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EEGW: AN ENERGY-EFFICIENT GREY WOLF ROUTING PROTOCOL FOR FANETS

Shahzad Hameed[1], Qurratul-Ain Minhas[2], Sheeraz Ahmed[3], Asif Nawaz[4] Asim Ali[5], Ubaid Ullah[6]

[1,2] Quaid-i-Azam University, Islamabad, Pakistan

[3]Iqra National University, Peshawar, Pakistan

[4]Higher College of Technology, Dubai, UAE

[5,6]BRAINS Institute, Peshawar, Pakistan

Corresponding Author: **Dr. Sheeraz Ahmed**

Email: sheeraz.ahmad@inu.edu.pk

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Abstract

Unmanned Aerial Vehicles (UAVs) or flying drones are employing to retrieve data from their respective sources and help to accomplish Flying Ad hoc Networks (FANETs). These wireless networks deal with challenges and difficulties such as power consumption, packet losses, and weak links between the nodes. This is due to the high mobility of nodes, frequent network partitioning, and uncertain flying movement of the flying drones. Consequently, reduce the reliability of data delivery. Moreover, unbalanced energy consumption results in an earlier failure of flying drone and accelerate the decrease of network life. The performance of FANETs depends on the capabilities of the energy consumption of each flying drone. They are expected to live for a longer period to manage the cost overhead. Energy-efficient routing is an important factor that helps in improving the lifetime of FANETs. In this research, we propose an Energy-Efficient Grey Wolf (EEGW) routing protocol for FANETs. This protocol is comprised of Grey Wolf Optimizer (GWO) inspired by the leadership hierarchy of grey wolves. It helps in minimizing the energy consumption, packet loss ratio, and aerial transmission loss incurred during transmission.

Keywords : Energy efficient, Flying drones, Routing protocol, Grey wolf algorithm

I. Introduction

The degree of FANETs is different as compared to traditional ad hoc networks such as MANETs and VANETs. This is due to the high speed of nodes, dynamicity of network topology, and scarce spectrum of FANETs. Flying nodes are capable to assist wireless communication in the air. FANETs provide communication between nodes particularly flying drones with Base Station (BS) [VII]. They are deployed in dire contexts to establish communication. Link disconnections and route breakage have been observed during flight missions due to frequent network partitioning. In addition, flying nodes consume high energy as compared to slow-moving vehicles. They have usually equipped with limited energy of batteries [XIV]. Nodes of FANETs act as a wireless relay to extend coverage for wirelessly connected ground devices. Further, the movements of the node are usually set to fly, yet these can be updated according to the flying mission or environmental situation. FANETs achieved progressive improvement in technological advancement. The operation of flying nodes is highly optimized and dedicated for different applications. The mobility of nodes in FANETs is higher than MANETs and VANETs. Thus mobility schemes for traditional ad hoc networks are not appropriate for FANETs.

There are some useful on-demand routing schemes used for MANETs, VANETs, and FANETs such as ad hoc on-demand distance vector (AODV) [XII], time-slotted ad hoc on-demand distance vector [VI], modified- ad hoc on-demand distance vector [III], and Dynamic Source Routing (DSR) [XV]. These schemes considered different mobility models for UAVs movements and proposed for the discovery of optimal routes and different constraints of FANETs. However, each scheme can use for a particular application or condition.

Our proposed research helps to employ the mobility information where the energy level of each node guarantees the communication strength whereas calculating a sudden link breakage before its occurrence. FANET energy efficient AODV routing protocol for flying ad hoc networks (FEEAODV) [IX] is a recent development in the research area which analyzed the energy challenges. However, search and rescue operation has been affecting due to technology. Hence FANETs make this possible in a short time. Usually, the multi-UAV setup has important applications in agriculture especially crop monitoring [VI] and in general public scenarios [XIII]. It helps the people to get achievement in human protection and crowd surveillance. Figure 1 depicts the possible applications of FANETs.

Fig. 1. Applications of FANETs

In article [IV], a store-carry-forward approach is adopted for multi-UAVs with high mobility approach. This approach is used to record the images and videos from the post-disaster area and transfer them to BS. To maximize the sum rate of uplinks, a multi-UAV allocates sub-channels for UAV-to-X communication [XX].

In [XVI], multi-UAVs have been deployed to form a rapid network to recover communication in a disaster area. They consist of the flexible aerial node. To realize the energy, communication, and security requirements of 5G [X], UAVs have been embedded with solar panels. They have been together with a solar-powered charging station. They have been deployed to overcome energy constraints. Moreover, to reduce energy consumption, Euclidean distance-based analysis is performed in [VIII]. This research computes the distance which is used to regulate the transmission power for hello messages. This requirement enhances the network performance such as throughput and packet delivery ratio. This research also considered the aim of minimizing energy consumption. In these researches, all tools have been used to identify the flight of nodes over an operational area. However, all are dependent on different factors such as GPS for the actual position of the node. Different biological inspired techniques have been investigated for FANET however there is no universal solution that can take place for routing and energy in a highly dynamic topology network [II].

To overcome the energy and routing challenges, the leadership hierarchy of grey wolves is investigated in this research for FANETs. An EEGW routing protocol ensures connectivity among the flying nodes. This is also suitable for other wireless applications. This research comes into the inspiration of social behavior and leadership hierarchy of grey wolves. The hunting mechanism of grey wolves is also an important factor for routing analysis of FANETs. There are four types of grey wolf namely alpha, beta, delta, and omega. They are engaged in simulating the social leadership hierarchy. Moreover, three are three steps for hunting the prey such as searching for prey, encircling the prey, and attacking prey. This paper analyzed the best route using biological-inspired GWO [XI]. This research contributes to the distance, energy, and link behavior for FANET`s routing.

The routing of FANETs defines a set of regulations to transfer the data from the source node to the destination node. Above mentioned articles have been used to achieve the results according to the specific mission. However, to the best of our knowledge, the social hierarchy of grey wolves using GWO is still there to investigate for FANETs routing.

II. The Grey Wolf Algorithm

Grey wolves are live in a pack. The size of the pack is usually 5~12 grey wolves. They have a strong social-dominant hierarchy. The leader of the grey wolves is called Alpha(α). Orders of the alpha (α) are dictated to the entire pack. He is responsible for making decisions regarding hunting, sleeping place, time to wake etc. He may not be a strong member however the best in terms of managing the pack. They may be male or female in the wolves and they are also called dominant wolves.

Beta (β) is a second position of the grey wolf hierarchy. They help alpha in many actions. They are also called subordinate wolves. They may also be male or female in gender. If alpha wolves die or become aged, they are suitable wolves for alpha. They order the lower level wolves however should regard the alpha. They are the advisor to the alpha and discipliner for the pack.

Delta (δ) is the third position in the grey wolf hierarchy. They have been categorized in different fields such as scouts, sentinels, elders, hunters, and caretakers are the family of the delta.

Finally, omega (ω) is the lowest level grey wolf in the entire pack. They are responsible to submit to all the other dominant wolves. They play the role of scapegoats and are allowed to eat lastly after hunting. Contributions of omega wolves support to complete the pack and maintain the dominant structure. The social leader hierarchy of grey wolves is shown in figure 2.

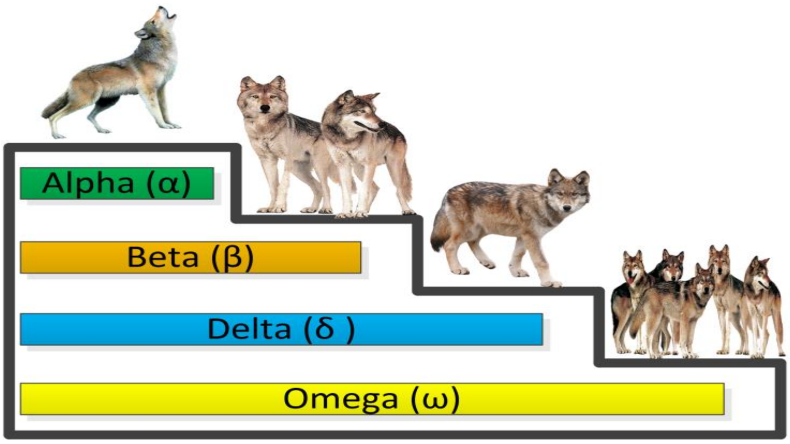

Fig. 2. Leadership Hierarchy of GWO

Mathematically modeling for the social leadership hierarchy and hunting behavior of grey wolves is discussed in this section. Alpha (α) is assumed the best solution while beta (β) and delta (δ) are assumed the second and third-best solutions respectively. The rest of the searching candidates have assumed omega (ω). Consequently, hunting prey is directed by `$\alpha$` where `$\beta$`, `$\delta$` support the leader whereas `$\omega$` wolves follow the first three wolves. During the hunting process, grey wolves encircle the prey and can be modeled using Eqs (1) and (2). This helps to update the position of grey wolves from the current position to the new position [XI].

$$\vec{D} = \left|\vec{C}\vec{X}_p(t) - \vec{X}(t)\right| \tag{1}$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A}\vec{D} \tag{2}$$

Where $\vec{X}_p$ is a position vector of prey whereas $\vec{X}$ is a position vector of the grey wolf. $\vec{A}$ and $\vec{C}$ are coefficient vectors while \`$t$\` and \`$t+1$\` show the current and next time step for the individual respectively.

The vectors $\vec{A}$ and $\vec{C}$ are calculated as [XI]:

$$\vec{A} = 2\vec{a}.\vec{r}_1 - \vec{a} \tag{3}$$

$$\vec{C} = 2\vec{r}_2 \tag{4}$$

Where $\vec{r}_1, \vec{r}_2$random vectors [0, 1] and components of are $\vec{a}$ are linearly decreased from 2 to 0 during iterations.

Grey wolves can identify the location of prey for hunting. However, searching, encircling, and attacking are the three major steps of grey wolves for hunting. The leader alpha is responsible to lead the hunt. Beta and delta can also contribute to the hunting process. To the mathematical model and simulate these steps, we assume that alpha is the first best solution while beta and delta have better knowledge about the location of prey. The obtained three best solutions are stored and updated for the next time step. Alpha, beta, and delta approximate the location of the prey while the rest of the wolves randomly update their positions according to the movement of the prey. These actions are performed with the help of the following equations [XI].

$$\begin{cases} \vec{D}_\alpha = \left|\vec{C}_1\vec{X}_\alpha - \vec{X}\right| \\ \vec{D}_\beta = \left|\vec{C}_2\vec{X}_\beta - \vec{X}\right| \\ \vec{D}_\delta = \left|\vec{C}_3\vec{X}_\delta - \vec{X}\right| \end{cases} \tag{5}$$

$$\begin{cases} \vec{X}_1 = \vec{X}_\alpha - \vec{A}_1\,\vec{D}_\alpha \\ \vec{X}_2 = \vec{X}_\beta - \vec{A}_2\,\vec{D}_\beta \\ \vec{X}_3 = \vec{X}_\delta - \vec{A}_3\,\vec{D}_\delta \end{cases} \tag{6}$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \tag{7}$$

We are assuming that nodes of the network are scattered and fly at a fixed altitude(H). Since all nodes know the location of the destination as well as their location. Consider that $z(t)$ shows the trajectory on the horizontal plane and can be written as $z(t) = [x(t), y(t)]^T \in R^{2\times1}$, where $0 \le t \le T$. Time-varying distance from a node to destination is expressed as [XVIII]:

$$d(t) = \sqrt{H^2 + \|z(t)\|^2}, \ \ 0 \leq t \leq T \tag{8}$$

The network is initialized with the random deployment of the flying nodes and they have better knowledge about their neighbors. This is assumed to obtain various tasks such as the location of relays, location of the destination, and different routes to the destination. However, each node can broadcast an information packet that contains the ID of the node, location of the node, and residual energy of each node. These nodes update their positions as per neighboring sites. Hence, the cost function for each node is mathematically calculated as:

$$\rho = \frac{\max(\mu_{S,R_1}, \mu_{S,R_2}, \mu_{S,D}) + \max(R.E_{R_1}, R.E_{R_2}, R.E_D)}{\min\left(|d_{S,R_1}|^2, |d_{S,R_2}|^2, |d_{S,D}|^2\right)} \tag{9}$$

Where μ_{S,R_1}, μ_{S,R_2} , $\mu_{S,D}$ are the Signal-to-Noise Ratio (SNR) of the links i.e. from $S \rightarrow R_1$, $S \rightarrow R_2$ and $S \rightarrow D$ respectively. The residual energy $R.E_{R_1}, R.E_{R_2}, R.E_D$ are the energy of R_1, R_2 and R_D respectively. Moreover, distance d_{S,R_1}, d_{S,R_2} and $d_{S,D}$ from the source node to relays and destination respectively.

Figure 3 shows the block diagram of the EEGW routing protocol for FANETs. The routing complexity of FANETs can be overcome by considering biologically inspired behaviors of grey wolves. At first, the network is initialized which includes random deployment of the nodes, equal transmission range for each node, and mobility of the nodes using GWO. Source node broadcasts an information packet using GWO and waits until all the packets are received from other nodes. The retrieve signal computes the residual energy and position of nodes that exist within the communication range of the source node. If there is no best solution found in the received signal, this signal will send again by the source node. Nodes are flying randomly and calculate the same for the next best solution. However, if it found the best candidate solution, it will update the new best solution and broadcast the leading message to the entire network. Now source node can rank the nodes with help of retrieved information. This will update the stored information and grade the best nodes by 1st, 2nd and 3rd best.

The source node is now able to set for the best position move. The mobility of the node has been examined and control by using the GWO algorithm and this concept provides the solution for locating the best node in flying environments. This can help to replace the best node with a source node where the destination is one hop away from the source node. This is the leading position for the source where it can conserve energy and provide the best route for the rest of the nodes. The best transfer of the packet is subject to the shortest distance and high residual energy of the node.

Hence, opting for the hierarchy of grey wolves can overcome the energy problem in a highly dynamic network. Every node has a balance residual energy for network completion. Now unnecessary packet forwarding and route discovery cannot take place in EEGW and this is achieved by the inspiration of the social hierarchy of the grey wolf algorithm.

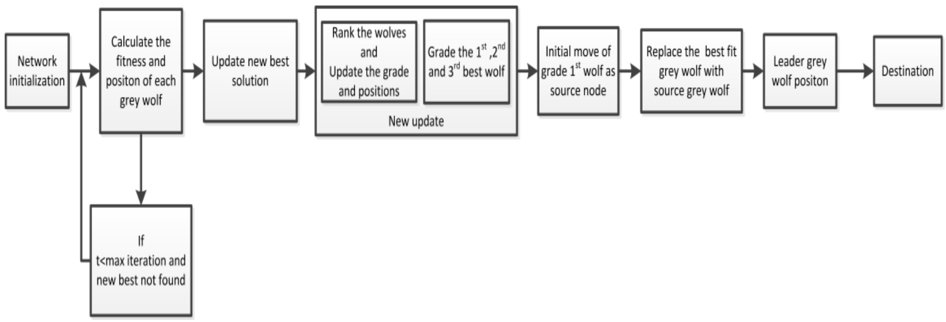

Fig. 3. Block diagram of EEGW methodology

III. Characteristics of Energy Efficient Grey Wolf Routing Protocol

Characteristics of EEGW routing protocols are shown in figure 4. To differentiate the flying nodes, they are categorized in terms of energy and positioning using the leadership hierarchy of grey wolves. They are termed alpha, beta, delta, and omega in terms of battery health. These are ranked as 1st leading node, 2nd leading node, 3rd and 4th leading nodes respectively. They have been ranked by mean of residual energy and distance to the destination. The leadership hierarchy of the grey wolves brings the first three best candidate solutions for the entire network which helps to balance the energy distribution and route selection. Nodes are differentiated by level of residual energy to accomplish the flight operation.

It is difficult to handle the dynamic topology network where the mobility of nodes is high. There is a need to handle the flight of nodes to reduce the packet drop and losses during transmission. The leadership hierarchy of grey wolves provides an easy replacement in case of node failure. They have better knowledge about neighboring nodes which may prolong the lifetime of the network. EEGW routing protocol is suitable for wireless connected networks. Energy and routing are the major interest of FANETs implementation. Once the dynamic topology networks are balanced by the level of energy and position of the node, they are helpful to meet the challenges of FANETs. Grey wolf algorithm overcomes the issues of energy and unnecessary route discovery for FANETs. Hence, balancing the energy and best route from source to destination is achieved in EEGW routing protocol.

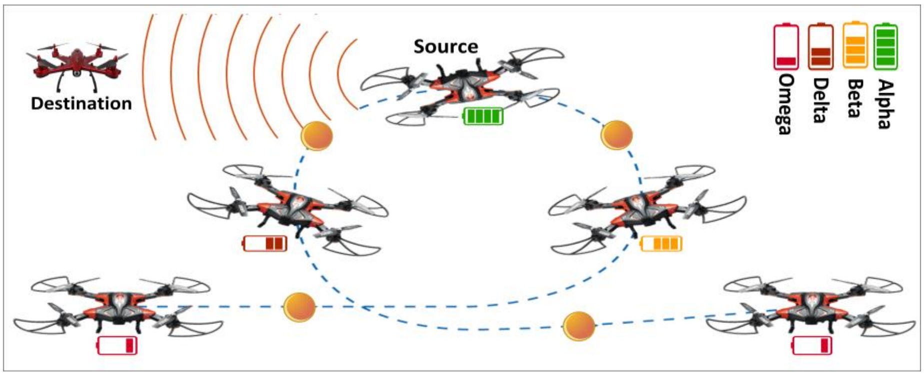

Fig. 4. Characteristics of Energy Efficient Routing Protocol for FANETs

IV. Simulation and Results

The performance of the EEGW routing protocol is compared with the BAT-FANET routing protocol. This is compared by increasing the equal number of rounds. BAT-FANET and EEGW protocols have been distinguished by biologically inspired BAT algorithm and GWO respectively. These protocols are simulated on the computations. They have been considered for successive packet forwarding. An EEGW routing protocol ensures a minimum rate of retransmission of packets, particularly when uses GWO. Simulations run in a round where optimal values of the respective protocols have been saved and updated during iterations. In every round, active nodes transmitted the desired information to the energy-efficient nodes for packet forwarding. This can help the nodes to retain the updated data for the next iteration. This is crucial to handle the dynamic topology network information appropriately, however, this is achieved in EEGW routing protocol. Network simulation parameters are shown in table 1.

Table 1: Simulation Parameters

Parameters	Values
Volume of Network	500m^3
Number of Nodes	120
Energy of Node	0.07 joules
Node Flight	Random
Total Number of rounds	3500
Maximum Transmission Range	350m
Type of Channel	Wireless channel
Type of Antenna	Omni antenna

Figure 5, shows the performance of energy consumption of EEGW and BAT-FANET protocols. A significant reduction of energy consumption is achieved by EEGW as compared to BAT-FANET routing protocol. This is due to considering the social hierarchy of grey wolves for energy balancing. Every node is responsible to cooperate with neighboring nodes for accomplishing the packet forwarding. Hence, due to adopting the social disciplinary hierarchy of grey wolf, EEGW can preserve better energy than BAT-FANET. This efficiency not only uses to solve the computational issues of FANETs but can also be beneficial in real-time application scenarios.

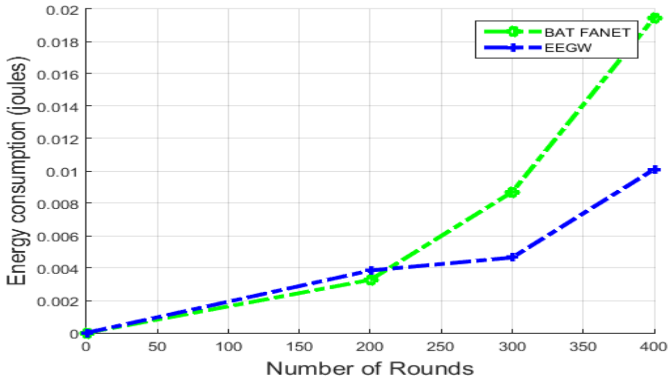

Fig. 5. Energy Consumption (joules) vs Number of Rounds

Figure 6, shows the comparison of EEGW and BAT-FANET in terms of packet loss ratio. Improvement in the reduction of packet loss ratio is an effective achievement when dealing in with a highly dynamic topology network. This is due to the choice of best candidate selection and their positions. To reduce the packet delivery ratio, the following assumptions have been taken as the first three leading nodes, minimum forwarding distance between nodes, the residual energy level of each node, and successive packet delivery ratio. Thus, packets in the EEGW protocol are reached to the sink with a lower delay as compared to the BAT-FANET.

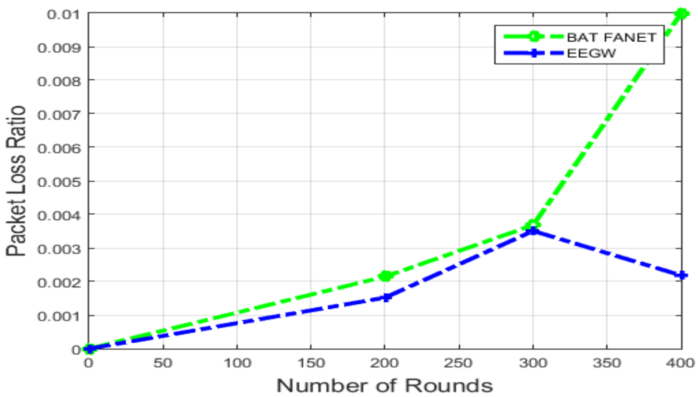

Fig. 6. Packets Loss Ratio vs Number of Rounds

Figure 7, presents the comparison of EEGW routing protocol and BAT-FANET routing protocol in terms of aerial transmission loss. Although both the protocols comply with biologically inspired algorithms, the resulting plots show the significant reduction of aerial transmission loss due to the strategy of the grey wolf leadership hierarchy. As far as round increases, EEGW protocol improves the reduction of aerial transmission loss. EEGW protocol considers the minimum distances of the packet forwarding between the nodes in sparse as well as dense networks. Hence lower aerial transmission loss is achieved in EEGW as compare to BAT-FANET.

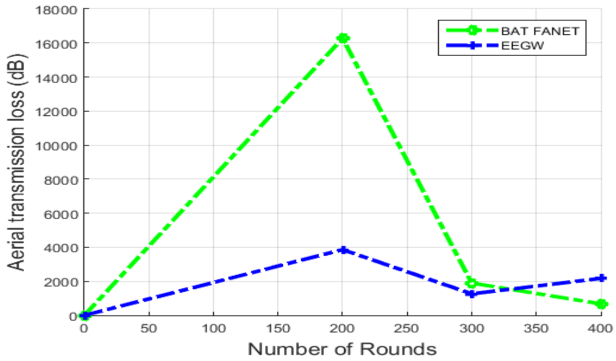

Fig. 7. Aerial Transmission Loss (dB) vs Number of Rounds

V. Conclusion

In this research, an energy-efficient grey wolf (EEGW) routing protocol is presented for FANETs. Energy-efficient routing is an important factor that helps in improving the lifetime of FANETs. This protocol is based on the biologically inspired technique of GWO. It helps in minimizing the energy consumption, packet loss ratio, and aerial transmission loss incurred during a transmission. The inspiration of the social hierarchy of grey wolf is taken into consideration because there are only a few protocols focused on naturally inspired behaviors of species. EEGW and BAT-FANET protocols are differentiated by the algorithms of GWO and BAT respectively. EEGW routing protocol achieved lower energy consumption, lower aerial transmission loss, and lower packet loss ratio as compared to BAT-FANET routing protocol.

Conflicts of Interest:

There is no conflict of interest regarding this article

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