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Energy Efficient Communication for WSNs using Grey-Wolf Optimization Algorithm

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Abstract:
Wireless sensor networks (WSN)are utilized for measuring various parameters such as pressure, temperature or humidity monitoring, in buildings to monitor smoke and fire, surveillance monitoring and also for environmental monitoring etc. These sensors are comprised of numerous small electronic devices known as sensors which are operated on battery. The wireless sensors are deployed in the chosen region according to the area of interest so that it can continue sensing for a long duration. But to keep these sensors active for a desired duration, the network's lifetime should be necessarily prolonged with less power consumption because unbalanced battery usage becomes a major challenge in WSNs. There has been a vast research in last few decades on different types of protocols depending upon the type of network i.e. homogenous or heterogeneous. It is seen that energy efficiency can be obtained by clustering methods. Various meta-heuristic optimization techniques also have been proposed earlier to resolve the optimization problems. In this paper, we aim to achieve energy efficiency by using fuzzy logic for cluster formation and Grey Wolf Optimizer (GWO) for cluster head (CH) election.

Introduction:

Vast applications of wireless sensor networks in military surveillance, healthcare monitoring, industrial process control, environmental monitoring, home intelligence, structural monitoring etc. has made WSNs one of the advanced technology that can change the world [1]. In such applications, low cost sensors are deployed all over the region considered for monitoring. These sensors which are operated on batteries reports its sensing information (that can be temperature, pressure, humidity, water level or light intensity) to the base station (BS) located usually in the centre of the field. But to keep these sensors active for a desired duration, the network's lifetime should be necessarily prolonged with less power consumption because unbalanced battery usage becomes a major challenge in WSNs [2, 3].

Most of the research surveys concentrate on clustering approach that is being used in sensor networks. A large coverage and network scalability can be achieved through the clustering technique in WSNs. In this approach single CH is chosen for an individual cluster which will transmit sensing information to the BS. Clustering technique is aimed for energy efficient operation and increasing network's lifespan.

There are various optimization methods which has been researched and gained enormous popularity over a few decades. Some of these optimization techniques are Genetic Algorithm (GA), Ant Colony Optimization (ACO), and Particle Swarm Optimization (PSO) etc. These all are meta-heuristic optimization algorithms. Meta-heuristic approaches are becoming common because they are simple, flexible, and derivation-free and has the capability to avoid local optima.

Related Work:

Various strategies have been proposed in literature to provide energy efficiency in wireless network but hierarchical clustering techniques are best suited option. As we know WSNs are comprised of various sensors. The sensor node structure can be explained well with the help of Fig. 1. Power supply, sensing, processing and communicating are the major tasks handled by a sensor node [3]. The sensing unit sense the analog signal and converts it into digital form with the help of analog-digital convertor in order to make it recognized by processing/microcontroller unit. Further this sensed information is transmitted to communication unit which further pass it to the BS. Each sensor node performs its task depending on the decision taken on the basis of its computing knowledge, data it posses, energy and communication resources. The sensor nodes must have the capacity to route information to other nodes or BS or to such an external node which will connect to the network infrastructure or internet. In terms of energy efficient network, hierarchical routing protocols are considered to be the best [4].

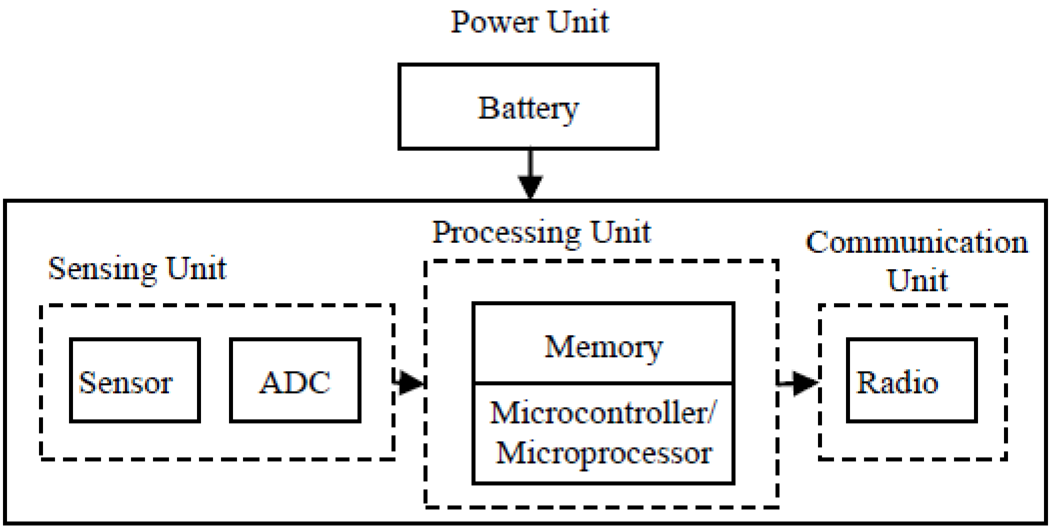

Fig. 1: Sensor Node Structure [3]

If these sensor nodes are grouped together, it forms a cluster. Clustering in WSNs is depicted in Fig. 2. These clusters generate hierarchical structures which help to use the resources in a more efficient manner. LEACH [6], APTEEN [7] and SEP [8] are some of the clustering techniques. In the clustering approach single CH is chosen for an individual cluster which will transmit sensing information to the BS.

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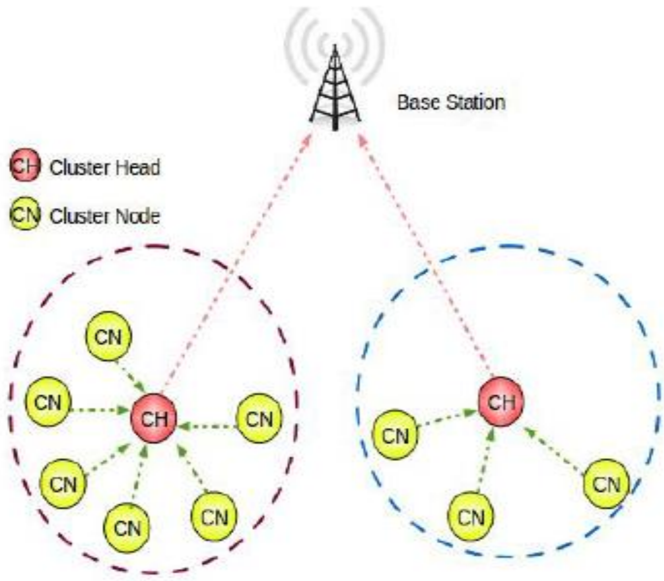

Fig. 2: Cluster formation in WSNs [3]

LEACH Protocol:

The 1st most common hierarchical clustering protocol used to reduce battery consumption of sensor network is LEACH protocol. In this protocol CHs are elected on the basis of probability model. Coordinating and transmitting data between the BS and other nodes is the responsibility of cluster head (CH). The major attributes to evaluate signal strength are distance and residual energy [6].Likewise traditional protocols if the CH is elected during the network lifetime, the nodes with lower remaining energy will die quickly due to clustering tasks, resulting in end of lifespan of sensor belonging to that cluster. Hence LEACH utilizes randomized rotation of cluster heads so as to not drain the energy of a single node, which will enhance the total lifespan of the network. Furthermore "Data-Aggregation" involved in LEACH further reduces the energy consumption and improves network lifespan.

APTEENProtocol:

In [7], APTEEN protocol is proposed which is actually a hybrid protocol used to provide an overview of the network at a periodic intervals. These protocols are expected to work in an energy efficient manner and they also enable the user to generate past, present and future data. This protocol is having an outstanding performance as it uses the best both proactive and reactive characteristics of the networks in order to provide data periodically and warnings in critical situations.

Stable-Election-Protocol (SEP):

This protocol takes in consideration the heterogeneity of sensor nodes, means each node has a different energy level as compared to other nodes. The CH election process in SEP involves the initial energies of participating nodes. This CH selection mechanism will extend the stability period and it is very important in many conditions where response from every sensor node is desired. In SEP network region is composed of a number of normal nodes (n) whose energy is E_0 and a fraction of advance nodes (m) with energy (α) times greater than normal nodes. Where α is energy factor. SEP maintains balance between energy consumption of normal and advance nodes to extend the stable region. In other words advance nodes are elected as clusterhead more often than normal nodes in order to maintain balanced energy consumption [8].

Let E_0be the normal node's initial level of energy, thus advance node's energy will be $E_0*(1 + \alpha)$. Hence the new heterogeneous network's total amount of energy will be:

$$n * (1 - m) * Eo + n * m * Eo * (1 + \alpha) = n * Eo * (1 + \alpha * m) \quad (1)$$

Hence total energy of WSN will be $(1 + \alpha) * m$times more than as compared to homogenous environment. This will increase the number of epochs in proportion to energy which is first improvement over conventional protocols like LEACH. To extend the stability period new epoch must be$1/popt * (1 + \alpha \cdot m)$, since the networks has $\alpha*m$ times greater energy and $\alpha*m$ more normal nodes.

Grey Wolf Optimizer:

Some of the optimization techniques that have been proposed earlier and gained popularity are Genetic Algorithm (GA), Ant Colony Optimization (ACO), and Particle Swarm Optimization (PSO) etc. In [9], particle swarm optimization (PSO) technique has been proposed to solve the problem of optimization in clustering nodes. This approach works similar to the swarm of bees or birds and tends to find a best solution for the described problem while working in group. These meta-heuristic methods evaluate the solution on the basis of some fitness function thereby reducing the energy consumption [9, 15].Another optimization approach proposed in [10] is Grey wolf optimizer method. This method is inspired from the hunting approach of the grey wolves which are considered to be top predators. Grey wolves generally move in pack of around 5 to 12 individuals. This optimizer actually works similar to the hunting behaviour of the grey wolf's pack. The hunting behaviour of the pack can be explained briefly as follows (Fig. 3):

1. Tracking, chasing and approaching the prey.
2. Pursuing, encircling and harassing the prey until it stops moving.
3. Attacking the prey.

The leader of the pack is called as alpha. It can be a male or female which makes decision on hunting, wake-up time, sleeping place etc. The rules/orders made by alpha are to be obeyed by the rest of the pack/group. Hence alpha possesses the to-most level in the hierarchy [10, 11].

The next order in the grey wolf pack is beta. The beta wolf is responsible for advising the alpha in decision making process and to make alpha's decision to be followed by other lower level pack. Beta can be male or female. He/she is responsible to maintain discipline among the pack. In case of alpha's death or similar circumstances, beta is the appropriate candidate to take alpha's place.

Fig. 3: Hunting behaviour of the pack[10]

The lowest level in the grey wolf hierarchy is omega. This category of wolf is dominated by all other wolves and has to surrender to the dominant wolves. Omega wolves have to follow all the orders given by the superior wolves. They are even allowed to eat at last when all other wolves finish eating. From this, it seems that omega wolves are not as important as other wolves.

Another level is delta level in the hierarchy. Delta wolves come at lower level than alpha and beta but at higher level than omega. Delta wolves have to surrender in front of alpha and beta but they dominate omega. This category of wolves is comprised of caretakers, elders, hunters and scouts. So there overall responsibility is to safeguard the pack and take care of pack concerning their heath and food. The hierarchy of grey wolves is shown in Fig. 4.

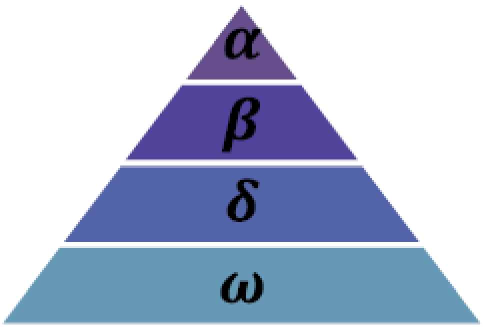

Fig. 4: Grey Wolf Hierarchy[10, 11]

The best solution in mathematical representation of social hierarchy of wolves while designing Grey Wolf Optimizer (GWO) is considered to be alpha 'α'. The 2nd and the 3rd best solutions are 'β' and 'δ' respectively. The hunting decisions are taken by α, β and δ wolves whereas 'ω' (omega) wolves obey above 3 wolves. Fig. 5 depicts the possible hunting locations and encircling behaviour of wolves.

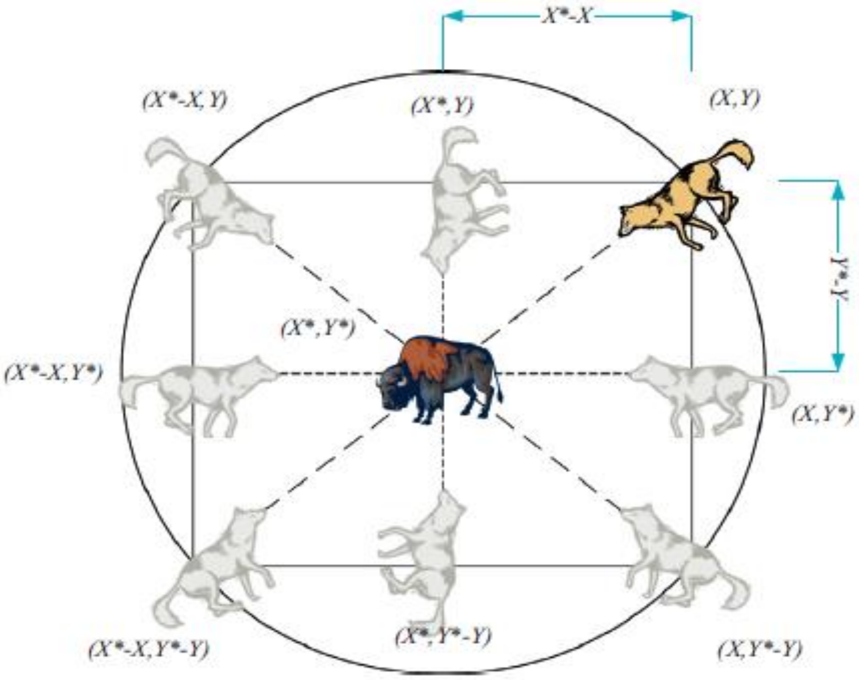

Fig. 5: Possible hunting locations and encircling behaviour of wolves [10,11]

The encircling behaviour of the wolves around its prey can be represented mathematically as follows:

$$\vec{D} = \left|\vec{C}.\vec{X}_p(t) - \vec{X}(t)\right| \tag{2}$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A}.\vec{D} \tag{3}$$

Where, X is the position vector of the wolf, A and C are coefficient vectors and t is the current iteration

Fuzzy Logic:

Fuzzy logic was proposed by LotfiZadeh in 1965[11]. This initial concept led to development of a multi-valued fuzzy logic concept was Boolean logic's extension. As stated by the author, Fuzzy Logic says rather than being accurate or exact provides a rough overview of the situation .So the data has to be precise and explain the exact situation in brief. If systems can adapt such ability their performance would be more efficient. Also increasing system complexity diminishes our capability to make exact statements about its behaviour unless it reaches a threshold beyond which accuracy and implication becomes totally unrelated [11]. Fuzzy logic was intended to manage flawed data, which in this present reality is more frequently the standard than the exemption. According to Zadeh fuzzy logic is the method of dealing with partial and undependable information. The operation of fuzzy logic is divided into fuzzy sets, fuzzy operators and if-then rules.

i. Fuzzy Sets:

The aggregated data which is available in the form of total information can be created into fuzzy sets. For example, the speed can be denoted by “0” for slow speed and by “1” for fast speed. But if the speed is between 0 and 1 then how its speed can be described? For such question fuzzy sets were created using membership functions. For example: Fuzzy set can be created as 0-0.25, 0.25-0.50, 0.50-0.75and 0.75-1 defining speed as slowest, slow, fast and fastest respectively. Membership functions (MF) for fuzzy sets have to follow certain fuzzy set rules and can be defined in such order only. The purpose of design and the MF shape defines the fuzzy set.

ii. Fuzzy operators

The conventional fuzzy set theory can be extended to a multi-valued fuzzy logic system if one can interpret the values of membership functions used to define rules [10]. Unlike the conventional Boolean theory which needs that there can only be two states possible either true (1) or false (0), fuzzy logic states that a fact is not always totally true or totally false. The degree of truthfulness and falseness can vary in the range of 0 to 1. In such a way a fact can be true, truer or less true and so on. Subsequently Boolean logic is viewed as a special fuzzy logic case where 0 and 1 is assigned to membership functions [12].

iii. IF-THEN Statement:

The basic rules/instructions which are predefined in order to describe the system’s working are known as If-Then rules. The behaviour of fuzzy logic system can be modelled in linguistic manner by some basic instructions that are easily understandable by machine, called as if-then rules [13]. These rules create a semantic relationship between situation and the action to be performed. Precisely if-then rules are the set of instructions that defines interaction of fuzzy sets and logic operators by means of membership functions.

Proposed Algorithm:

In this paper, we aim to achieve energy efficiency by using fuzzy logic for cluster formation and Grey Wolf Optimizer (GWO) for cluster head (CH)election. Hence the algorithm is divided into Part I and Part II as follow:

Part-I: Fuzzy logic based Cluster Formation:

Energy efficiency in WSNs can be achieved with the use of clustering techniques, in combination with traditional methods such as LEACH, TEEN, APTEEN, HRP, SEPetc. Utilize minimum distance criteria for cluster formation even though the residual energy parameter is not considered by them. Network connectivity could be at risk if a node connects to such a cluster with nearly dead CH. This could be a case where network operation gets suspended. To avoid this problem a smart cluster forming solution based on fuzzy logic is utilized in this research. Here, during the cluster formation each node evaluates the parameters such as residual energy, distance to BS and distance to CH and on this basis decides its probability of being connected to any available CH. The architecture of fuzzy cluster formation protocol is shown below:

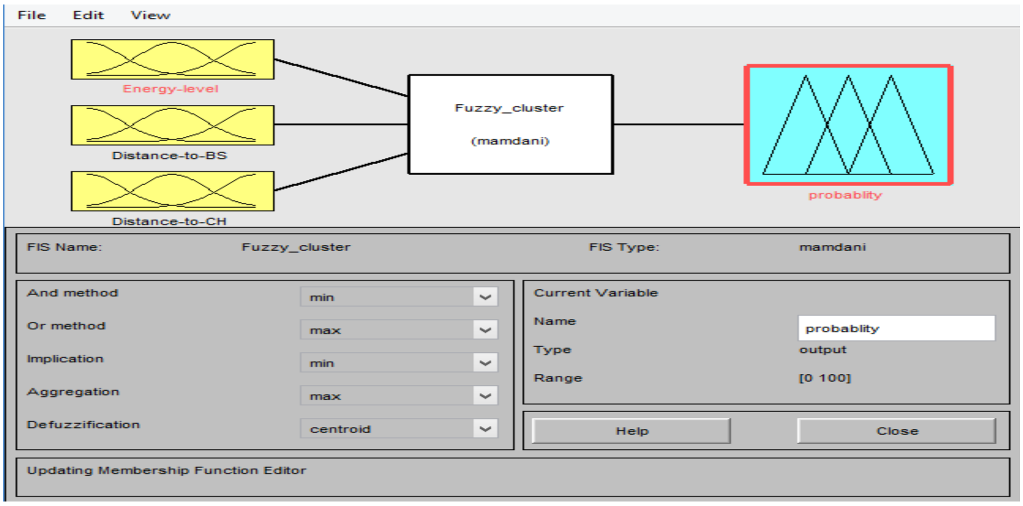

Fig. 6 : Architecture of Fuzzy Cluster Formation Protocol

Fig. 6 illustrates FIS system based on Mamdani's model. Three input variables i.e. energy level, distance to BS and Distance to CH are used to model the output variable "Probability" through a set of 27 rules given as follows.

If	Energy	Distance to BS	Distance to CH	Then	Output
IF	Low	Reachable	Reachable	THEN	18
IF	Low	Reachable	Considerable	THEN	9
IF	Low	Reachable	Far	THEN	19
IF	Low	Considerable	Reachable	THEN	3
IF	Low	Considerable	Considerable	THEN	6
IF	Low	Considerable	Far	THEN	17
IF	Low	Far	Reachable	THEN	1
IF	Low	Far	Considerable	THEN	2
IF	Low	Far	Far	THEN	11
IF	Adequate	Reachable	Reachable	THEN	16
IF	Adequate	Reachable	Considerable	THEN	20
IF	Adequate	Reachable	Far	THEN	24
IF	Adequate	Considerable	Reachable	THEN	7
IF	Adequate	Considerable	Considerable	THEN	8
IF	Adequate	Considerable	Far	THEN	21
IF	Adequate	Far	Reachable	THEN	4
IF	Adequate	Far	Considerable	THEN	5
IF	Adequate	Far	Far	THEN	10
IF	High	Reachable	Reachable	THEN	25
IF	High	Reachable	Considerable	THEN	26
IF	High	Reachable	Far	THEN	27
IF	High	Considerable	Reachable	THEN	13
F	High	Considerable	Considerable	THEN	15
IF	High	Considerable	Far	THEN	23
IF	High	Far	Reachable	THEN	12
IF	High	Far	Considerable	THEN	14
IF	High	Far	Far	THEN	22

Here we are using three input parameters i.e. Energy, Distance to BS and Distance to CH. For each parameter we are considering 3 cases which give 27 total probable conditions. These conditions are stated in the above table. A fuzzy relation is a relationship between input variables, described by a membership function. Triangle and Trapezoidal membership functions are mostly used because their degree is more easily determined. When we double click on any of the input (yellow plot) of FIS variables, the membership function opens up. We can adjust the desired input by clicking anywhere in the plot. This will let changed value be highlighted with red index line. Same procedure is followed to modify other input values. When we release the line, a new calculation is performed and we can see the fuzzy process taking place.

Part-II: Grey Wolf Optimizer based CH election:

Once the clusters are formed, we are left with the M number of clusters. Now the task is to elect one CH in each cluster using grey wolf algorithm. The CHs will be selected by comparing the node's position in the cluster with the grey wolf hierarchy.

The energy model used for system analysis is depicted in Fig. 8.

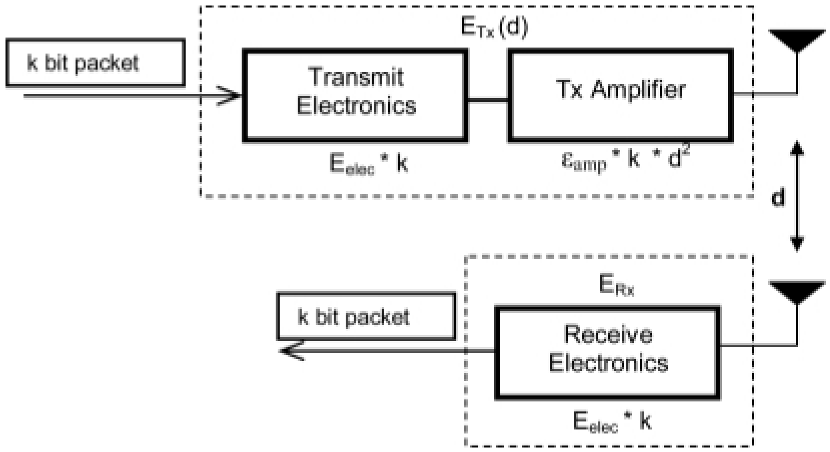

Fig. 8: Energy dissipation Model [15]

The sensor nodes are comprised of a transmitter and a receiver. Hence when a node transmits E_{Tx} amount of energy is dissipated in transmission which is given as:

$$E_{T_x}(l,d) = \begin{cases} L.E_{elect} + L.\epsilon_{fs}.d^2 & if\ d < d_0 \\ L.E_{elect} + L.\epsilon_{mp}.d^4 & if\ d \geq d_0 \end{cases} \quad (4)$$

Where, E_{Tx} is the Energy dissipated during transmission, E_{elect} is the Energy dissipated per bit of transmitter and receiver.ϵ_{fs} is the Energy dissipated due to free space path loss,$\epsilon_{mp}$is the Energy dissipated due to multipath propagation and d is the distance between transmitter and receiver.

If $d=d_0$, then from Equation (4), we get :

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \quad (5)$$

The energy dissipated at receiver is given as:

$$E_{R_x} = L.E_{elect} \quad (6)$$

The optimal probability for the cluster head election of a node is given by:

$$p = \frac{k}{n} \quad (7)$$

If the concept of alive nodes is used in Equation (7), then the optimal no. of CHs derived for no. of alive nodes (n_{alive}) will be:

$$K_{opt} = \frac{p}{n_{alive}} \quad (8)$$

Where,K_{opt} is optimal number of CHs and n_{alive} is the no. of alive nodes for the existing round. The main task of GWO algorithm is to find the optimal number of cluster-heads so that the number of alive nodes in each round will be maximized.

Experimental Setup

For our simulation study an area of 100x100 meter square has been considered with 100 nodes deployed uniformly. We have simulated the performance of LEACH and proposed clustering algorithm for heterogeneous environmental conditions with the simulation parameters as described in Table-1 below.

TABLE 1: SIMULATION PARAMETERS

Field Dimension	100x100 $\boldsymbol{m^2}$
Number of Nodes	100
Election Probability	0.1
Percentage of heterogeneity	0.1, 0.2
$\boldsymbol{\alpha}$	2, 3
Number of Rounds $\boldsymbol{r_{max}}$	30000

TABLE 2: ENERGY DISSIPATION OF WIRELESS SENSOR NETWORKS

Network Operation	**Energy Dissipation**
Transmitter/Receiver Electronics	E_{elect}= 50*nJ/bit*
Data Aggregation	E_{DA}= 5*nJ/bit/report*
Transmit Amplifier if $d_{toBS} \leq d0$	ϵ_{fs}= 10*pJ/bit/m*2
Transmit Amplifier	ϵ_{mp}= 0.0013*pJ/bit/m*4

if $d_{toBS} \geq d0$	

Simulation Results:

To compare the performance of proposed scheme with conventional LEACH based scheme, Network lifetime, Throughput and Number of elected Cluster Heads are chosen as reference parameters. Simulation results given in fig-(10, 11 and 12) shows that the proposed scheme has better stable and unstable period as compared to conventional scheme while the numbers of Packets delivered to Base station are much less resulting in much lower overhead at Base Station. Furthermore the proposed scheme also provides less number of Cluster-Heads.

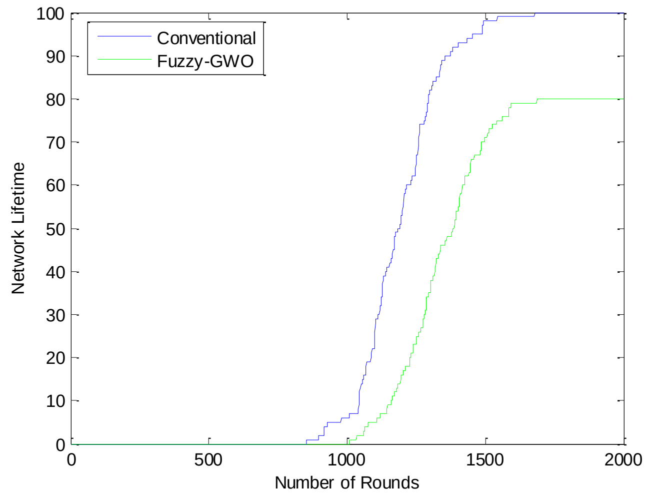

Fig. 9: Comparison of Lifetime for conventional and Proposed Fuzzy-GWO scheme

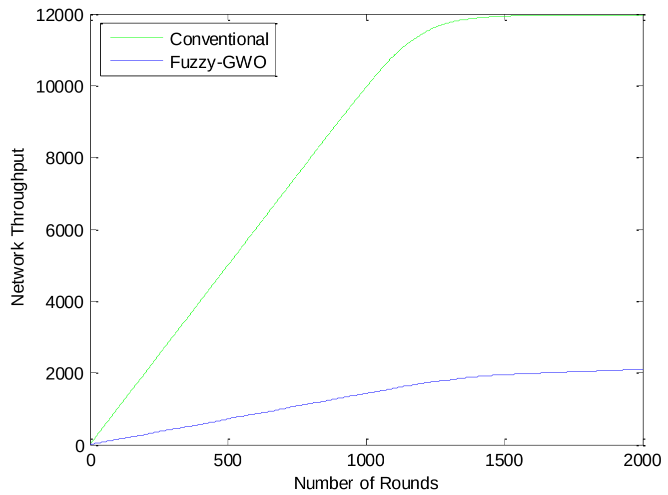

Fig. 10: Comparison of Network Throughput for conventional and Proposed Fuzzy-GWO scheme

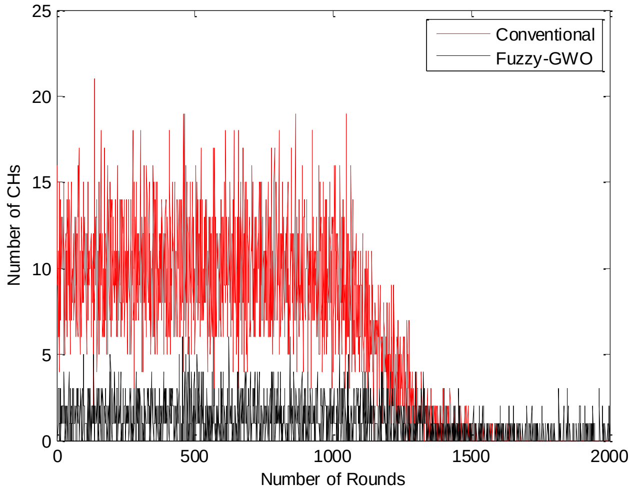

Fig. 11: Comparison of Number of CHs Elected for conventional and Proposed Fuzzy-GWO scheme

Conclusion:

This research work is focused towards the development of energy efficient Clusterhead election and cluster-formation scheme. For this purpose, this work incorporates fuzzy based cluster formation scheme and Grey wolf optimization based clusterhead election scheme. To evaluate the performance of proposed scheme a MATLAB based framework has been developed. Simulation results based on Network lifetime and Throughput are presented and compared with conventional LEACH based scheme. Simulation results shows that proposed scheme outperforms conventional scheme in both Stable and Unstable period of network operation.

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