Energy Efficient AODV Routing Protocols for FANETs

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Abstract – All system units in flying UAV like transmitter, receiver equipment, control unit, information processing unit and payloads are powered by in build power sources. UAVs equipped with the limited on-board energy capability restrict the flying time, which will significantly affect the performance of a FANETs. Optimizing the energy consumption among nodes is one of the important research challenges. Optimization techniques for energy usage can be implemented at different OSI layer level. In our study we focused on OSI networks layers solution for performance improvements based on energy efficient routing techniques in flying ad hoc network environments. The Routing algorithm that is used in MANETs applications can be optimized and used in FANETS as in both networks' majority of the operational characteristics similar. But Few characteristics in FANETs like distance coverage, node mobility velocity, capacity and types of power supply used differentiate from other mobiles networks (VANETs, MANETs). During the first phase of our work, we evaluated the performance of classical routing protocols AODV, DSR, DSDV in FANETs using energy metrics. Result in first phase revel that AODV performance is superior to other protocols in FANETs. In second phase we designed EEAODV protocols which use energy metrics in addition to hop count for path optimization. Finally details performance comparison study between EEAODV and AODV performed, the result shows that EEAODV performance is much better that AODV. For our performance evaluation we used NS-3 simulator and random waypoint mobility models.

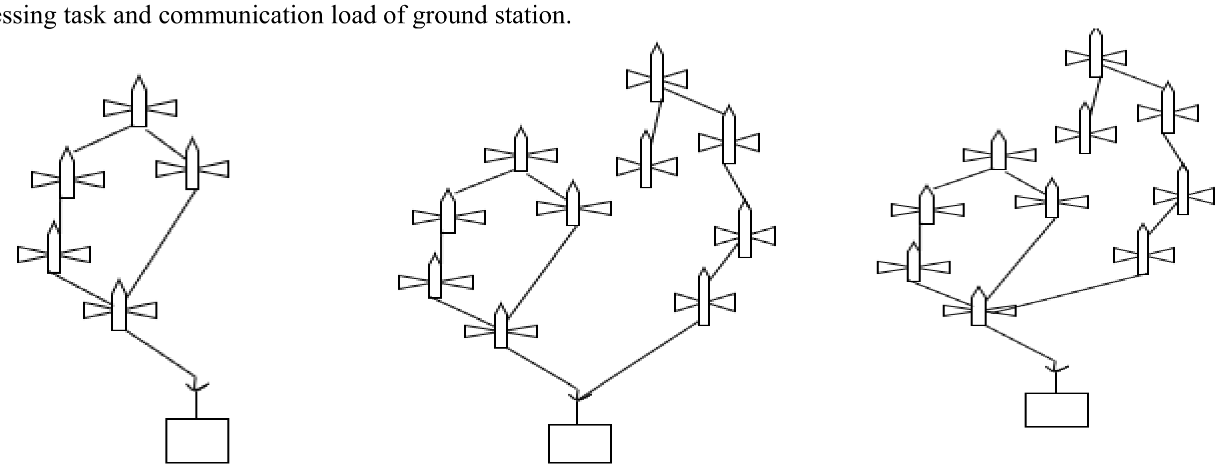
Keywords – Unmanned Aerial Vehicles, Mobile Ad-Hoc Network, Ad Hoc On Demand Distance Vector Protocols, Dynamic Source Routing Protocols, Destination Sequence, Distance Vector Protocols.

I. INTRODUCTION

Flying ad hoc network is a wireless mobile network, where the mobiles nodes are small size drone or small air vehicles equipped with communication & other specialist equipment used for different applications[1]. The main advantages of FANET compared to MANET are its coverage distance, remote area service, fast deployments, and real time data processing capability to take action at the spot, especially when it is used in control applications. Because of the availability of cheap UAV devices like drone and small air vehicles and other data collection, processing equipment's like camera, sensors, microcontroller, GPS, RF interfaces and communication equipments the application of FANETs is increasing vastly. To list few important applications, modern agriculture form drones are used for watering the plant based on the moisture level condition [2] drones are used in production factory to control the stack materials availability across different store which helps to maintain the stock at the required level, UAV are also used to provide communication service in remote village and hills area where establishing infrastructure network is impossible [17,18].

Some unique feature such us altitude, nodes mobility speed, power supply systems, size of nodes, coverage capability and node density of the fanets differentiates it from other mobile wireless network like manets and vanets [15,16] Most general multi UAV based communication architecture proposed by the author [19,20], are pictured in **Fig1**.

Fig 1 (a) shows simple architecture where one backbone UAV acts as gateway between ground station and other flying UAV nodes. As backbone nodes handles all communication traffic between nodes and ground station, if the backbones UAV fails entire network breakdowns. Second architecture in the **Fig 1 (b)** shows multi groups; here for intra group communication does not need support of ground station and the final architecture in **Fig 1 (c)** represents multi layers where systems contains many groups and here groups can share the traffic without the help of ground station, so it reduces the processing task and communication load of ground station.



(a) **(b)** **(c)**

Fig 1. Most General Multi UAV Based Communication Architecture.

The life time of UAV nodes are very less, Because of flying nodes consumes more power for its operation moreover it's power source is mostly limited and standalone batteries. In order to increase life time of the fanet, we must design system which consumes less power. In many way researcher try to implement energy efficiency in the past. In our research work, we tried to implement network layers solution [6]. The most important and suitable mobile ad hoc network protocols such as AODV, DSR, DSDV etc are not energy efficient as they do not consider intermediates nodes energy levels while discovering path between source and destination[7].

Our study divided into phase 1 and phase 2, in first phase we evaluated the performance of existing classical Routing (aodv, dsr, dsdv) in fanets environments using network performance metrics. Based on the performance result of phase 1 we selected AODV as our base protocols. During phase two we incorporated energy efficient metrics in route discovery process of AODV, and compared the performance of our modified AODV (EEAODV) with the AODV [8].

The rest of the paper is arranged as follows. Section two presents simulation parameters, metrics and energy consumption model .In Section three performance comparison study of AODV,DSR and DSDV is presented. In section four related works are discussed. And in section five we discussed about proposed work algorithms and mathematical model. In section six simulation results are analyzed and compared the performance of AODV AND FEEAODV. Finally conclusion presented in section SEVEN.

II. SIMULATION PARAMETERS, METRICS AND ENERGY CONSUMPTION MODEL

In our study, a series of extensive simulations based on NS-3 are carried out to examine the performance of an three existing classical MANETS routing protocols on FANETs environmnets and proposed new energy aware routing protocols based on AODV for FANETs. The proposed energy aware modified form of AODV protocols is implemented using C++ and TCL. Awk programming langauge is used to analyze the simulation results. For mobilty model we used random waypoint mobility model as its one of the widely used module in wireless ad hoc networks environments [4,5]. **Table 1** shows simulation parameters.

Table1. Simulation Parameters

No of nodes	10 to 40
Intial energy	60 to 200 joule
Maximum speed	30 m/sec
Minmum speed	10 m/sec
Bandwidth	2Mbs
Packet size	512 Bytes
Data traffic	CBR
Pause time	20 Sec
Simulation time	1500 sec
Node queue length	100 packet
Coverage area	5 km *5km
Tx power	1.65 watt
Rx power	1.45 watt
Trasmisison range	500 meter
TH	30 joules

The most important two condition that greately affects the performance of the FANETs networks are Mobilty and node density.This two condition are used to evauate the performance of the FANETs.In our evauation any one of this condition is fixed and while other one is varied during simulation **.**

Performance Metrics
New energy aware routing protocols performance are evaluated using the following performance metrics.

Packet Delivery Ratio
It is the ratio between total number of packets received and number of packets generated & transmitted.

Network Lifetime
The amount of time taken for the first node to deplete completely its energy.

Standard Deviation of Residual Energy of All Nodes
The energy differences among the nodes after the simulation time.

Network Delay
The avearge time taken by the packets to travels between source to destination .

Energy Consumption Model
With reference to IEEE 802.11 specification for WAVLAN , the current value of transmitting node & receiving nodes are 280 m A and 330 m A respectively using battery of 5 V with 2 Mbps data rates [3,4].

The total energy needed to transmit or receive a packet is :e = t_p *I*V (joules),

(t_p time needed to transmit or receive a single packet by a node I =curent ,V =voltage)

Packet transmission time $t_p = (phs/(2 * 10^{6}) + pps / (2 * 10^{6}))$sec,

Where ' phs' is the packet header size and 'pps' is packet payload size. (bits/sec)

The energy used by a node when a packet is transmitted (T_e) and received (R_e)can be calculated using the following equation .

$$T_e = (0.33*5*(phs+pps))/2*10^6 \quad (1)$$

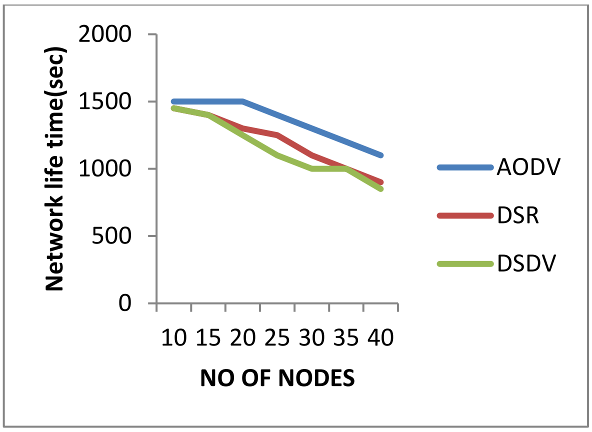
$$R_e = (0.28*5*(phs+pps))/2*10^6 \quad (2)$$

III. PERFORMANCE EVALUATION OF EXISTING MANET PROTOCOLS IN FANETS

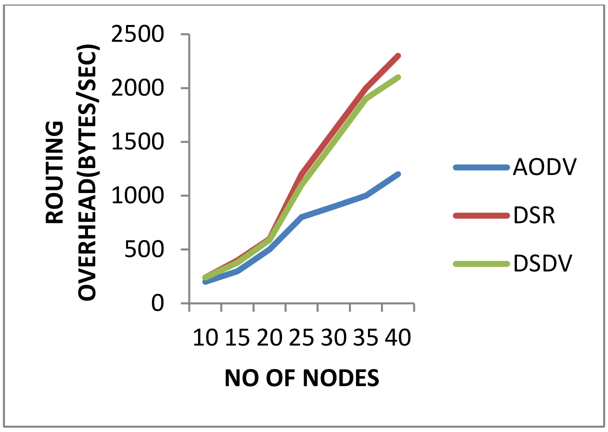
In this section we evaluate the relative performance AODV,DSDV and DSR protocols. It provides a answer to one of the research question "Which conventional routing protocol of MANETs is an energy efficient protocol in FANETs environments.And also it gives answers for the questions why we selected AODV protocols for our proposed implementation.

Performance Analysis of DSDV, AODV and Routing Protocols on FANET
We used the following metrics to evaluate the performance of DSDV,DSR and AODV.

1. Network life time
2. Routing overhead
3. Energy consumption
4. Packet delivery ratio.



(a)



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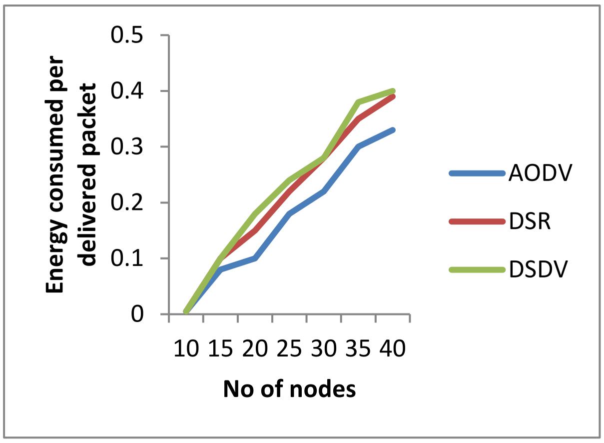

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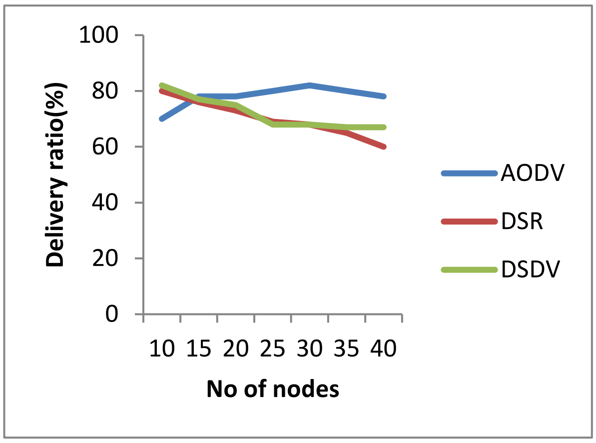

(d)

Fig 2. The Graph, (a) Network Lifetime Versus Number of Nodes, (b) Routing Overhead Versus Number of Nodes, (c) Energy Consumption Versus Number of Nodes, (d) Delivery Ratio Versus Number of Nodes.

Fig 2 (a) shows Network Lifetime Versus Number of Nodes, **Fig 2 (b)** shows Routing Overhead Versus Number of Nodes, **Fig 2 (c)** shows Energy Consumption Versus Number of Nodes and **Fig 2 (d)** shows Delivery Ratio Versus Number of Nodes.

Network Lifetime

Observing the graph we can say that when the number of UAV nodes increased the life time of network decreases for all three protocols. It is because of increasing routing overhead and control packets flow into the networks.Among this three protocols AODV can extend network operational time longer than DSR and DSDV**.**

Routing Packet Overhead

Amount of control packet and packet overhead flow in the network increases due to broadcasting nature of discovery packet in AODV and DSR & due to frequent Routing table update with the neighbou ring nodes in DSDV.By comparing the graph of the routing overhead versus node density,we can say that when the node density is below 20,there is no much significant differences among the protocols,but for higher node density, when no of nodes increases above 20 ,AODV performace is better than other two protocols.

Energy Consumption

Amount of energy consumed while routing packet mainely depends on size of each packets,amount of proceesing power needed at the intermediate node to process and and forward each packet ,total no of data and control packet generated by nodes etc.By looking at the graph we can say that energy consumed per delivered packet for AODV is very less compared to other two protocols**.**

Packet Delivery Ratio

Packet delivery ratio influenced by channel contention ,packet collisions rate ,node buffer overflow ,DLL link failure etc.Our simulation result indicates that AODV performance is much better than DSR and DSDV.This result because of high channel contention and packet collision rate in DSDV, due to frequent routing table updates with neighbours and in DSR more buffer overflow due to more processing time needed at the intermediate node.

Performance Result Summary

From the result of our performance evaluation, we conclude that AODV performance is moderately good ,compared to other two protocols for all tested metrics .Main reason for the poor performance is frequent node failure due to exhausted battery energy.So the network performane can be improved if we include energy related metrics ,while route discovery in AODV.Usage of energy related metrics in route discovery process, balances energy consumption among nodes which in turn increases the node life time and network running time.So in our next work we have presented new energy efficient routing techniques based on AODV for FANETs.

IV. RELATED WORK

In [10], Jin-Man Kim and Jong-Wook Jang proposed new routing algorithms based on AODV protocol to increase the life time of networks in MANETS using Mean energy value. In their work they modified RREQ field of AODV to adapt new field to collect remaining energy of each node in path. Finally, the mean energy of the network will be calculated by dividing sum of all energy level of each path to number of hops in path.

The authors in [11] proposed a new algorithm based on AODV called ALMEL-AODV, which uses node remaining energy level as a cost metric to increase the nodes lifetime in the network. ALMEL-AODV add extra field in RREQ which is used to store sum of the residual energy of each path. Finally the destination node selects two paths having greater residual value and sends the path details to source. Source will use the second path if the main path fails.

In [12], authors proposed new algorithm based on AODV called PS-AODV, which balance the nodes load in the network by avoiding the intermediate nodes occupied with more processing task. During path discovery the nodes forward the RREQ packet only if the load of the node is below some level otherwise RREQ discarded. Nodes load is calculated by the formula, the product of node usable energy and length of buffer queue.

The author in [13] proposed a new energy efficient AODV based algorithm called E2AODV which uses queue length as a cost metric to select the nodes for the required path. To decide node overloaded or not it uses threshold value which is adaptive, threshold value are calculated based on average nodes queue in the path. When a node receiving RREQ packet checks current queue length and compares it with current threshold value, if the value is less it forward otherwise it will drop RREQ packet.

In paper [14] the authors proposed a new AODV based routing algorithm called EBAODV, here the energy metric is predetermined energy value decided by source node. Source node send RREQ packet with the node energy required level, upon receiving the RREQ packet intermediate node compares the requested energy level with its current energy level, if they are equal or greater it will forward otherwise discard it.

V. PROPOSED WORK

In this work we proposed a new energy efficient routing algorithm based on AODV for FANETs. We used AODV as base protocols because of the result we obtained from our analysis in chapter 3. Our algorithm uses minimum node residual energy, sum of node residual energy and hop count as cost metric to find optimal energy efficient route. The original RREQ packet field of AODV is modified to include this metrics. Table 2 shows modified RREQ field.

Table 2. Modified RREQ Field

Type
Broadcast ID
Destination IP Address
Destination Sequence Number
Source IP Address
Source Sequence Number
Residual Energy Minimum (REM)
Total Residual Energy (TRE)

Mathematical Model of NRE-AODV

Let us assume a route $r_k = c_0, c_1, c_2, \ldots, c_d$, where c_0 source node and c_d destination node , 'h' hop count between source node and destination node a function $r(c_i)$ denotes the residual energy of node 'c_i 'then the Average Total Residual Energy (ATRE) and Average Residual Energy Minimum (AREM). for the route r_K is calculated as:

$$AREM\ (r_K) = \left(\min_{\forall C_i \in r_K} r(c_i)\right)/h \tag{3}$$

$$ATRE\ (r_K) = \left(\sum_{\forall c_i \in r_k} r(c_i)\right)/h \tag{4}$$

The algorithm finds optimal route O_R using the the following rule:

If (there are paths with the minimum node residual energy value (REM) greater or equal to the threshold (TH) value then

It selects a path having maximum of the difference of Average Total Residual Energy (ATRE) and threshold (TH) i.e.

$$O_R = \max_{r_k \in A}\left(\left(ATRE(r_k)\right) - TH\right) \tag{5}$$

Else

It selects a path having maximum of the difference of Average Residual Energy Minimum (AREM) and threshold (TH)

$$O_R = \max_{r_k \in A}\left(\left(AREM(r_k)\right) - TH\right) \quad (6)$$

Where ‘A’ is the set of all routes under consideration and ‘TH’ is a predefined energy threshold

Algorithm
Intermediate node algorithm

1. Checks the freshness of received RREQ using source id and broadcast id field
2. If it is new or duplicate with greater sequence number, then intermediate nodes updates REM, TRE field and rebroadcast RREQ.

REM=min (current intermediate node residual energy, REM of received)
TRE= (Current intermediate node residual energy + REM of received)
Else discard RREQ

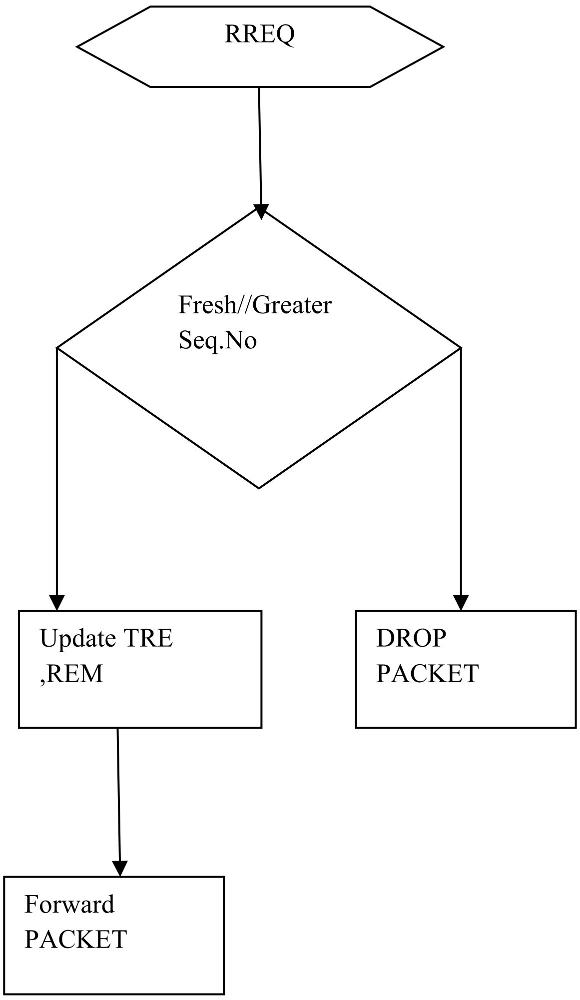

Fig 3. Flow Chart Intermediate Node.

Fig 3 shows the flow chart intermediate node.

Destination Node Algorithm

1. Checks received RREQ is first or duplicate using source id and broadcast id
2. If it is new calculates the O_R value and store it in table
3. If it is not new, it checks waiting time ‘w_t’
4. If ‘w_t’not expired, finds the O_R value and checks this value with the previously stored value,if it is greater or equal with smaller hop count , then it replace the new value or discards the new RREQ.
5. It will continue to execute the above steps until ‘w_t’ expires,
6. Once the waiting time expired, RREP packet will be send back to source via route which has maximum value of O_R.

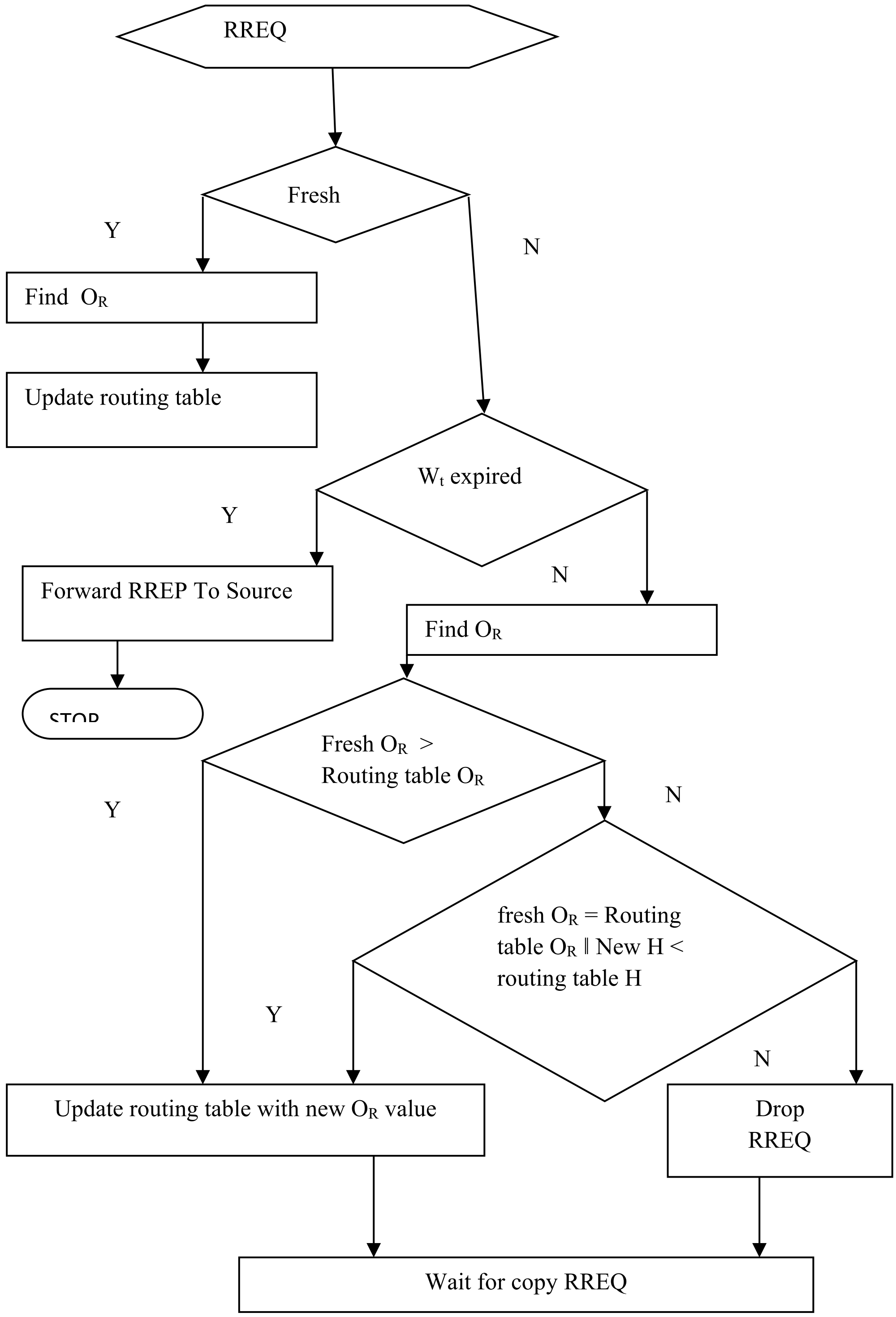

Fig 4. Flow Chart Destination Node.

Fig 4 shows the flow chart destination node.

Energy Threshold Selection

Energy threshold has a major impact on network performance, as lower value setting may result algorithm to include minimum energy node in the route, causes rapid energy exhaustion which in leads to frequent link breakage. Setting higher value threshold may leads to non optimal route selection, decreases the network performance .So selecting appropriate threshold value is very critical for performance optimization. To find the optimal threshold value we conducted simulation on our proposed algorithm to see the network lifetime and load distribution performance by varying 'TH' from 0 % value to 100 %.

Energy Threshold Versus Network Lifetime

The impact of the energy threshold on network lifetime of our proposed algorithm is shown in **Fig 5** from the result we can say that when threshold value increases ,network life time also increases, this is because alorithum avoids low energy nodes in the selected route.when the energy level reaches above 35 % it attains almost peak value ,after that further increase has very little variation on network life time.

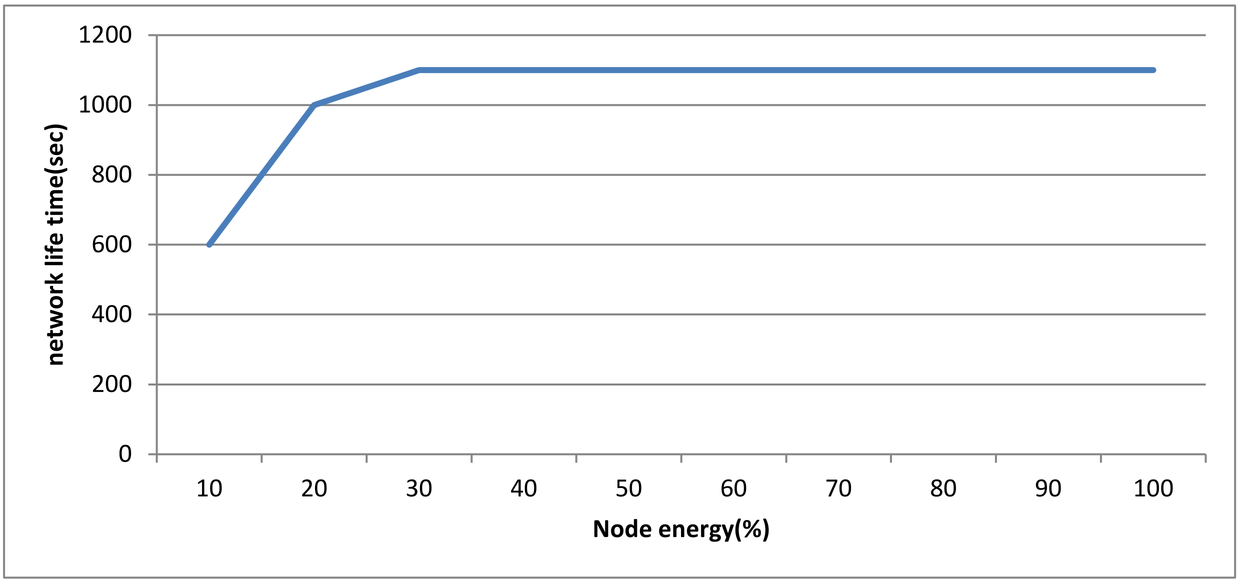

Fig 5. Energy Threshold Versus Network Lifetime.

Energy Threshold Versus Standard Deviation of Nodes Energy

The impact of the energy threshold on deviation of nodes energy level of our proposed algorithm is shown in **Fig 6** .From the result we can say that when threshold value increases from 0% to 30 % standard deviation of nodes energy decreases ,at 30% it reaches minimum value.When we increase 'TH' above 30 % deviation of nodes energy also increases.So we can conclude that at 30% 'TH' , nodes energy difference is minumum ice, nodes energy consumption is balanced.

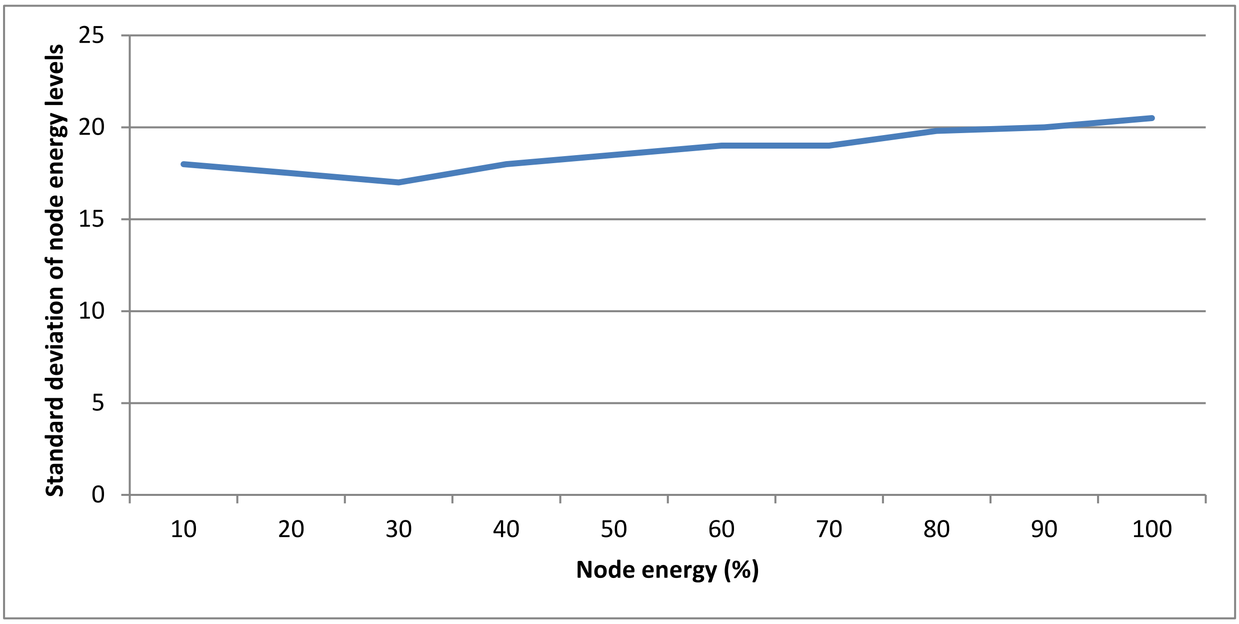

Fig 6. Energy Threshold Versus Standard Deviation of Nodes Energy.

VI. PERFORMANCE EVALUATION

In order to evaluate the performance of the EEAODV the classical AODV protocol in NS-3simulator has been modified to include the functionality of EEAODV routing algorithms. The simulation results of FEEAODV is compared with Ad hoc Distance Vector(AODV).The node mobilty speed is maintained constant(30 m/sec),while node density is varied from 10 to 40.

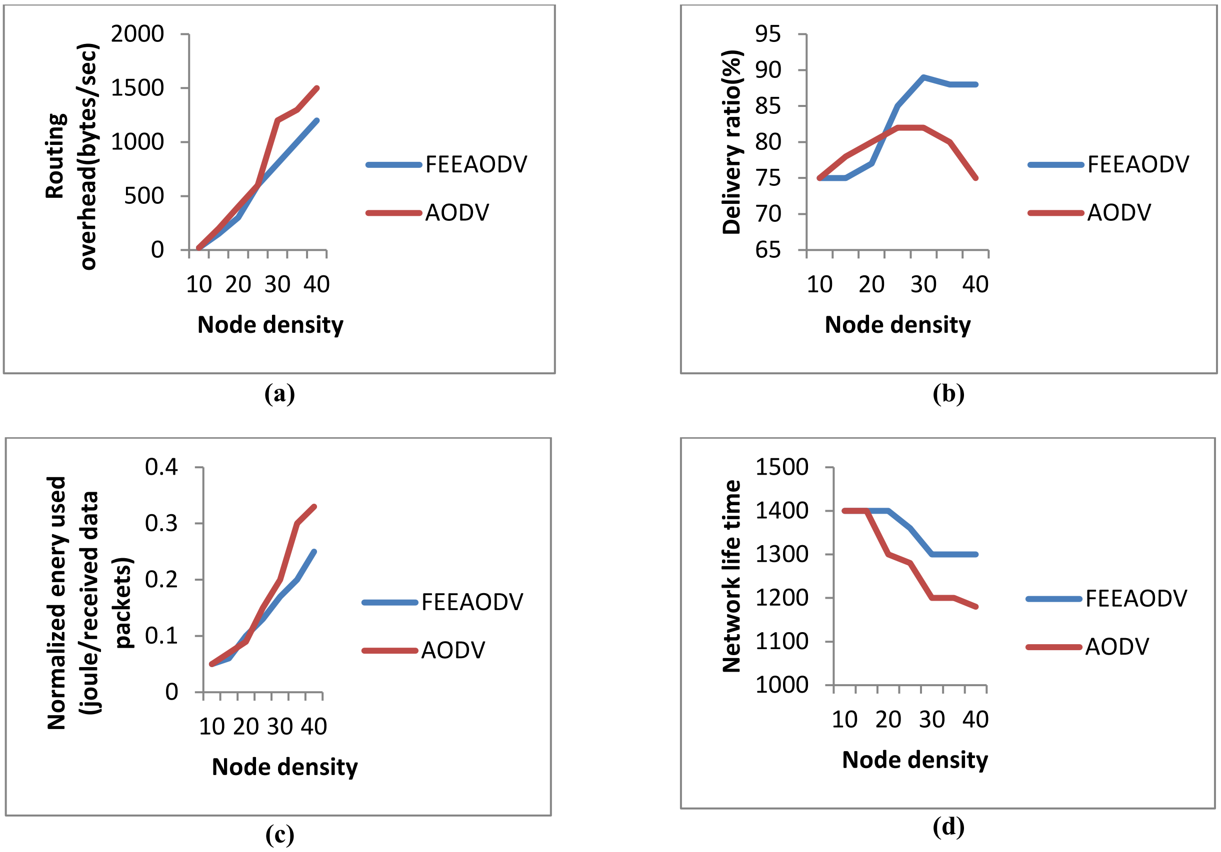

Fig 7. Network Density Impact on Performance, (a) Routing overhead (bytes per second), (b) Delivery ratio(%), (c) Normalized energy consumption (joule received packets), (d) Network life time(sec).

Simulation performance analysis conducted in terms of normalized routing overhead **Fig 7 (a)**,packet delivery ratio **Fig 7 (b)**, normalized energy consumption **Fig 7 (c)**, network lifetime **Fig 7 (d)**.Based on our simulation reusult we can conclude that the new modified AODV routing protocols EEAODV perform better that than classical AODV in FANETs environments for the considered performance metrics.

VII. CONCLUSION

In this research we proposed a new energy aware FANET routing prorocols that includes Residual Energy Minimum (REM), Total Residual Energy (TRE),Hop count as a routing cost metric.This metrics are used to find the energy effiecient path that provides maximum network time ,balances the energy consumption among the UAV nodes and uniformly share the loads among the UAV nodes.

In NS-3 the classical AODV discovery packet(RREQ)has been modified to includes the additional field required in EEAODV.Simulation is conducted on EEAODV protocols and the performance output interms of network life time,delivery ratio,routing overhead and energy consumption have been compared with the AODV.Analysis result indicates that our new EEAODV achives better performance than AODV.One of the major draw back of EEAODV is still uses same floodings techniques of AODV for path discovery process which consumes more energy during path discvery process.we intent to address this uses in our next work.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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Competing Interests
There are no competing interests.

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