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Smart IoT Control-Based Nature Inspired Energy Efficient Routing Protocol for Flying Ad Hoc Network (FANET)

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ABSTRACT The increasing demand of routing in the field of communication is the most important subject in ad hoc networks now a days. Flying Ad Hoc Network (FANET) is one of the emerging areas that evolved from Mobile Ad Hoc Networks. Selecting the best optimal path in any network is a real challenge for a routing protocol. Because the network performance like throughput, Quality of Service (QoS), user experience, response time and other key parameters depend upon the efficiency of the algorithm running inside the routing protocol. The complexity and diversity of the problem is augmented due to dynamic spatial and temporal mobility of FANET nodes. Due to these challenges the performance and efficiency of the routing protocol becomes very critical. This paper presents a novel routing protocol for FANET using modified AntHocNet. Ant colony optimization technique or metaheuristics in general has shown better dependability and performance as compared to other legacy best path selection techniques. Energy stabilizing parameter introduced in this study improves energy efficiency and overall network performance. Simulation results show that the proposed protocol is better than generic Ant Colony Optimization (ACO) and other traditional routing protocols utilized in FANET.

INDEX TERMS FANET, routing, nature inspired algorithms, ACO.

I. INTRODUCTION

Modern day realization of FANETs is the result of instrumental growth and development in the field of wireless communication technologies. According to Gartner [1], by 2020 worldwide 5G wireless network infrastructure revenue will surpass over $4.2 billion, which will be an increase of 89% in the revenue as compared to following year 2019. These numbers reveal that wireless technologies will provide more coverage and enhanced data rates rendering optimal applications of FANET. In flying adhoc networks nodes are generally mobile and can move in all three axes. Communication between nodes is usually achieved by using Point to Point (P2P) or MultiPoint Relay (MPR) [2] techniques. Point to point communication is only possible when two nodes are at closed proximity with each other. However, if nodes are far away from each other then MPR techniques are utilized. In MPR any intermediate node can become and act as a packet forwarder or relay agent. Such arrangement of nodes is utilized in literature of Adhoc networks [3] like Mobile Adhoc Network (MANET), Vehicular Adhoc Network (VANET), Robot Adhoc Network (RANET) and Ship Adhoc Network (SANET).

In past two decades, extensive work has been presented in these domains especially on MANET and VANET [4]–[7]. Flying Adhoc Network (FANET) comprising of small Unmanned Aerial Vehicle (UAV) has recently gained attention due to (i) ease of availability, (ii) versatility, (iii) adaptability, (iv) autonomy and (v) easy deployment [8] techniques. FANETs have found applications in both military and civilian domain for example disaster site inspection and management, search and rescue operations, forest fire detection, traffic and urban monitoring, reconnaissance and patrolling, environmental sensing, etc. [9].

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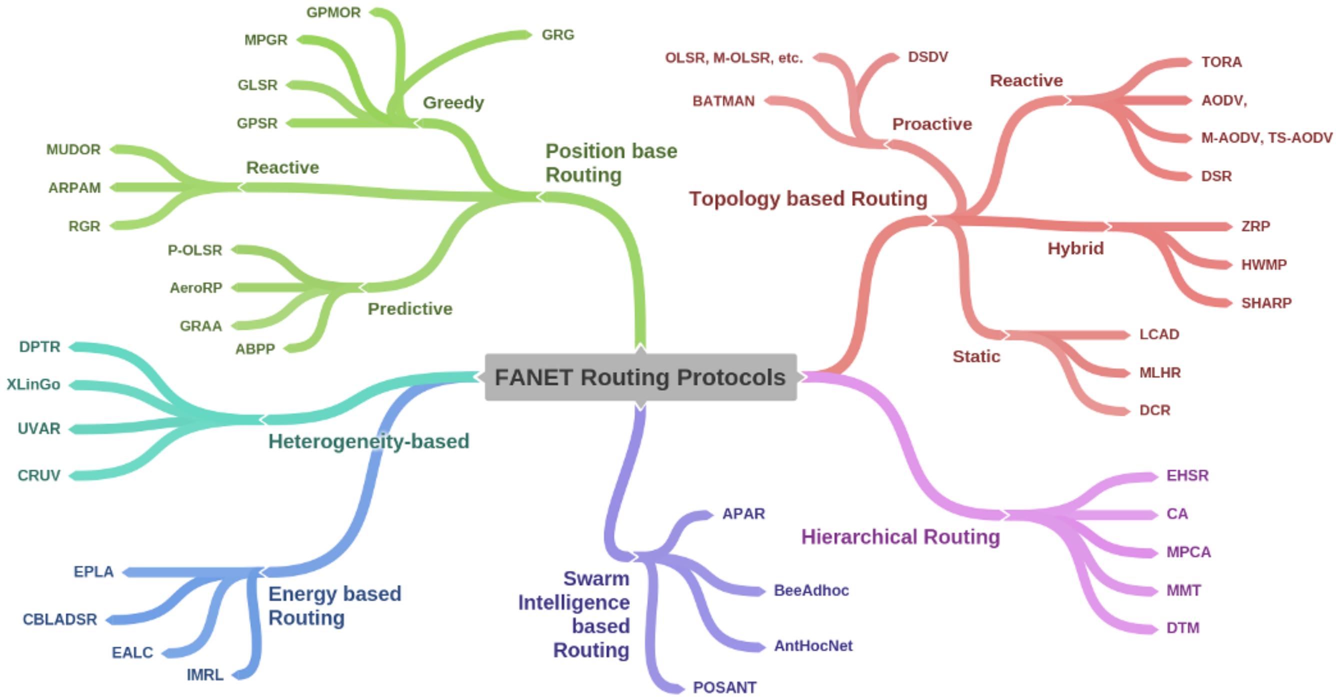

FIGURE 1. Taxonomy of FANET routing protocols.

Adhoc network of smaller UAVs (drones) have operational benefits over large UAVs [10] due to lower maintenance and operational cost. Multi-UAV systems have reduced mission accomplishment time, simpler electronics with added benefits of scalability and survivability. However, flying adhoc network of drones inherit the complications of a typical adhoc network [11]. Self-configurable and autonomous nature of adhoc networks render challenge of 'efficient routing schemes' [12].

Due to highly mobile and dynamic nature of FANET, a routing protocol should be capable enough to adapt the changing requirements of the network. FANET routing protocol should be sensitive to packets drop, delay/jitter because these factors seriously effect the quality of service of any network. Secondly it should provide acceptable level of throughput against the network load, which means that a routing protocol must be scalable. Third and most important consideration is it should be capable enough to conserve nodes energy to enhance network lifetime. In this paper we proposed a nature inspired routing protocol for flying adhoc networks that addresses these challenges.This article presents ant colony optimization - metaheuristics based energy efficient routing protocol for FANETs. Simulation results show significant reduction in packet drop rate, end to end delay, and improvement in network throughput, packet received ratio and work done (bits / joule) over other FANET protocols. Rest of the paper is structured with Section II consisting of taxonomy and literature review of FANET routing protocols. Section III discusses Ant Colony Optimization (ACO) algorithm followed by Section III which presents our proposed algorithm. Section IV demonstrate the simulation arrangement along with results trailed by conclusion and future direction in Section V.

II. LITERATURE REVIEW

As discussed in Section I flying adhoc networks is basically derived from mobile adhoc networks which implies it inherits many good features of MANET. However at the same time different limitations and challenges are also inherited [13]. Since in FANET nodes can move in all three dimensions at the same time due to which the problem space grows exponentially. Among many challenging issues one fundamental problem which is highlighted by [14] is currently industry lacks specialized FANET routing protocols or atleast they are in development stages at the moment and not ready for production rollout. Due to this limitation FANET currently depends on MANET routing protocols which are useful for FANET also. Therefore, in this section we will present taxonomy of routing protocols which are applicable and useful for flying adhoc networks. Taxonomy of MANET / FANET routing protocol is presented in Figure 1. These protocols are classified based on different parameters such as nature of operation, drones deployment strategy, mobility models etc. Oubbati *et al.* [15] suggested that FANET protocols can be categorized based on how nodes build network topology, form clusters, inspired from nature and exploit swarm intelligence, position based communication models and apply hybrid approach etc. Figure 1 presents us a holistic bird's-eye view of FANET routing protocols. Based on their working behavior and nature of operations, each category can be further divided into smaller sub-categories as the shown in figure.

In literature review it can be seen that most authors used Network Simulator 2 (NS2) and MANET routing protocols in flying adhoc networks [8], [16]–[18]. One trivial reason could be the limited support of protocols in the simulator being used in the study. We also analyzed that Random Way Point (RWP) is the most widely studied mobility model in flying adhoc networks [8], [19]–[23] despite of it has failed to provide reliable results [24] which unfold research gap in this domain.

III. ANT COLONY OPTIMIZATION ALGORITHM - *METAHEURISTICS*

Routing is the process of selecting the best path between source and destination [25]. Selection of best path can be based on certain objective(s) such as minimizing or maximizing: time, number of hops, link utilization, quality of service, security etc. Complexity of selecting best path rises exponentially in wireless networks, specially when nodes are mobile and can move in all three directions (x, y and z - axes). In this section firstly we will describe nature inspired ant colony optimization algorithm and then we will present our proposed routing algorithm in the next section.

Nature inspired optimization algorithms have shown great tendency to solve complex problems [26]. ACO is a Swarm Intelligence (SI) based technique inspired from the collective behavior of different animals, birds, insects, flies and other species. Particles or agents in a swarm generally demonstrate collective intelligence [27] which is actually the result of indirect local communication. Indirect communication in ant colonies is achieved with the help of 'pheromone' [28]. Pheromone is a volatile chemical substance deposited by the ants to influence other following ants.

When an ant moves from its nest to search food it leaves a trail of pheromone behind it which is followed by other ants. Pheromone possesses two important characteristics which are known as *evaporation* and *concentration*. When a path is selected by frequently by several ants the concentration of pheromone becomes increase on that path. Therefore, the path which has higher pheromone level has higher probability of being selected. Similarly when a path is not being selected frequently, the concentration of pheromone on that path drops which is known as 'pheromone evaporation'.

One important aspect of shortest path discovery in ant colony metaheuristics is the random behaviour demonstrated by few ants. In food searching process an ant can also select a path randomly ignoring paths even have higher pheromone concentration. It means that ants might not follow pheromone trail (concentration) all the time. Instead, they may select any path based on their local behavior or heuristics [30]. This local behavior is a crucial ingredient to achieve *exploration* a method to escape out of 'local minima'.

Figure 2 demonstrates the result of an experiment performed by Goss *et al.* [29] with real colony of Argentine ants. In this figure when ants face an obstacle there will be an equal

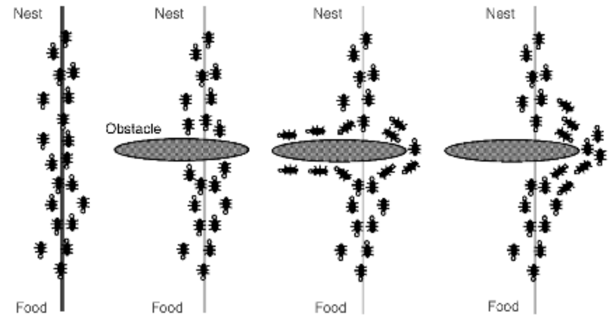

FIGURE 2. Ant colony searching for food source.

probability of choosing left or right branch. However, it can be observed from the figure that ants who take left path will find food source more quickly as compared to other ants who selected right path. So it will take less time for ants to reach food source and back to the nest which will eventually leave high concentration of pheromone more quickly on that path. Therefore, in this way ants will learn optimal shortest path. This indirect form of communication as discussed earlier is known as *stigmergy* [31].

Rest of the paper is organized as follows. In Section III-A we describe the inclusion of parameter 'energy stabilization threshold' *es_param*. In Section III-A1 and III-A2 we presented the method to calculate energy stabilization threshold for the given topology and its sole purpose respectively. In Section III-B we presented our proposed routing algorithm and its detail steps.

A. ENERGY STABILIZATION THRESHOLD (EST)

As discussed above in Section III one important measure to evaluate routing protocol performance is network lifetime. We have introduced energy stabilization threshold in our proposed protocol design. The purpose of energy stabilization threshold (*es_threshold*) is to conserve drones /nodes energy and improve overall network lifetime, Quality of Service/ Experience (QoS/E) by limiting the forwarding of packets. In the following sections we will discuss (i) method to calculate *es_threshold* for the topology and (ii) how it is being used in our proposed algorithm.

1) CALCULATING ENERGY STABILIZATION THRESHOLD

Energy stabilization threshold is actually calculated by using equation 1. Equation 1 is derived by applying statistical testing over the proposed simulation model. Afterwards, the equation is generalized by applying heuristics.

$$es\_threshold = \frac{ie}{e^{n/ie} * \frac{a+b}{c}} \tag{1}$$

where,
n: total number of nodes
ie: nodes initial energy
a: topology size in x-dimension
b: topology size in y-dimension
c: topology size in z-dimension

TABLE 1. Simulation parameters.

Parameter	Value
Simulator	Network Simulator v2.35
Simulation Time	180 seconds
Topology Area	1000m x 1000m x 1000m
Mobility Model	Random Way Point (RWP)
Movement Speed	10 m/s
Traffic Type	Constant Bit Rate (CBR)
Packet Size	512 bytes
Number of Nodes	30 (ex. base station)
Nodes initial energy	75 Joules

For our simulation model refer Table 1, Eq. 1 yields the value 25 joules. So we configured the *es_param* to 25 joules. In the next section we will discuss how this parameter is being used in our routing scheme.

2) PURPOSE OF ENERGY STABILIZATION THRESHOLD

As discussed in Section I multipoint relay is one important practice which is being followed by intermediate nodes in adhoc networks to forward packets to next hop. However it has some serious implications such as unnecessary higher network load and energy consumption. Higher network load generally leads to network congestion and packet drop. For flying adhoc networks where nodes are operated via batteries, nodes energy becomes a critical resource. Energy stabilization threshold limits the intermediate nodes to further process and forward multipoint relay packets; if the nodes' energy has been dropped below EST. Simulation results presented in Section IV show that EST has positive impact on number of key parameters such network lifetime, throughput, end to end delay etc.

B. PROPOSED ALGORITHM (E-AntHocNEt)

In this section we present proposed nature inspired energy efficient routing protocol for flying adhoc networks. Our proposed protocol is based on classical ant colony metaheuristics (refer Section III. It consists of three main steps, (i) generation of initial feasible solution (ii) daemon action if any (optional) - derive from ACO and (iii) pheromone update process.

1) GENERATION OF INITIAL SOLUTIONS

Nature inspired algorithms are generally iterative in nature, means algorithm follow a course iteratively to find best optimal solution. At each iteration ants build new feasible solutions. In every iteration the probability of an ant to select next node '*j*' from node '*i*' is actually given by Eq. 2,

$$p_{i,j}^{k} = \frac{\tau_{i,j}^{\alpha} * \eta_{i,j}^{\beta}}{\sum_{l \in N_i} \tau_{i,j}^{\alpha} * \eta_{i,j}^{\beta}} \tag{2}$$

where,
$p_{i,j}^{k}$ *is probability of transition of the* k^{th} *ant from vertex 'i' to 'j' by using link l*
$\tau_{i,j}$ *is quantity of pheromone on the edge l*
$\eta_{i,j}$ *is heuristic value of link l which is normally* $\frac{1}{d_{i,j}}$ *where* $d_{i,j}$ *is the Euclidean distance between 'i' and 'j'*

Algorithm 1 Proposed Nature-Inspired eAntHocNet Algorithm

```
Initialization Phase: Initialization of pheromone trail
and other parameters. repeat
    for each ant do
        Generate feasible solution
        Daemon Action (optional)
        Update the pheromone trails
        repeat
            if pkt.dst equal neighbor then
                call increasePheromoneValue method
            else
                if dst.phValue > 0 then
                    if dst.nextHop.energy < es_param
                    then
                        call removeEntryPheromone
                        method
                        call updateNeighbors method
        until For all neighbors
until Stopping Criteria
```

N_i *represents neighbors of node 'i' and*
α *and* β *are parameters to weight the significance of pheromone and distance in the selection of next vertex.*

Eq. 2 makes use of two important parameters that actually influence the probability of taking the move (i) Pheromone trail $\tau_{i,j}$ shows the pheromone concentration of the link. In ACO, pheromone concentration indicates a posteriori condition that is the probability of selecting a path becomes higher if it has higher pheromone concentration (ii) attractiveness $\eta_{i,j}$ of taking move i, j. Attractiveness is calculated by using heuristics indicating a priori desirability.

2) DAEMON ACTION

Daemon actions are optional processes that can be invoked to perform certain problem or scenario specific tasks. For example, collection of global information to take centralize decision as ants work in decentralize way etc. Daemon actions are usually called after solution construction phase.

3) PHEROMONE UPDATE PROCESS

From Eq. 2 it is evident that '$\tau_{i,j}$' pheromone concentration plays crucial role in select a path. Therefore the purpose of pheromone update process is to increase the value of $\tau_{i,j}$ for good solutions. This is known as *reinforcement*. We can also decrease the value of $\tau_{i,j}$ for bad solutions. But generally it is achieved via pheromone *evaporation*, in which pheromone concentration is decreased for all paths to avoid premature convergence on sub-optimal solution. Eq. 3 describes how ACO algorithm update pheromone values.

$$\tau_{i,j}(t+1) = (1-\rho) * \tau_{i,j}(t) + \sum_{k=1}^{m} \Delta\tau_{i,j}^{k}(t) \tag{3}$$

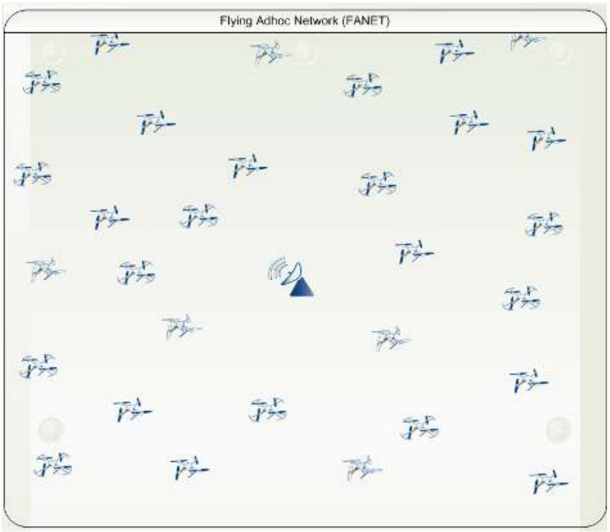

FIGURE 3. Network topology for FANET.

where,

- $1 \leq \rho \leq 1$ is the evaporation rate.
- m is the number of nodes
- $\Delta\tau_{i,j}^{k}$ is the quantity of pheromone laid at edge i,j.

IV. SIMULATION AND RESULTS

In this section we will present and compare simulation results of our proposed routing protocol - eAntHocNet. We used Network Simulator - 2 (NS2) for simulation and evaluation of eAntHocNet routing protocol. This section is organized as follows, in Section IV-A we presented different configuration parameters related to our simulation such as topology layout, mobility model, traffic patterns, simulation duration etc. In Section IV-B we discussed different evaluation measures and simulation results of eAntHocNet, AntHocNet, DSR, M-DART & TORA routing protocols. In Section IV-C we discussed and presented critical findings of our study.

A. TOPOLOGY LAYOUT & SIMULATION CONFIGURATION

Network topology layout and simulation related parameters are presented in Figure 3 and Table 1 respectively. Drones are placed randomly in the network area having size of 1000m x 1000m. All drones placed randomly except the base station which is placed at the center the center of the topology. Drones move randomly using Random WayPoint (RWP) mobility model. We used five different protocols for comparison however comparison of our proposed routing protocol is actually with ACO algorithm because it is modified version of it.

B. EVALUATION PARAMETERS AND RESULTS

In this section we will present evaluation parameters used in the study and simulation results. We used following parameters to study the behavior and impact which is presented below.

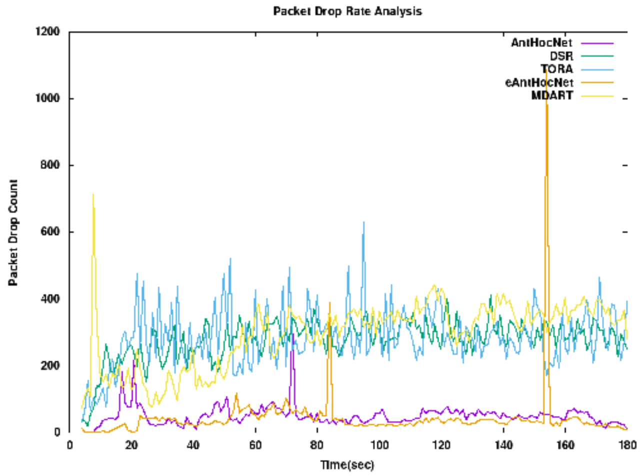

FIGURE 4. SpreadSheet of packet drop per second.

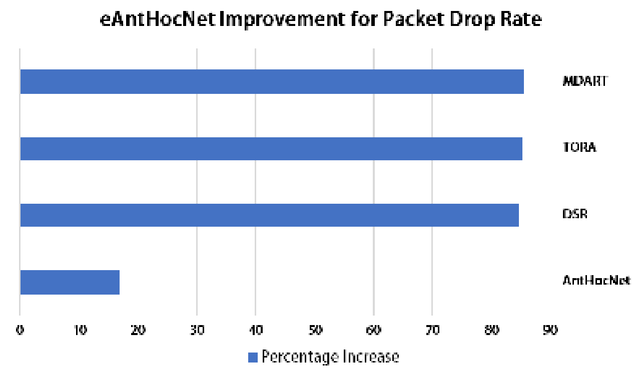

FIGURE 5. Percentage improvement in packet drop rate due to eAntHocNet in comparison with other routing protocols.

1) PACKET DROP RATE (PDR)

Packet drop rate can be defined as "the number of packets dropped per seconds". In a typical network when packets start dropping it not only effects network response time but also it impacts the Quality of Service (QoS) significantly. Due to increase in packet drop rate and network delay, overall throughput of the network is also seriously deteriorated. Figure 4 demonstrates packet drop spread over the course of complete simulation. You will observe that eAntHocNet improves packet drop rate significantly as compared to AntHocNet, DSR, MDART and TORA routing protocols. Furthermore, Figure 5 shows improvement (average in perentage) in packet drop rate for our proposed routing protocol.

2) NETWORK THROUGHPUT

The total number of successfully received packets (generally in terms of packet size) per unit time is known as network *throughput*. Throughput is calculated only for successfully delivered packets at the destination. It can be calculated by using Eq. 4

$$Throughput = \frac{\Sigma\ received\ \ packets\ \ size}{time} \tag{4}$$

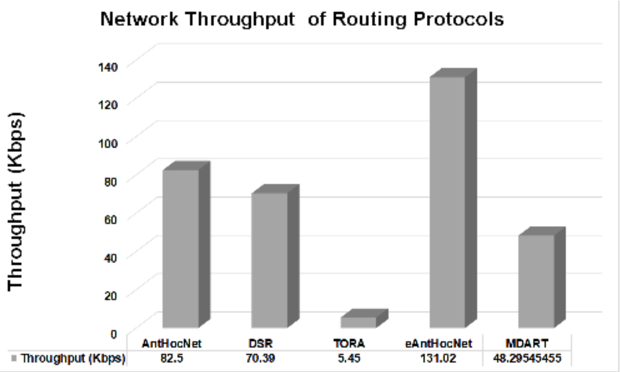

FIGURE 6. Comparison of network throughput.

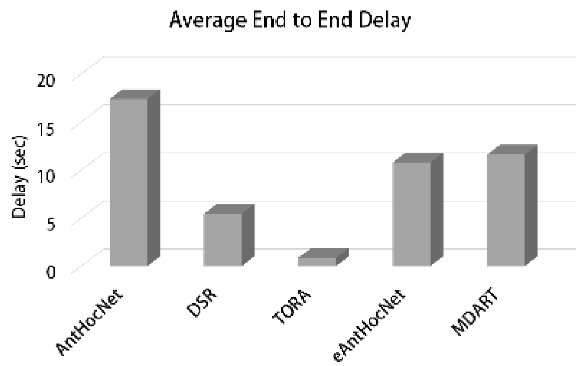

FIGURE 7. Average end-to-end delay of packet transmission.

TABLE 2. Superiority of eAntHocNet in throughput over other protocols.

	AntHocNet	DSR	TORA	MDART
eAntHocNet	+58.81	+86.14	+ 2302.08	+171.29

TABLE 3. Packet received ratio for AntHocNet, DSR, TORA, MDART & eAntHocNet protocols.

Routing Protocols	Packet Received Ratio (%)
AntHocNet	7.10
DSR	6.06
TORA	0.46
eAntHocNet	11.30
MDART	4.16

Throughput is one of the important parameter to assess the performance and scalability of a routing protocols. Figure 6 shows network throughput for the simulation. We observed significant improvement in network throughput for eAntHocNet routing protocols in contrast to all other routing protocols. Comparison of eAntHocNet with AntHocNet, DSR, MDART and TORA routing protocol is presented in Table 2.

3) PACKET RECEIVED RATIO

Packet received ratio measures the number of packets successfully delivered or received at destination node out of total number of sent packets. It can be calculated by using Eq. 5. Table 3 shows statistics for eAntHocNet routing protocol. If you analyze this table you will observe that packet received ratio for eAntHocNet is higher than all other protocols.

$$Packet\ Received\ Ratio = \frac{No.\ of\ packets\ received}{Total\ sent\ packets} \tag{5}$$

4) AVERAGE END TO END DELAY

Average end-to-end delay represents the average time taken by the packets to reach its actual destination. It is calculated by subtracting the time when it reaches its destination from the origination time of the packet. In NS2 each traffic flow has unique identifier, which can be used to track the complete packet life till dropped or received by the receiver. Average end-to-end delay is calculated according to Eq. 6 and presented in Figure 7.

$$D_{avg} = Tr_{avg} - Ts_{avg} \tag{6}$$

TABLE 4. Work done capacity or amount of bits successfully tx/rx per no. of joules.

	AntHocNet	DSR	TORA	eAntHocnet	MDART
Work done (Kbits / J)	8.72	6.25	0.46	13.45	5.01

where,
D_{avg} is average delay,
Tr_{avg} is packet receive time average,
Ts_{avg} is packet sent time average.

5) WORK DONE (bits per joule)

Work done capacity or bits per joule represents the total number of bits that the network delivers per Joule of energy in the network. Work done can be calculated by using Eq. 7.

$$W = \frac{\sum N_b}{\sum E_t} \tag{7}$$

where,
W represents work done (Kbits per joule),
N_b represents no. of bits successfully transmitted and received at receiver,
E_t represents total amount of energy consumed.

C. RESULTS

eAntHocNet shows great tendency to reduce packet drop rate which is very critical measure for the performance of a routing protocol. Reduce packet drops per second improves network throughput and quality of service. Similar effect is also noticed widely in network throughput. Improvement in network throughput shows potential improvement in network scalabality. Packet received ratio is also improved which is one other measure of Quality of Experience (QoE). Bit per joule is an important parameter that contribute towards network lifetime. It measures how much energy is required to provide an acceptable throughput. eAntHocNet has highest value which shows that it can enhance network lifetime significantly. Lastly it also shows good measurable improvement in end to end delay.

V. CONCLUSION AND FUTURE WORK

Flying Ad Hoc Network is rapidly emerging area which describes dynamic pattern of mobility, continuously changing physical structures, due to which making a novel routing protocol is a challenging task to perform. In this research a new metaheuristics based routing protocol is proposed to overcome the challenges of existing routing problems of flying adhoc networks. The proposed routing protocol eAntHocNet is compared with its base protocols AntHocNet and TORA, DSR and MDART legacy routing protocols. From the simulation results it is proved that eAntHocNet performed better in all aspects in comparison with other protocols. Since Random Way Point (RWP) is the only mobility model used in our study; hence future study on behavior of proposed routing protocol incorporating different mobility scenarios can be a good contribution.

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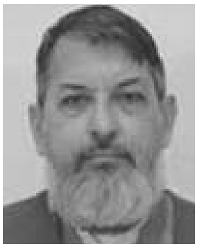

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