends the DP to the receiver from the sender. Figure 1 shows the architectural diagram of the FFROR.

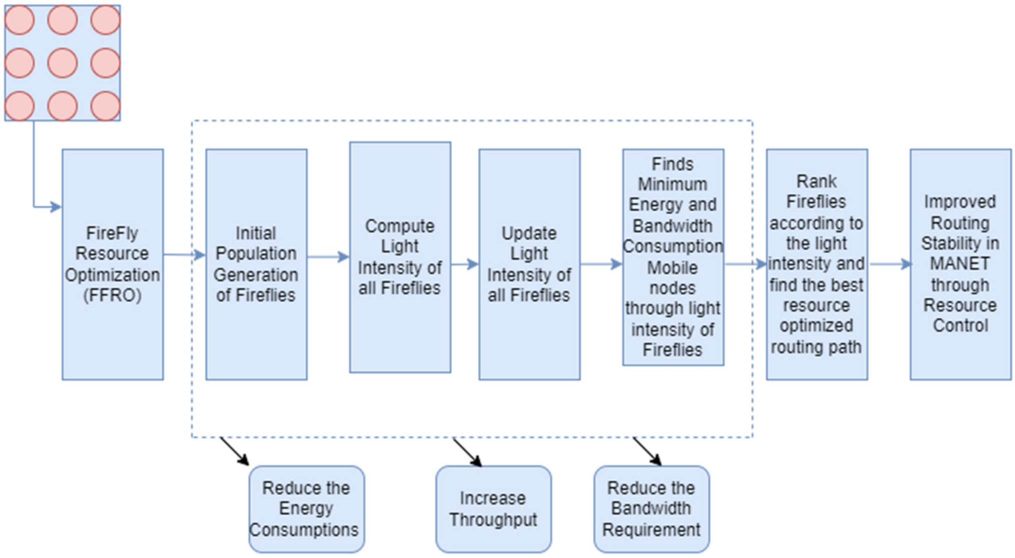

Figure 1. FFROR technique.

From Figure 1, it is understood that the FFROR technique effectively finds the resource-optimized route path using the FFROR algorithm for transmitting the DP in MANET. The resource-optimized mobile nodes are selected based on the objective function (i.e., minimum energy consumption nodes and minimum bandwidth utilization). The MN, which consumes less energy and less bandwidth utilization, is taken as the resource-optimized mobile node. After that, the FFRO algorithm ranks the mobile nodes and finds the resource-optimized route path. By selecting the resource-optimized route path in MANET, the routing stability is increased.

FireFly Resource Optimization (FFRO) Algorithm for Routing Stability Improvement

A FFRO algorithm is a meta-heuristic approach used for solving the resource control problem and for increasing the routing stability in MANET. Using the flashing light behavior of fireflies, the proposed FFRO algorithm is presented. In the FFRO algorithm, the group of fireflies moves to brighter locations by flashing light intensity with the objective function of finding the resource-optimized path. Firefly's flash is used with the aim of operating as a signal system to attract other fireflies. The firefly algorithm is formulated by the assumptions given below:

- All fireflies are unisexual where; each firefly is attracted to every firefly;
- Attractiveness is directly proportional to brightness; for two fireflies, a less bright firefly is attracted by the brighter one, and the intensity decreases when the distance between the two fireflies increases;

- When no fireflies are brighter than the given firefly, it moves randomly, and the brightness of the firefly is increased or decreased based on the objective function.

The firefly optimization algorithm assumption is made to find the resource-optimized firefly to increase the routing stability in MANET during the DP transmission. For improving the routing stability, the resource utilization (i.e., energy consumption and bandwidth utilization) is to be controlled. Let the objective function $f(y)$ of the FFRO algorithm in MANET be taken as minimum energy consumption (y_1) and minimum bandwidth utilization (y_2). The energy consumption (y_1) of the mobile node is calculated as follows:

$$\boldsymbol{Energy\ consumtpion}\ (\boldsymbol{E_c}) = \boldsymbol{E_t} - \boldsymbol{E_r}. \tag{1}$$

From (1), 'E_t' represents the total energy, and 'E_r' denotes the residual energy after transmitting the DP. Then, the bandwidth utilization (y_2) of a node is measured as below:

$$Bandwidth\ utilization = total\ bandwidth - unused\ bandwidth. \tag{2}$$

From (2), the minimum bandwidth utilization node is selected for DP transmission in MANET. The main aim of the FFRO algorithm is to identify the resource-optimized mobile nodes in MANET for efficient DP transmission to increase the routing stability. Initially, all fireflies are dislocated in the network randomly. In fireflies, light intensity variation and formulation of attractiveness need to be taken. The attractiveness of a firefly is evaluated using brightness or light intensity, which is related using objective function $f(y)$. The light intensity 'L_I' of a firefly at y is mathematically represented as follows:

$$L_I(y) \alpha f(y). \tag{3}$$

The attractiveness 'A' varies with distance r_{pq} among pth and qth the fireflies. The attractiveness changes with the degree of absorption as light intensity is minimized with distance. The light intensity is a function of distance 'r' mathematically formulated as

$$L_I(r) = L_o e^{-\gamma r}. \tag{4}$$

From (4), 'L_o' represents the actual light intensity, and 'γ' denotes the light absorption coefficient. A firefly's attractiveness is associated with the light intensity seen by adjacent fireflies. The attractiveness 'A' of a firefly is represented as follows:

$$A = A_o \exp(-\gamma r^m),\ m \geq 1. \tag{5}$$

From the above Equation, 'r' represents the distance between two fireflies, A_o is attractiveness at $r = 0$, and 'm' is the number of fireflies taken. Euclidean distance in the FFRO algorithm evaluates the distance between two fireflies, p and q, at y_p, and y_q is formulated as

$$r_{pq} = \sqrt{\sum_{k=1}^{d} \left(y_{p,k} - y_{q,k} \right)^2}. \tag{6}$$

From (6), the movement of less bright firefly p to brighter firefly q is represented as below:

$$y_p = y_p + A_o e^{-\gamma r_{pq}^2} (y_q - y_p) + \alpha(R - 0.5). \tag{7}$$

From the above Equation, the second term is because of attraction, and the third term is randomization using α, which represents the randomization parameter. 'R' represents the random no generator issued in [0, 1]. Let us consider that $A_o = 1$ and $\alpha \in [0, 1]$. The randomization term is expanded to normal distribution N (0, 1). The formula used for any pair of fireflies 'y_p' and 'y_q' is represented as

$$y_p^{t+1} = y_p^t + A \exp\left(-\gamma r_{pq}^2\right) \left(y_q^t - y_p^t\right) + \alpha_t \epsilon_t. \tag{8}$$

From the above equation, α_t denotes the parameter controlling step size, while 'ϵ_t' represents vector drawn from Gaussian or another distribution. The proposed algorithm mainly contains two objective functions, known as minimum energy consumption and minimum bandwidth utilization. These objective functions are used for determining the light intensity of fireflies to find resource-optimized route paths in MANET, which result in increasing the routing stability. In MANET, the resource utilization is calculated by evaluating the light intensity of the firefly by using the proposed algorithm. Based on the light intensity of the firefly, the DP is moved from one firefly to another firefly. After that, the FFRO algorithm ranks fireflies according to the light intensity and finds the best resource-optimized route path for DP transmission. With the aid of the algorithmic process below, the proposed FFRO algorithm efficiently chooses the resource-optimized route path. This, in turn, helps in increasing the routing stability while sending the DP from the transmitter to the receiver. The algorithmic process of the firefly optimization algorithm is shown below.

The proposed FFRO Algorithm 1 initially generates the firefly population and calculates the firefly's light intensity based on objective functions. With the help of calculated light intensity, the FFRO algorithm finds the resource-optimized MN in MANET. Then, the source node finds the adjacent resource-optimized mobile nodes and calculates the distance between them. Suppose the light intensity of firefly q is higher than the light intensity of firefly p; in that case, firefly p moves towards firefly q (i.e., the DP in MNp is transmitted to mobile node q). The attractiveness of the firefly (i.e., resource utilization of mobile node) changes with distance r, consequently estimating the new solutions and updating light intensity until the termination condition is met. Finally, the proposed FFRO algorithm ranks fireflies according to the light intensity and finds the best resource-optimized MN for transmitting the DP to the destination node.

Algorithm 1. Firefly Algorithm for Resource Optimization

Input : Source Node 'SN', Destination Node 'DN', Intermediate Nodes $MN_1,\ MN_2, MN_3, MN_4, MN_5, MN_6, MN_7, MN_8, MN_9, MN_{10}$, Number of paths
Output: Improves routing stability in MANET
Begin
Step 1: Define Objective function f(y); $y = (y_1, y_2)$
f$(y) = y_1 =$ minimum energy consumption and $y_2 =$ minimum bandwidth utilization;
Step 2: Create the initial population of fireflies $y_p = (p = 1, 2, \ldots, n)$;
Step 3: Calculate light intensityL_I at y_p determined by f(y) using (4)
Step 4: Define absorption coefficient γ
Step 5: while$(t < \mathit{Termination\ Criteria\ not\ met})$
Step 6: for $p = 1:\ n$ (all n fireflies)
Step 7: **for** $q = 1:\ n$ (all n fireflies)
Step 8: Calculate the distance r between firefly p and firefly q using (6)
Step 9: if $\left(I_q > I_p\right)$
Step 10: Move firefly p towards firefly q using (7)
Step 11: **end if**
Step 12: attractiveness changes with distance r via $exp(-\gamma r)$;
Step 13: Compute new solutions and update light intensity;
Step 14: end for q
Step 15: end for p
Step 16: If
Step 17: Rank fireflies according to the light intensity and find the best resource-optimized route path for DP transmission
Step 18: end while
Step 19: DP transmission from the source node to the destination node
End

4. Results and Discussion

Simulation experiments were conducted to analyze the performance of the FFROR technique using the NS2 Network simulator. The number of DPs selected for experimental use is 100. In our simulation, the designed technique sends the DPs from sender to receiver using the intermediate mobile nodes randomly distributed in the square area. Table 1 lists the set of input parameters and evaluates the performance of the FFROR technique.

Table 1. Simulation parameters.

Simulation Parameters	Values
Simulator	NS 2.34
Protocol	AODV
No, of mobile nodes	50, 100, 150, 200, 250, 300, 350, 400, 450, 500
No, of Data packets	10, 20, 30, 40, 50, 60, 70, 80, 90, 100
Simulation time	200 s
Number of runs	10
Node speed	0–30 m/s
Network area	1000 m × 1000 m
Packet size	200 Kbps
Bandwidth	20 MHz
Initial energy	20 J

5. Simulation Results and Analysis

The experimental evaluation of the FFROR technique is carried out with metrics such as energy consumption, bandwidth availability, routing stability, and throughput. The proposed FFROR technique is compared with the existing methods, namely, the energy-aware and error-resilient (EAER) routing [1] protocol, minimal energy consumption with optimized routing (MECOR) [4] protocol, energy-efficient and stable multipath routing (EESMR) technique [25], and optimized energy-efficient route assignment (OEERA) scheme [26]. The performance of the above method is compared and analyzed with the help of tables and graphs.

5.1. Impact of Energy Consumption

Energy consumption is measured by the product of energy consumed by a single MN and the total number of mobile nodes in MANET. The lower the energy consumption, the more efficient the method.

Table 2 shows energy consumption for the proposed FFROR Technique and the existing methods. The number of mobile nodes is 50 to 500 for experimental purposes. The table value clearly shows that the proposed FFROR technique has achieved less energy consumption than the existing works. The FFRO algorithm chooses the minimum energy consumption MN for transmitting the data packets. From the results, the energy consumption of the proposed FFROR technique is reduced by 22%, 43%, 13%, and 36% compared to the existing EAER [1], MECOR Protocol [4], EESMR technique [25], and OEERA scheme [26], respectively.

5.2. Impact of Bandwidth Utilization Rate

The bandwidth utilization rate is defined as the amount of bandwidth utilized to the total available bandwidth in the network. It is evaluated in percentage (%).

Table 3 illustrates the bandwidth utilization rate to the number of DPs sent, ranging from 10 to 100 during the routing in MANET. The table value shows that the proposed FFROR technique has achieved a lower bandwidth utilization rate than the existing works. When the number of DPs sent increases, the bandwidth utilization rate also increases correspondingly. However, the bandwidth utilization rate in the proposed FFROR technique is less because of its use of the FFRO Algorithm. In the FFRO Algorithm, minimum bandwidth utilization MN is selected for transmitting the data packets. From the results, the proposed FFROR technique has reduced the bandwidth utilization rate by 23% when compared to the EAER Protocol [1], 34% when compared to the MECOR Protocol [4], 13% when compared to the EESMR technique [25], and 29% when compared to the OEERA scheme [26].

Table 2. Calculation of energy consumption.

No, of Mobiles Nodes (Number)	Energy Consumption (Joules)				
	Proposed FFROR Technique	EESMR Technique [25]	EAER Protocol [1]	OEERA Scheme [26]	MECOR Protocol [4]
50	32	39	48	55	68
100	35	42	51	60	70
150	39	46	52	62	72
200	43	49	54	68	75
250	46	52	57	70	79
300	48	53	59	72	80
350	49	55	61	74	81
400	51	57	63	76	85
450	52	60	64	77	86
500	53	61	65	80	87

Table 3. Calculation of bandwidth utilization rate.

No, of Mobiles Nodes (Number)	Bandwidth Utilization Rate (%)				
	Proposed FFROR Technique	EESMR Technique [25]	EAER Protocol [1]	OEERA Scheme [26]	MECOR Protocol [4]
50	45	52	60	65	75
100	47	55	63	70	77
150	49	56	67	73	80
200	52	60	70	75	83
250	55	62	73	77	85
300	58	66	75	82	88
350	61	70	78	83	90
400	63	72	81	86	92
450	65	75	84	89	94
500	68	77	87	91	96

5.3. Impact of Throughput

The throughput is the ratio of the number of DPs sent to the total number of DPs received. It is evaluated as a percentage (%).

Table 4 illustrates the throughput of the number of DPs sent, ranging from 10 to 100 during the routing in MANET. From the Table 4 value, it is clear that the proposed FFROR technique has achieved higher throughput than the existing works. From Table 4, it is clear that the proposed FFROR technique provides higher throughput results compared to existing the protocol. When the number of DPs sent increases, throughput also increases correspondingly. Nevertheless, the throughput in the proposed FFROR technique is high when sending the data packets through the resource-optimized route path. The resource-optimized route path is selected using FFRO algorithm. From the results, it is evident that the proposed FFROR technique has increased the throughput level by 20% when compared to the EAER Protocol [1], 41% when compared to the MECOR Protocol [4], 8% when compared to the EESMR technique [25], and 28% when compared to the OEERA scheme [26].

Table 4. Calculation of throughput.

No, Data Packets Sent (Number)	Throughput (%)				
	Proposed FFROR Technique	EESMR Technique [25]	EAER Protocol [1]	OEERA Scheme [26]	MECOR Protocol [4]
10	81.23	73.61	65.31	61.22	55.32
20	83.96	75.26	66.32	62.34	57.34
30	84.63	77.31	68.91	63.24	58.62
40	86.01	80.11	70.23	65.87	59.11
50	87.36	82.16	72.96	67.42	60.32
60	89.63	83.61	74.12	70.05	64.32
70	90.26	85.02	76.34	72.46	65.23
80	91.85	86.07	78.65	73.55	66.74
90	93.56	87.11	79.98	76.51	69.42
100	95.78	88.63	81.36	78.16	70.35

5.4. Impact of Routing Stability

The routing stability is defined using the stable energy nodes and bandwidth utilization rate through the packet transmission from the sender to the receiver. Figure 2 represents the routing stability of three different methods, such as the FFROR Technique, the EAER protocol [1], the MECOR protocol [4], the EESMR technique [25], and the OEERA scheme [26]. The figure shows that the proposed FFROR technique has achieved higher routing stability than the existing methods.

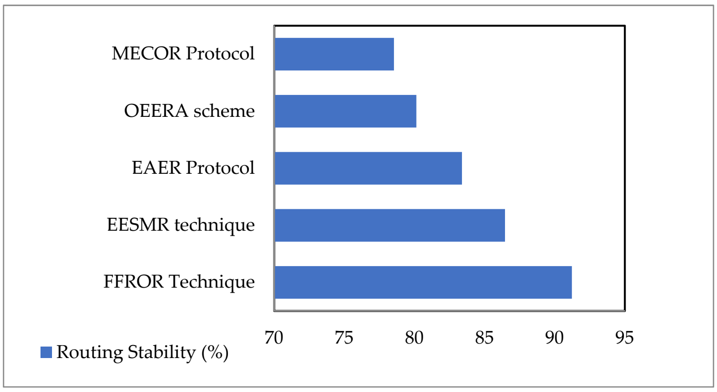

Figure 2. Measurement of routing stability.

Figure 2 shows the measurement of routing stability of three different methods via the FFROR technique, EAER protocol [1], MECOR protocol [4], EESMR technique [25], and OEERA scheme [26].In this figure, the x-axis denotes the percentage of routing stability and the y-axis denotes the different types of protocol. The proposed FFROR technique presents better performance results compared to the EAER Protocol [1], the MECOR Protocol [4], the EESMR technique [25], and the OEERA scheme [26]. The proposed FFROR technique aims to provide the minimum energy consumption nodes with the minimum bandwidth utilization nodes for sending the DP from sender to receiver. Therefore, the proposed FFROR technique improved the routing stability by 8% when compared to the EAER Protocol [1], 13% when compared to the MECOR Protocol [4], 5% when compared to the EESMR technique [25], and 14% when compared to the OEERA scheme [26].

6. Conclusions

An effective firefly resource-optimized routing (FFROR) technique is introduced to control resource utilization and to improve the routing stability during the DP transmission in MANET. The firefly resource optimization (FFRO) algorithm in the FFROR technique generates the initial population of fireflies and calculates the light intensity of all fireflies based on objective functions. The FFRO algorithm ranks fireflies consistent with light intensity and finds the best resource-optimized mobile nodes to send the DP to the destination node. Lastly, the route path is selected for transmitting the DP using the resource-optimized MN. Thus, the FFRO technique improves the routing stability and throughput. Experimental evaluation and parameter analysis are performed regarding energy consumption, bandwidth availability, routing stability, and throughput. Experimental analysis shows that the FFROR technique can minimize energy consumption by 29% and improves the routing stability by 10% compared to state-of-the-art techniques.

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