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Link and Loss Aware GW-COOP Routing Protocol for FANETs

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ABSTRACT The dynamic network topology of Flying Ad hoc Networks (FANETs) leads to challenges during communications. This becomes complicated when dealing with multiple transmission paths and relays. Conventional routing protocols proposed fail to address the dynamic issues inherent in FANETs. This work addresses it by diversifying the selection of relay in order to establish the significance of cooperative diversity technique. Inspiration is taken from bio inspired computing which assists in finding solutions to several challenging tasks. The natural behavior of the different species leads to elevated design concepts of protocols. This paper proposes GW-COOP (Gray Wolf Algorithm using Cooperative Diversity Technique) routing protocol for FANETs. This protocol consists of Gray Wolf Optimizer (GWO) that drives gray wolves' social hierarchy and collaboration technique. First, we opt the design implementation of gray wolves natural posture GWO to handle flying node requirements. Second, we envision the idea of cooperative diversity using two relays to sustain either of the source-to-destination links. The design of protocol is novel in that previously such cooperation techniques are not employed in FANETs. Moreover, the concept of two relays with bio inspired algorithm is first time proposed here. In order to establish the performance of the GW-COOP protocol, this paper compares GW-COOP with two different protocols BAT-COOP (Bat Algorithm using Cooperative Diversity Technique) and BAT-FANETs protocols. The simulation results show that the GW-COOP protocol outperforms BAT-COOP protocol in terms of transmission loss, energy consumption, link delay and packet loss ratio. The results indicate improved GW-COOP performance over BAT-FANET and BAT-COOP. Approximately 67% and 52% reduction is observed in transmission losses compared to BAT-FANET and BAT-COOP respectively. Moreover, a decrease of 61% and 54% in terms of energy consumption, 24% and 9% in terms of link delay, and 58% and 48% reduction in terms of packet loss ratio, is also observed.

INDEX TERMS FANETs, cooperative diversity, routing protocol, gray wolf optimization, bio-inspired protocol.

I. INTRODUCTION

Unmanned Aerial Vehicle (UAV) is an unmanned aircraft autonomously navigated or remotely piloted without human control. The degree of mobility of drones (UAVs) in 3-D space is an important characteristic of dynamic topology networks. Naturally, they are deployed with mobility dimensions, often in the short term and rarely in a long-term. It is not simple as traditional ad hoc networks due to the high speed of nodes and frequent topology changes. Unmanned Aerial Systems (UAS) are expected to be the future of air transportation. They are deployed efficiently to perform the required tasks in a highly dynamic and cost-effective manner. UAVs or drones are usually equipped with batteries with flying times ranging

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from 30min to 55 min in addition to being limited in power and may cover large areas for communications [1].

UAV deployment is applied in various military operations, commercial activities and civilian applications [2]. FANETs can facilitate networking on demand due to lower network traffic and provide connectivity, especially UAVs with the Base Station (BS) [3]. As a result, BS can manage the data and issue alert messages in case a trouble or an incident is discovered [4]. Thus FANETs cannot only improve coverage area but assist in rescue operations. Multiple networks of drones have the ability to monitor the crop in agriculture [5], automated surveillance in the field [6], and various public venues [7]. However, the reliable connections and power limitations of these small devices are major challenges to investigate.

FANET spectrum is scarce and is usually deployed in difficult scenarios. They may assist in eliminating or timely detection of the risks of endangering human lives in disaster situations. It can be easily established under metrological conditions and develop highly automated aerial platforms. FANETs may be employed to carry equipment in the ionosphere for a specified period of time. The latest technology features of FANETs lead to lower cost compared to other dedicated networks. At present, FANETs have wide applications such as air surveillance for industrial facility inspection and mapping. Besides, FANETs are often used for non-trivial tasks, such as monitoring wild animals in their natural habitat, studying volcanoes or glaciers, search and rescue operations, etc. Fig. 1 depicts a general architecture for FANET connections.

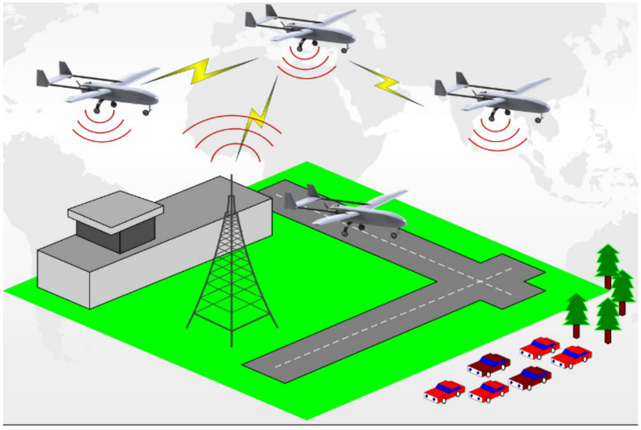

FIGURE 1. **General architecture for FANETs connections.**

FANETs technology is capable enough to carry different sensors. The drones act like radio relay providing coverage for wirelessly connected ground devices. It is currently undergoing pioneering progressive improvement in terms of functionality and customization for different applications. Repetitive diffusion is commonly found in unconstrained localization where conventional solutions do not guarantee connectivity. FANETs provide communication among UAVs to support various short-term applications [8]. The intrinsic ability of LoS (Line of Sight) communication can facilitate the use of high frequency and are attractive for its inexpensive high-speed deployment and a very effective complement to traditional ad hoc networks. It is investigated in practice for the detection and geolocation [9], Temporary Flight Restrictions (TFR's) and efficient prediction of forest fire [10] by ensuring secure trajectories for military [11].

All tools are used to identify and control drone flight over a specific area. It depends on determining factors employing the Global Positioning System (GPS) of the drone. Further analysis is performed to improve the navigation models, and thus the flight paths of the UAVs and the navigation characteristics follow the real-life scenarios in FANETs [12]. An additional complex issue is that the presence of FANETs is closely related to the energy limitations imposed by weight, size and power consumption of UAVs [13]. High speed, uncertain traffic and power restrictions are the main issues for FANETs.

Biological inspired algorithms require attention to tackle routing challenges. Gray wolves' leadership hierarchy of cooperative diversity overcomes the FANETs routing limitations. No scientific procedures are conducted to use the objective of maintaining high performance cooperation with FANETs. However, the enhanced iBAT-COOP routing protocol [14] is a recent development in routing of FANETs that opt for cooperative diversity. This technique can also be useful when implementing the disciplinary flying such as reaching the Gray Wolves' hierarchy. Our proposed work allows for routing in ad hoc networks as well as other wireless development technologies. GW-COOP protocol ensures reliable communication between sparsely connected nodes. This inspires the leadership hierarchy and hunting mechanism of Gray wolves. Alpha, beta, delta and omega are Gray Wolves' species that are employed for simulating a hierarchy of driving while searching, encircling and attacking of prey are the main steps of hunting. This paper envisages a cooperation technique for the best possible routes based on energy, relay positioning and distance to target. This protocol also takes into account Signal to Noise Ratio (SNR) and link condition to an effective level of handling FANET routing.

II. LITERATURE REVIEW

In [15], unstable link connectivity and frequent network segmentation of FANETs routing have been investigated. Although link connections have been made to route FANET, it degrades the network performance due to unnecessary routes finding and maintenance to regenerate the routes. Consequently, it cannot be accepted into critical mission of FANETs such as rescue operations [16] and disaster relief [17]. In order to reduce the effect of frequent link disconnections and improve routing, these studies focused on highly dynamic network topology at high cost. To meet these challenges, there is a great need to improve network connectivity which helps achieve QoS performance. It has been ensured that disconnections and network sections were minimized while anticipating the next geolocation of the UAV which was used to maintain the path or to define intermediate nodes for the route.

Route performance of a flying network has been analyzed in [18] and [19] wherein UAVs are at high altitude and low altitudes have been investigated in [20]. In order to improve a trajectory performance, high altitude UAVs can provide large coverage and improve communication between the nodes while low-altitude platforms provide limited coverage which improves local communication between nodes. This paper observed that UAVs could collaborate with high and low altitude platforms. Multiple UAV networks include a large number of data packets, generated by a wide range of different drone messages, called ultra-densification set-up. In this analysis, the challenges of a collective approach of low- and high-altitude UAV flight are not investigated.

In [21], authors evaluated an indoor and outdoor ambient factor of the multiple UAVs network. This can help to find the geographic location and locate fuel for drones in a network with long routes. In these articles, significance of relay nodes and challenge of UAV after replacement has been ignored. The unstable location of the UAVs consume considerable amount of energy, which causes packet loss and network overhead. In article [22], authors proposed a framework for UAVs to BS communication where all UAVs are directly connected to various ground BSs. In this research, one or more than one BS can communicate with each UAV simultaneously. This type of network includes various advantages such as improved fault tolerance capability in event of drone failure, management of parallel missions and development of computation and storage capabilities. However, communication between drones is not possible in this framework because all the data is routed through BSs. Consequently this can cause high latency. Due to the centralized structure of network, it requires more bandwidth which leads to expensive cost because each UAV gets a dedicated bandwidth. Hence, the total bandwidth is expected to reach the proportionality scale as the number of drone increases. Although some on-demand routing schemes such as custom distance vector (AODV) [23], time-slotted AODV [24], modified-AODV [25] and dynamic source routing (DSR) [26] are used in MANETs and VANETs, there is a different mobility model for FANETs. These schemes have been proposed to discover the optimal route in an uncertain network topology model. They are able to adapt to the various limitations that can happen in FANETs. However each technique can only be used in a specific application or situation.

The authors in [27] investigated the channel capacity while the drones' collision rate has been studied in [28]. Demand for high channel requires high channel capacity. These challenges are further investigated for routing in different mobility structures with different social behaviors of swarms such as swarms of bees, ants, school of fish and pack of wolves. Social behavior of Grey Wolf has not been estimated for its high dynamic mobility network. There are different biologically inspired hybrid routing schemes such as ant colony optimization [29], moth flame optimization [30], [31] and grey wolf optimization [32], [33] for low mobility ad hoc networks. However these research works are intended to consider the significance of cooperative diversity technique.

FANET's cooperative routing design involves a set of rules and mechanisms that defines to transfer information from source to destination. The aforementioned researches have used to accomplish the task according to application. However, to our knowledge, no convincing research has been found which is absolutely determined what research can be superlative and should attempt to be declared universal solution for FANETs routing. Hence a disciplinary hierarchy of gray wolves is implemented to deal with the uncertain mobility of FANETs. In addition, the relay and relay selection has been diversified plan to see the significance of cooperative diversity technique that can reduce the packet losses and the link delay that can enhance network performance.

III. GRAY WOLF OPTIMIZER (GWO)

This section details the leadership hierarchy of grey wolves, cooperative diversity, system model and flow chart for GW-COOP routing protocol.

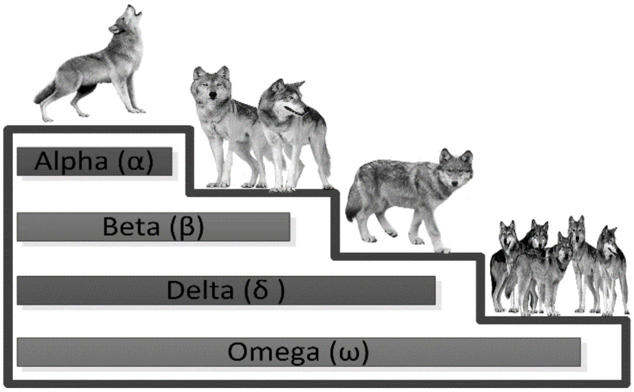

FIGURE 2. Leadership hierarchy of gray wolf optimization.

A. LEADERSHIP HIERARCHY OF GREY WOLF OPTIMIZATION

The primitive ability of the gray wolf is to distinguish between wolves at first and then choose alpha wolf who is responsible for leading the hunt. However at some point the beta wolf and delta wolf may contribute to hunting. Gray wolves often search according to their alpha, beta and delta position. They are the three best solutions in the entire pack as shown in Fig. 2. These ranks are chosen according to the suitability and location of each gray wolf of prey. These better solutions lead the pack to hunt prey. The movement of each grey wolf is stored in the course of iteration for the next possible position. This social hierarchy is concerned with employing collaborative diversity in the GW-COOP protocol.

Grey wolves usually prefer to live in a pack. On average their pack size is 5∼12 and they have a very strict social dominant hierarchy. Alpha (α) wolves are the leaders and their decisions are dictated by the pack. It is not necessary that alpha is the strongest member but the best in terms of organizing the pack irrespective of gender. They are also called dominant wolves since their directions should be followed by the pack. Typically alpha is responsible for making decisions about hunting, where to sleep, and time to wake, and so on. There are some unusual behaviors that have been observed as an alpha follows other wolves in a pack.

Beta (β) is the second ranking of hierarchy of gray wolves. They are secondary wolves that assist alpha in various activities or decision making. They can also be either male or female. In the event if one of alpha wolves dies or gets old enough and is not able to perform well, beta wolves are likely the best candidate for replacing that alpha. The Beta wolf commands the other lower level wolves. They should respect alpha and plays the role of an alpha advisor and disciplinarian for pack. Beta is responsible for promoting action plans developed by alpha in an entire pack and giving feedback to alpha.

Delta (δ) is the third inline of gray wolves hierarchy. Although delta wolves must obey alphas and betas, they dominate omega(ω), the low level in the hierarchy. Scouts, sentinels, elders, hunters and caretakers all belong to the delta class. Scouts are responsible for watching the territory's boundaries and warning the herd if there is any danger. Sentinels protect and guarantee the safety of the pack. Elders are experienced wolves who used to be alpha or beta. Hunter helps the alpha and beta when hunting prey and providing food for packs. Finally, caretakers are responsible for caring for the weak, sick and injured wolves in the flock.

The lowest level in the hierarchy of gray wolves is omega(ω). They are the last wolves allowed to eat and act as a scapegoat. They are responsible for submission to all other dominant wolves. Although the omega coyote is not a significant pack individual, the contributions of the omega wolves help complete the packing and maintain the dominance structure. It has been observed that in case of omega, the entire package encounters internal fighting and problems.

B. COOPERATIVE DIVERSITY USING TWO RELAY

The single hop scheme employs direct transmission from source to destination. It is difficult to deal with dynamic network wherein nodes are highly mobile and single path transmissions do not guarantee reliable transmission. Different broadcast techniques can offer a promising future but the cooperative diversity scheme has its own potential. This scheme supports FANETs by looking at the transmitted signals as contribution. The significance of this scheme is evaluated when multiple antennas are not possible. In this context, the nodes share the packets with its neighbors and establish group to transmit data to the destination. As an alternative to single path, cooperative multipath diversity is used to forward the packets to the destination. Further, this can enable different parameters of frequency, time and spatial diversity that cannot withstand multiple antennas. Thus, there is a greater chance of multiple connections within the transmission range of the node to successfully transfer the packets to the destination.

In the multi-hop routing diversity, first hop is significant compared to subsequent hops. GWO offers three best candidate solutions and is sufficient to employ cooperative diversity technique. Therefore our network takes into account the two hops consisting of a alpha (source), Prey/Target (destination) and beta and delta (R_{-1} and R_{-2}) two best relays in a row as shown in Fig. 3. The source can send information either directly or through relay to the destination. The destination combines the received signals using the Enhanced Signal to Noise Ratio Combining (ESNRC) scheme. Moreover, Amplify-and-Forward (AF) protocol is studied under different integration methods in wireless cooperative diversity systems. Compared to the optimal SNR incorporation, ESNRC employs an average SNR instead of instantaneous SNR. The performance of ESNRC is close to the optimal SNR performance that combines in the AF protocol. However, this scheme reduces receiver complexity in cooperative diversity systems.

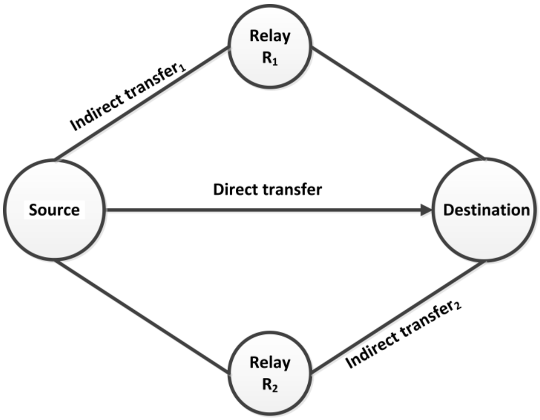

FIGURE 3. Concept of cooperation using two relay in GWO.

C. GW-COOP SYSTEM MODEL

The network consists of randomly deployed flying nodes in a certain area. In order to communicate with their intended receiver, the nodes follow the grey wolf principles as shown in fig. 4.

The best candidate in the network is alpha and is called the source, located hop away from destination. Beta and delta are second and third best candidates which are considered as R_{-1} and R_{-2} respectively. The rest of the network nodes are assumed omega which are part of the contributor's catalyst. The Gray wolf hierarchy is taken into consideration where source can lead the data transmission. This can be either a direct transfer or indirect transfer. The uncertain architecture of FANETs does not allow the transmission of single path,

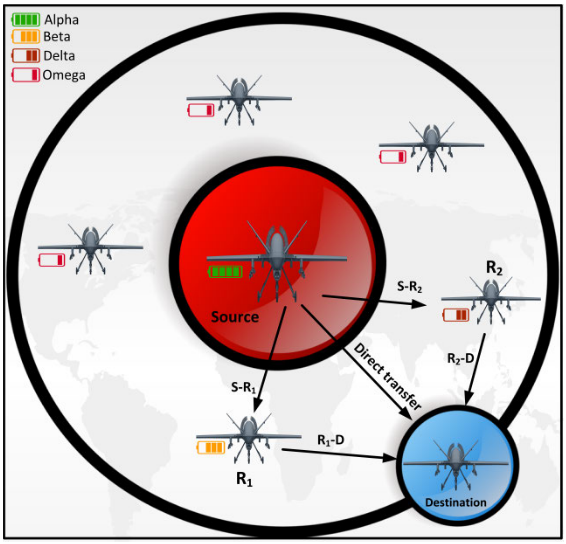

FIGURE 4. GW-COOP system model.

so this research allows for different paths to ensure that packets are delivered at destination. The source leads the network to transmit data in three possible ways, either direct transport (source to destination) or indirect transport 1 using R_{-1}(source to R_{-1} and R_{-1} to destination) or indirect transfer 2 using R_{-2} (source to R_{-2} and R_{-2} to destination). Both relays use AF technique to forward the packet. They are responsible for amplifying the received signal and sending it to the destination. No single-path or relay is dependent on reliable transmission especially for FANETs. The two-relay concept is useful for providing the complementary path to a destination. The pseudo code of the GW-COOP algorithm is presented in Table 1.

Link stability is also a challenge in routing FANETs which is overcome by using the two-relay concept. This allows to keep at least one route to the destination. Stability and control of flying node is complex in FANETs. However, GW-COOP protocol ensures the network connectivity during self-healing arrangement of dynamic networks. This supportive arrangement deals with the dynamicity of networks where every node plays a role in routing. $\overrightarrow{A}$ and $\overrightarrow{C}$ are coefficient vectors whereas components of $\overrightarrow{a}$ is linearly decreased from 2 to 0 over the time step. The fluctuation range of $\overrightarrow{A}$ is also decreased by $\overrightarrow{a}$. If the value of $\overrightarrow{A}$ falls in $-1 < \overrightarrow{A} < 1$, it is in attacking mode and converge to prey however $\overrightarrow{A} > 1$ or $\overrightarrow{A} < -1$ considers the wolf for searching mode or diverge from each other to search for prey as shown in Fig. 5. Moreover, $\overrightarrow{C}$ is a random value in $[0, 2]$. This component provides random weights for prey in order to stochastically emphasize $(C > 1)$ or deemphasize $(C < 1)$ the effect of prey in defining prey whereas $\overrightarrow{C}$ is not decreased in contrast to $\overrightarrow{A}$.

It is now necessary to provide a better communication path by maintaining the links between the nodes. This allows the nodes to send data to the destination as either direct transfer or indirect transport. The GW-COOP protocol provides a solution to the packet loss problem using gray wolf social hierarchy and cooperation technique. This maximizes the connected node in the network that guarantees data delivery at the destination.

TABLE 1. Pseudo code for proposed solution.

```
Proposed GW-COOP algorithm

Initialize the random deployment of flying nodes
Determine a, A and C for all nodes by equations (3) and (4)
Evaluate the fitness of each node by equation (5)
$Gw_\alpha$ = the first best solution
$Gw_\beta$ = the second best solution
$Gw_\delta$ = the third best solution
for (iteration 1 to Maximum)
Update the position of current best node by equation (7)
Compute the distance of nodes to the destination
Update the fitness of all nodes
Update $Gw_\alpha, Gw_\beta, Gw_\delta$
Determine the nodes within communication range of each node
Update the neighboring solutions
  if node satisfy cost function by equation (12)
      Update the position of node for routing phase
  else
search for best position of node by flying randomly
Update the sequence
  end if
    if critical data is determine by corresponding node
Direct path transfer by equation (24)
    else
Cooperative phase
Calculate the R.E of source node
Determine the nodes for $R_1$ and $R_2$
      if (R.Es > R.E of $R_1$ or $R_2$)
Direct path transfer
      else
Update position of nodes by adjusting a, A and C
Use $R_1$ path and $R_2$ path
Amplify and forward relay strategy for both relays
ESNRC for received signals at destination by equation (26)
      end if
    end if
   end if
end for
```

D. FLOW CHART FOR GW-COOP ROUTING PROTOCOL

This sub section details the flowchart of a GW-COOP protocol using the gray wolf social hierarchy and cooperation technique. The implementation of the GW-COOP protocol represents the significance of the cooperation technique in FANETs. The complexity of directing FANETs is overcome by inspiring biological behaviors of the species. The network is configured by population and random deployment of flying nodes. The fitness and position of each node is calculated to the destination which measures the ranking for each node. This is subject to the condition that if the first three best solutions are found during iteration, they will be ranked in the sequence as first, second, and third nodes of the best named nodes, source, R_{-1} and R_{-2} respectively. However,

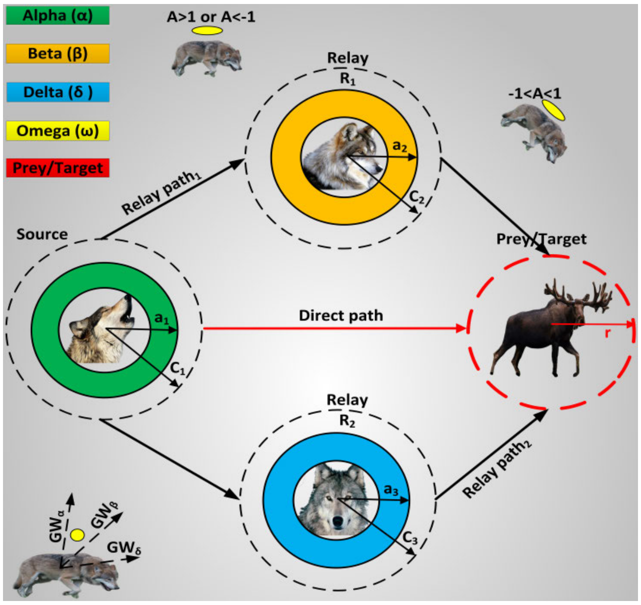

FIGURE 5. Schematic diagram of GW-COOP routing using cooperation technique.

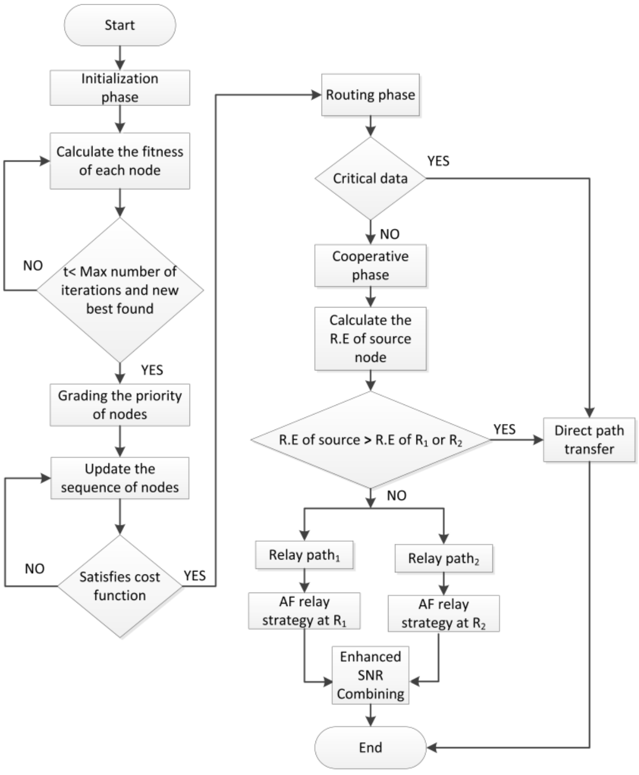

FIGURE 6. Flow chart for GW-COOP routing protocol.

if this condition is not fulfilled and the iterations are not reached to the maximum, this will revert the search again until the condition is met as shown in Fig. 6. The rest of the wolves are not considered Omega for cooperative operation. The sequence obtained the position of the nodes, the distance to the prey are stored and updated at this point for the next iteration step.

The biological inspiration for the GWO guide is driving the disciplinary flight positions of the nodes during the flight mission. After the completion of GWO, our proposed action step into the cooperative diversity phase. The proposed cost function finds the relay selection in the FANETs and the routing phase begins. Before setting the routing up, it is assumed that the nodes dedicated to flying are intelligent. They know the importance of the type of data. FANETs finds usually deployment in disaster environment for immediate rescue response, as each node knows its fitness value, ranking position and distance to the destination. When the routing phase begins, the cooperative diversity is implemented. Data is transferred in various ways. The source sends the data to destination either from direct transfer or relay transfer. There are two migration paths that involve forwarding the data to the destination. Although, breaking the link is a major challenge in FANETs routing, it is overcome by choosing the social classification of gray wolves. This can help to deploy the best nodes in the best position as a relay between source and destination. These relays feature the use of AF technique that enhances signal strength and provides the path to the destination. It can ensure the link availability from one of them to transmit data reliably. Instead of ensuring that the data is transported to the destination through a direct transfer or relay path, this research guarantees two relay paths that provide additional link reliability in FANETs. Thus if there is a link break in the flying movement of nodes, it may continue to be provided via a secondary relay.

Moreover, there are two types of data that reflect the network performance, that is, ordinary data and critical data. If there is any critical data task alert during flight mission, a critical queue will be activated to be operational. This alert will inform the process to use direct transfer to the destination. In direct transfer mode, source node is one hop away from the destination. There will be direct transfer of information from source to destination. Cooperative diversity is assumed to be created when critical data arrives in the queue, and the rest of information transfer is retained by choosing the two best relay paths either R_{-1} or R_{-2}. The cooperation process is accomplished when the source sends the data to the destination by choosing direct transport or relay transfer. The source sends the information simultaneously to R_{-1}, R_{-2} and the destination. Likewise, R_{-1} and R_{-2} send the received information to the destination. Multiple signals are received at destination, so instead of simply combining and adding, destination uses ESNRC merge scheme that combines multiple signals. ESNRC uses the average SNR instead of instantaneous SNR. This technique can only accept a signal of better quality in terms of SNR while ignoring the same incoming signals from other incoming channels. The ESNRC performance is close to optimal SNR by combining into the AF protocol.

IV. MATHEMATICAL MODELING FOR SOCIAL HIERARCHY OF GRAY WOLF OPTIMIZATION

For the mathematical modeling of the social hierarchy of wolves, alpha is the first best suitable solution. Consequently, beta and delta are considered the second and third best solutions respectively. The rest of the search agent solutions are assumed to be omega. Moreover, hunting is directed by 'α', 'β' and 'δ' in the GWO algorithm while 'ω' wolves pursue these three wolves. Since, gray wolves encircle the prey during the hunt so following equations present the mathematical modeling of the encircling behavior [34]:

$$\overrightarrow{Gw} = \left|\vec{C} * \vec{P}_p(t) - \vec{P}(t)\right| \tag{1}$$

$$\vec{P}(t+1) = \vec{P}_p(t) - \vec{A} * \overrightarrow{Gw} \tag{2}$$

where $\vec{A}$ and $\vec{C}$ are the coefficient vectors, $\vec{P}_p$ is the position vector of prey while $\vec{P}$ indicates the position vector of a grey wolf. Further, t and $t+1$ indicate the current and next time step of the individual respectively. The vectors $\vec{A}$ and $\vec{C}$ can be calculated as [34]:

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

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

Here $\vec{r}_1$, $\vec{r}_2$ are random vectors in [0, 1] and $\vec{A}$ is a random in the interval $[2\vec{a}, 2\vec{a}]$. The component of $\vec{a}$ is linearly decreased from 2 to 0 over the time step of iterations. In order to mathematically model the approaching prey, the value of $\vec{a}$ is decreased. The fluctuation range of $\vec{A}$ is also decreased by $\vec{a}$. However when value of $\vec{A}$ falls in $-1 < \vec{A} < 1$, it is in attacking mode and converges to prey. Further, $\vec{A} > 1$ or $\vec{A} < -1$ considers the wolf for searching mode. Moreover, $\vec{C}$ is random in an interval [0, 2]. In order to stochastically emphasize ($C > 1$) or deemphasize ($C < 1$), this component provides random weights for prey whereas $\vec{C}$ is not decreased in contrast to $\vec{A}$.

As stated earlier, alpha is responsible for leading the hunt however sometimes beta and delta may also contribute to the hunt. In order to mathematically simulate the behavior of gray wolves, we assume the best candidate solution is alpha while beta and delta have better knowledge of the potential location of prey. Hence, first three best solutions are saved and other search agents including omegas are required to update their positions according to the best solutions. Alpha, Beta and Delta estimate prey location while other wolves update their positions around the prey. The following formulas are given in this regard [34].

$$\begin{cases} \overrightarrow{Gw_\alpha} = \left|\vec{C}_1 * \vec{P}_\alpha - \vec{P}\right| \\ \overrightarrow{Gw_\beta} = \left|\vec{C}_2 * \vec{P}_\beta - \vec{P}\right| \\ \overrightarrow{Gw_\delta} = \left|\vec{C}_3 * \vec{P}_\delta - \vec{P}\right| \end{cases} \tag{5}$$

$$\begin{cases} \vec{P}_1 = \vec{P}_\alpha - \vec{A}_1 * \overrightarrow{Gw_\alpha} \\ \vec{P}_2 = \vec{P}_\beta - \vec{A}_2 * \overrightarrow{Gw_\beta} \\ \vec{P}_3 = \vec{P}_\delta - \vec{A}_3 * \overrightarrow{Gw_\delta} \end{cases} \tag{6}$$

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

We assume that FANETs consist of randomly scattered flying nodes. They fly at a constant altitude (H). We also assume that all nodes know their own locations as well as the destination location. Let $z(t)$ indicate the node trajectory projected on the horizontal plane and can be written as $z(t) = [x(t), y(t)]^T \in R^{2\times 1}$, where $0 \leq t \leq T$. As per the details in [35], the time-varying distance from a node to destination is expressed as:

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

Typically, a channel is more likely to have air-to-ground channel that have LoS link as compared to terrestrial ground-to-ground channels. Furthermore, it is assumed that the Doppler Effect is compensated due to node mobility. Therefore, the time-varying channel follows the free-space path loss model, which as per the details in [35] can be expressed as:

$$\begin{aligned} g(t) &= \frac{\lambda_0}{d^2} \\ &= \frac{\lambda_0}{H^2 + \|z(t)\|^2}, \quad 0 \leq t \leq T \end{aligned} \tag{9}$$

where λ_0 denotes the channel power at reference distance d_0. If receiver experiences an additional interference, the aggregate interference is assumed to be Gaussian distribution. Its power can be incorporated into the noise term σ^2. The total information bits $\bar{Q}$ then can be transmitted from node to ground station [35], and the function of the node trajectory $z(t)$ can be expressed as follows:

$$\bar{Q}(z(t)) = \int_0^T B\,log_2\left(1 + \frac{\gamma_0}{H^2 + \|\mathbf{z}(\mathbf{t})\|^2}\right)dt \tag{10}$$

The amplitude of the instantaneous channel in bits per second can be expressed as [36]:

$$\begin{aligned} Q(t) &= Blog_2\left(1 + \frac{P^* g(t)}{\sigma^2}\right) \\ &= Blog_2\left(1 + \frac{\gamma_0}{H^2 + \|z(t)\|^2}\right), \quad 0 \leq t \leq T \end{aligned} \tag{11}$$

where P^* is constant transmission power for a node, B denotes the channel band width, σ^2 is white Gaussian noise power at ground station, $\gamma_0 = {}^{\lambda_0 P^*}/_{\sigma^2}$ is the reference SNR at $d_0 = 1$m.

The network is initialized with various tasks such as flying nodes having knowledge of their neighbors, location of relays, destination and routes to the destination. Each node broadcasts an information packet containing the node ID, location and energy status. Nodes update their positions according to the neighboring sites. The cost function for each node is mathematically calculated as:

$$CF = \frac{\max\left(\eta_{s,R_1}, \eta_{s,R_2}, \eta_{s,D}\right) + \max\left(R.E_{R_1}, R.E_{R_2}, R.E_D\right)}{\min\left(\left|d_{S,R_1}\right|^2, \left|d_{S,R_2}\right|^2, \left|d_{S,D}\right|^2\right)} \tag{12}$$

where $\eta_{s,R_1}, \eta_{s,R_2}, \eta_{s,D}$ are the SNR of corresponding links from $S \rightarrow R_1$, $S \rightarrow R_2$ and $S \rightarrow D$ respectively. $R.E_{R_1}, R.E_{R_2}, R.E_D$ are the residual energy of R_1, R_2 and R_D respectively. Distance d_{S,R_1}, d_{S,R_2} and $d_{S,D}$ from the corresponding source node to relays and destination respectively.

The transmission is accomplished in two phases of GWO and cooperation. In the first phase, the source transmits symbol block x which is received at relays and destination simultaneously [37]:

$$y_{S,R_n} = \sqrt{E_s} x e_{S,R_n} + N_{S,R_n} \tag{13}$$

$$y_{S,D} = \sqrt{E_s} x e_{S,D} + N_{S,D} \tag{14}$$

where E_s is the per symbol average transmitted energy and N_{S,R_n}, $N_{S,D}$ represent noise terms at the n-th relay and the destination respectively. In the second phase, the selected relay terminal estimates the signal received at the first phase and then transmits the estimated symbol block $\hat{x}_n$ to the destination accordingly. As given in [37], the received signal at destination can be written as follows:

$$y_{R_n,D} = \sqrt{E_s} \hat{x}_n \zeta_{R_n,D} + N_{R_n,D} \tag{15}$$

where

$$\hat{x}_n = arg \min_{x \in \{-1.1\}} \left| y_{S,R_n} - \sqrt{E_s} x e_{S,R_n} \right|^2 \tag{16}$$

where $N_{R_n,D}$ is the destination noise term. All noise terms in Eqs. (13) - (15) are the Additive White Gaussian Noise (AWGN) component modeled as complex random variable with zero mean and variance of $N_0/2$. In our system model, the nodes are assumed to transmit signal with average signal strength. However, the average signal-to-noise ratio between any nodes can be expressed as [38]:

$$\eta = \frac{E_s}{N_0 W} \tag{17}$$

where W is the transmission bandwidth, N_0 is noise whereas instantaneous SNRs of $S \rightarrow R_n$,$R_n \rightarrow D$ and $S \rightarrow D$ can be expressed as [38]:

$$\begin{cases} \eta_{S,R_n} = E_s \left| e_{S,R_n} \right|^2 \big/ N_0 \\ \eta_{R_n,D} = E_s \left| \zeta_{R_n,D} \right|^2 \big/ N_0 \\ \eta_{S,D} = E_s \left| e_{S,D} \right|^2 \big/ N_0 \end{cases} \tag{18}$$

ESNRC scheme is used at destination to combine the signals of $y_{S,D}$ and $y_{R_n,D}$. Hence the combine signals at the destination can be expressed as [37]:

$$y_D = w_{S,D} y_{S,D} + w_{R_n,D} y_{R_n,D} \tag{19}$$

where $w_{S,D}$ and $w_{R_n,D}$ are weight coefficients which are the functions of $e_{S,D}$ and $\zeta_{R_n,D}$ respectively. Substituting $w_{S,D} = e^*_{S,D}$ and $w_{R_n,D} = \zeta^*_{R_n,D}$ into Eq. (19), combining signals at destination can be expressed as:

$$y_D = e^*_{S,D} y_{S,D} + \zeta^*_{R_n,D} y_{R_n,D} \tag{20}$$

In fact, localizing FANETs are counter-intuitive tasks for which only a few options are available. It is not easy to deploy nodes to a specific location in an uncertain environment. However in this case, flying nodes are equipped with a navigation system. They are exploited as reference nodes to support subsequent distributed localization schemes. They received data from an external environment and transported it to the destination using one or multi hop technique. Each node can either transmit or receive data by tuning into the transmission radius range from r_{min}(minimum transmission radius) to r_{max}(maximal transmission radius). Consider the nodes at minimum hop distance $d(t)$ and there exist two values of $m(h)$ and $n(h)$ such that distance $d(t)$ between nodes is bounded by the condition of $m(h) \leq d(m,n) \leq n(h)$. The quality of the bounds depends on network density μ. In particular for each $h > 0$ holds.

$$\lim_{\mu \rightarrow \infty} m(h) - n(h) = r_{min} \tag{21}$$

Sensors have different theoretical and physical properties. Depending on the features of the application and the device, numerous models of varying complexity are developed. However, the sensing capacity decreases as the distance increases.

Lemma: General sensing model G at an arbitrary point q for a sensor s is given by:

$$G(s,q) = \frac{\rho}{|d(s,q)|^k} \tag{22}$$

where $d(s,q)$ is the Euclidean distance between sensor 's' and point 'q', and positive constant 's' whereas 'ρ' and 'k' are the sensor technology-dependent parameters [39].

Assume nodes contain limited battery resources without recharging or replacing node after deployment. In cooperative communication, each node has the ability to transfer information to each other. The signals received at the destination can be expressed as follows:

$$y_D(x) = \begin{cases} y(x) & \left(\dfrac{\eta_{s,D}}{\eta_{s,R,D}}\right) > 10 \\ y_{S,D}(x) + y_{S,R,D}(x) & 0.1 \leq \left(\dfrac{\eta_{s,D}}{\eta_{s,R,D}}\right) \leq 10 \\ y_{S,R,D}(x) & \left(\dfrac{\eta_{s,D}}{\eta_{s,R,D}}\right) < 0.1 \end{cases} \tag{23}$$

In contrast, source node transmits the signal directly to the destination in the non-cooperative mode. The information between source and destination can be expressed as follows [38]:

$$y_{non-Coop} = log_2\left(1 + \left|h_{S,D}\right|^2 \eta\right) \tag{24}$$

where $|h_{S,D}|$ is a channel between source and destination. To be sustainable, data rate over this channel must be less than mutual information $y_{non-coop}$.

The transport between source and destination utilizes an intermediate node as a relay in the cooperative AF relay scheme. We assume that the relays operate in half duplex and the transmission is divided into two time slots. In first slot, source transmits the signal to the relays and destination simultaneously. In second time slot, the selected relays receive the signal, amplify it and then send to destination. The destination collects the received signals as merged with ESNRC. In this scheme, estimating the channel quality is sufficient to incorporate the signals while it is not important for receiver to know the exact characteristics. However, it ignores the incoming signals when the same signals are received from other, lower quality channels. If the channels have more or less the same quality, the incoming signals are rationed equally. The information exchange between the source and each of the n-th relay nodes is expressed as follows [38]:

$$y_{S,R_n}=\frac{1}{2}log_2\left(1+\left|h_{S,R_n}\right|^2\eta\right) \tag{25}$$

Given half-duplex constraint, factor $\frac{1}{2}$ reflects the two time slots for relaying. The mutual information between source–destination and destination-each of the n-th relay nodes is expressed as:

$$y_{ESNRC}=\frac{1}{2}log_2\left(1+\left(\left|h_{S,R_n}\right|^2+\left|h_{S,R_n}\right|^2\right)\eta\right) \tag{26}$$

Thus, maximum end-to-end mutual information in the cooperative AF is expressed as:

$$y_{Coop}=\max_{n\in N}\min\left\{y_{S,R_n},y_{ESNRC}\right\} \tag{27}$$

In the AF opportunistic relay, the relay is selected from the set of available best relays.

V. GW-COOP ROUTING CHARACTERISTICS

In order to improve the lifetime of FANETs, the energy consumption between flying nodes can be well-balanced by inspiring social behavior of gray wolves. Drones are deployed to FANET at random and different ranks are assigned to these drones according to their suitability, location and distance to the target. They are associated with the health of their energy. The best drone in terms of energy and location is considered as the source of the Alpha Drone. Likewise Beta and Delta are the second and third best drones and are considered as R_{-1} and R_{-2} respectively. The rest of the drones sympathize with the leading drones to accomplish the required mission. Any participation during data communication between source and destination with low residual energy is not considered. The source is placed one hop away from the destination. It has enough energy to send data directly to destination.

FANETs are dynamic and have an uncertain nature that does not allow flying nodes to depend on a single path. Cooperative diversity makes these networks suitable for handling signal strength of signal with AF technique. Subject to the frequent division of the FANETs topology, cooperative diversity not only provides the direct path to the destination, however can also provide the complementary paths such as R_{-1} and R_{-2} to the destination. The source is able to transmit data through the first best relay R_{-1} or the second best relay R_{-2} sequence. This enables the destination to receive data from either direction which reduces the packet loss ratio in FANETs. Finally ESNRC scheme is used to consider the strengthened signal as information signal at the destination.

VI. RESULTS AND DISCUSSION

In order to evaluate the performance of the GW-COOP protocol, this protocol is compared with BAT-COOP and BAT-FANET protocols. The BAT-COOP and GW-COOP protocols are distinguished by the BAT and GWO algorithms respectively. However, the BAT-FANET protocol is considered the bat algorithm without the cooperation technique. These protocols are simulated on the basis of computation where successive packet forwarding is considered. It ensures a minimum packet retransmission rate, particularly when using cooperative diversity.

The simulations are run in rounds where the best computed values for the respective protocols are stored and updated accordingly. In every round, active nodes convey the required information about the relay and energy levels of the nodes to the destination. This can assist the nodes to keep dynamic topology network information updated. At the end of every round 100, each node updates the best new values obtained so far and computes the information to the neighboring and destination nodes accordingly. Network simulation parameters are shown in Table 2.

TABLE 2. Simulation parameters for GW-COOP.

Parameters	**Values**
Network Volume	500m^3
Total Nodes	120
Initial Node Energy	0.07 joules
Node Flight	Random
Maximum rounds	4500
Transmission Range	350m
Channel Type	Wireless
Antenna Type	Omni

Figure 7 shows the graphical result of GW-COOP in terms of transmission loss. The GW-COOP has low transmission loss due to the availability of multiple cooperative nodes. Effective use of two relays and discipline of gray wolves has ensured to minimize the transmission loss. Hence it is valuable to deal with the transmission degradation caused by the FANETs random hopping model. Transmission loss (dB)

TABLE 3. Transmission Loss Vs Time.

Protocols	Time (minutes)										Results
	50	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**Improvement**
BAT-FANET	1391	2781	4172	5563	3262	958.4	1090	1221	880.3	539.8	167%
BAT-COOP	819.5	1639	2458	3278	2264	1250	1084	917.8	829.1	740.4	152%
GW-COOP	243.9	487.7	731.5	975.4	662	348.6	816	1283	1051	819.1	100%

TABLE 4. Energy Consumption Vs Time.

Protocols	Time (minutes)										Results
	50	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**Improvement**
BAT-FANET	0.03	0.07	0.10	0.14	0.28	0.42	0.62	0.83	1.14	1.99	161%
BAT-COOP	0.05	0.09	0.14	0.19	0.29	0.41	0.53	0.66	1.09	1.52	154%
GW-COOP	0.03	0.06	0.09	0.12	0.21	0.31	0.33	0.35	0.37	0.40	100%

TABLE 5. Link Delay Vs Time.

Protocols	Time (minutes)										Results
	50	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**Improvement**
BAT-FANET	330.1	660.2	990.3	1320	795	270	266	262	176.6	91.17	124%
BAT-COOP	248.9	498	746.8	995.7	720.5	445.4	286.6	127.7	131.9	136.1	109%
GW-COOP	176.1	352.2	528.2	704.4	552.9	401.2	367.1	332.9	292.6	252.3	100%

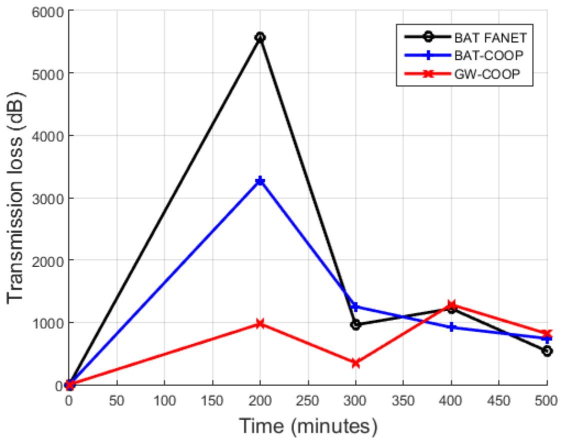

FIGURE 7. Transmission loss (dB) versus time (minutes).

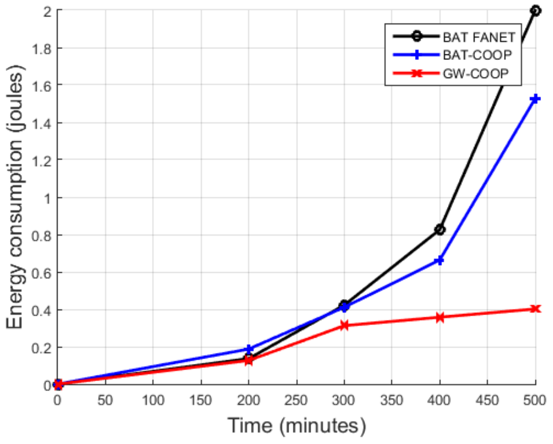

FIGURE 8. Energy consumption (joules) versus time (minutes).

versus time (in minutes) for BAT-FANET, BAT-COOP and GW-COOP is shown in Table 3. A comparison of the GW-COOP results shows an effective reduction in terms of transmission loss, that is, 67% and 52% for BAT-FANET and BAT-COOP respectively.

The plot in Figure 8 shows the performance of energy consumption of GW-COOP wherein decrease of energy consumption can be seen well than that of the BAT-FANET and BAT-COOP. This is due to the disciplinary implementation of gray wolf social hierarchy and the prioritization of the relay strategy. Hence, GW-COOP conserves better energy which is helpful in solving computational problems and real-time application of FANETs. Table 4 shows the numerical results for BAT-FANET, BAT-COOP and GW-COOP in terms of energy consumption (in Joules) versus time (in minutes). Significant reduction in energy consumption is achieved in the GW-COOP protocol as compared to the other protocols. BAT-FANET and BAT-COOP consumed 61% and 54% more energy than GW-COOP. This is due to intelligent movement of the flying nodes that are choosing the gray wolves social hierarchy and cooperation technique.

Minimum link delay in the GW-COOP protocol is achieved as comparison of the BAT-FANET and BAT-COOP protocols as shown in Figure 9. The performance of the GW-COOP protocol in terms of link delay is numerically presented in Table 5. Although the GW-COOP and BAT-COOP protocols comply with the cooperative diversity, the numerical results of GW-COOP protocol indicate 24% and 9% reduction in link delay compared to BAT-FANET and BAT-COOP

TABLE 6. Packet Loss Ratio Vs Time.

Protocols	Time (minutes)										Results
	50	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**Improvement**
BAT-FANET	0.00043	0.00087	0.0013	0.0017	0.0025	0.0033	0.0065	0.0096	0.0184	0.0273	158%
BAT-COOP	0.00032	0.00064	0.0095	0.0013	0.0027	0.0040	0.0070	0.0099	0.0142	0.0184	148%
GW-COOP	0.00047	0.00095	0.0014	0.0019	0.0025	0.0030	0.0043	0.0057	0.0054	0.0051	100%

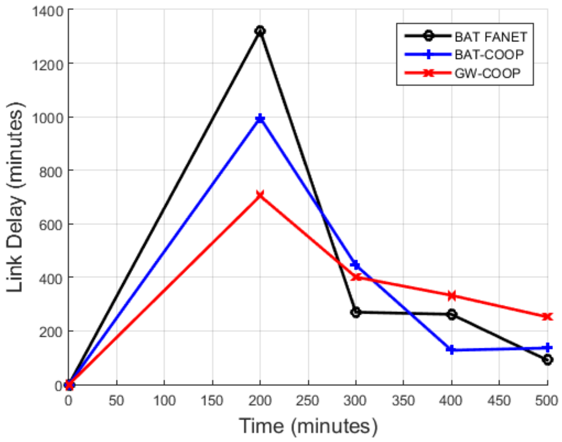

FIGURE 9. Link delay (minutes) versus time (minutes).

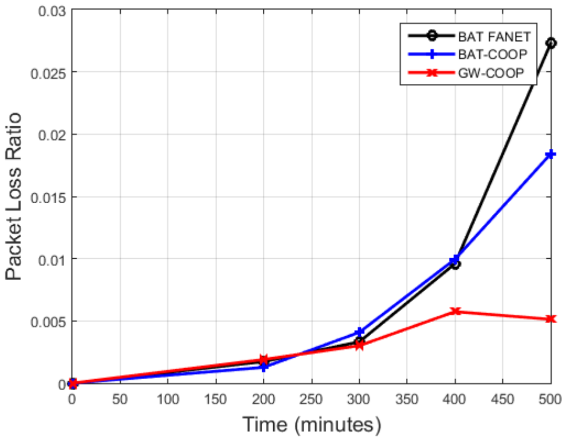

FIGURE 10. Packet loss ratio versus time (minutes).

respectively. This is due to the leadership hierarchy of gray wolves and the use of two-relay in the GW-COOP protocol. It takes into account the minimum forwarding distances between the cooperative nodes in sparse networks as well as dense networks. Consequently, the GW-COOP protocol ensures that there is communication between the nodes which reduces the link delay.

Figure 10 shows the performance of the GW-COOP protocol in terms of packet loss ratio. The GW-COOP protocol operates in accordance with two-relay collaboration using cooperative diversity. GWO especially selects three best solutions between source and destination. Hence, the GW-COOP protocol ensures the availability of paths from source to destination and reduces packet loss ratio. Numerical comparison of GW-COOP with BAT-FANET and BAT-COOP in terms of percentage packet loss is shown in Table 6. In order to improve packet delivery at the destination, the following considerations have been taken into account such as best relay node strategy, the minimum forwarding distance between nodes, and the best positions for the relay nodes.

VII. CONCLUSION

This research paper attempts to design link and loss-aware GW-COOP for FANETs routing protocol, based on biologically inspired technique of GWO and cooperative diversity scheme. Initially, the leadership hierarchy of gray wolf is employed for establishing a network followed by implementing the cooperative diversity technique. This leads to a well-connected network without compromising on the dynamic and ever changing network topology. Efficiency of GW-COOP routing protocol in terms of transmission loss, energy consumption, link delay and packet loss ratio are presented. Results of GW-COOP are compared with BAT-FANET and BAT-COOP protocols. GW-COOP and BAT-COOP protocols are differentiated by the algorithms of GWO and BAT respectively. A distinction is made between GW-COOP and BAT-COOP protocols by the GWO and BAT algorithms, respectively. However, opting the social hierarchy of grey wolves and the concept of two relays in cooperative diversity allow considerable reduction in transmission losses, energy consumption, link delay and packet loss ratio as compared to its counterparts of BAT-FANET and BAT-COOP protocols. The Link-delay of 704.5 min for GW-COOP compared to 995.7 min for BAT-COOP and 1320 min of BAT-FANET. The energy consumption of 0.12 compared to 0.19 and 0.14 of the similar schemes and transmission of 975.4 compared to 3278 and 5563 of the counterparts, while packet-loss ratio of 0.0019 compared to 0.0013 and 0.0017 of the counterparts protocols.

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