Available online at www.ijsrnsc.org
IJSRNSC
Volume-6, Issue-3, June 2018
Research Paper
www.ijsrnsc.org
Int. J. Sc. Res. in
Network Security
and Communication
ISSN: 2321-3256

A Nature Inspired Optimal Path Finding Algorithm to Mitigate Congestion in WSNs

G.P. Sunitha[1*], B.P. Vijay Kumar[2], S.M. Dilip Kumar[3]

[1*]Dept. of Information Science and Engineering, Jawaharlal Nehru National College Of Engineering, Shivamogga, India
[2] Dept. of *Information Science and Engineering, M S Ramaiah Institute Of Technology*, Bangalore, India
[3] Dept. Computer Science and Engineering, University Visvesvaraya College of Engineering, Bangalore, India

[*]Corresponding Author: *sunithagp17@gmail.com* , Tel.: 7829915422

Received: 26/May/2018, Revised: 06/Jun/2018, Accepted: 18/Jun/2018, Published: 30/Jun/2018

Abstract— In resource constrained wireless sensor networks, congestion control is an extremely important issue that need to be addressed. The individual capacities of the channels are exceeded by the bulk traffic and creates adverse effects on the performance of the network. Therefore, to resolve the congestion problems in wireless sensor network the challenge lies in developing more sophisticated routing techniques which are able to fairly deliver the data between source and destination with minimum consumption of energy and reduced congestion. In the recent times, various swarm intelligence based routing approaches are proposed that aided in congestion detection and control mechanisms. Most of them are found to be with lower convergence rate. Therefore, a nature inspired hierarchical routing technique which aims to reduce congestion and energy consumption with network longevity and faster convergence rate is proposed. In this technique, a static partition of the target area based on node density is done to optimize energy efficiency. Firefly behavior based routing is modeled to select the optimal path for data transmission. This approach is concerned with exploiting global behavioral patterns emerging from local interactions. The proposed technique aims to minimize congestion by applying network load balance.

Keywords—Congestion, optimal path, Energy

I. INTRODUCTION

A. Motivation

Congestion in wireless sensor network (WSN) is a complex issue in the limited resource WSN. To prevent the traffic loss in bulk, congestion control is considered of critical importance. It is considered as a promising area of research as network traffic is a time varying factor and it adversely affects the network performance in terms of packet loss, energy wastage, decreasing throughput and early collapse of the network. Therefore, congestion control is seeking the attention to achieve maximum network throughput and lifetime with optimal utilization of the available resources. In the WSN literature, Syed Afsar Shah et al., [1] several routing mechanisms such as multi-path routing, hierarchical routing and flow based routing are proposed to minimize congestion. Most of the mechanisms suffers from drastic energy drain and data implosion. Therefore, in the resource constrained WSN the design of routing protocols which minimizes congestion with energy conservation still remains a challenge.

Currently, nature-inspired routing protocols have emerged as an efficient solution to address routing problems in WSN Muhammad Saleem et al., ad WenjingGuoet et al., [2],[3]. In these intelligent protocols, the behavior of biotic communities and swarms are modeled and applied to a variety of networking problems. Hence, this paper focuses on routing in WSN that bears similarities to communication in biotic societies and swarms and focus on their propagation phenomena in routing.ontributions

In a large WSN that consists of n sensor nodes, the computational complexity of creating hierarchical topology and finding optimal route with congestion management is very high using brute-force approaches. In order to obtain less complex, faster and efficient solution of routing to achieve congestion mitigation and energy efficiency a nature-inspired swarm intelligence approach such as firefly optimization algorithm is investigated. The main objective formed is to develop a hierarchical firefly based routing algorithm for WSN with the consideration of congestion control and energy consumption, The main contributions of our proposed work are listed as follows:

- To maximize network lifetime through the formation of un-equal sized clusters based on node density.
- Derivation of efficient fitness function in making of routing decision with control of congestion.
- Provides local optimization to control the global network performance.
- Analyzing the proposed algorithm over its strength with existing algorithms.

B. Problem Statement

In a WSN of *n* sensor nodes, where each sensor node acts as a source/relay node, and WSN is considered as $G = (V,E)$ Where V is a set of vertices and E is the set of edges connecting vertices. There exists a node $BS \in V$ called the destination for all sensor nodes in the network. To transmit the data each source node $s_i \in V$ must select a next hop node $s_j \in V$ *where* $(s_i, s_j) \in E$ such that (s_i, s_j) should be an uncongested and energy efficient path towards *BS*. Reliable and energy efficient data delivery from source to destination is provided through hierarchical routing protocol. The routing decision is simulated through communication behaviors of the fireflies.

C. Outline of the paper

Various phases and aspects of the proposed technique is presented in different sections and the paper is organized as follows: Section II explores the existing works related to proposed technique with merits and demerits. The system model assumed and notations used in the algorithm are presented in Section II-A. Section III discusses the proposed technique with details of cluster formation and firefly routing algorithm. Section IV presents experimental setup and performance evaluation. Section V concludes the paper.

II. LITERATURE REVIEW

In a resource constrained WSN, the problem of congestion control and energy consumption is not new to the research community. A lot of research activities has done to develop efficient routing techniques to achieve congestion control and energy preservation. The routing algorithms are optimized by adopting the propagation behaviors of the biotic community. In this regard, a detailed overview of selected works on bio-inspired routing in WSN to address congestion control, hotspot and energy efficiency problems is discussed in this section.

In Mukhdeep Singh Manshahia et al., [4] proposed a congestion control algorithm based on bats behavior. A fitness function is formulated to predict congestion through throughput and energy. This algorithm convergence rate is slow as it considers entire population where as, the proposed algorithm wisely chooses the permutations which are nearer to solution and reduces complexity of the algorithm and achieves faster convergence.

A leapfrog based transmission congestion control protocol is proposed in Jia Dongyao et al., [5]. The protocol detects congestion using residual energy in a path satisfaction model and adopts multi-path flow to control congestion. This protocol has limited ability to predict congestion as it uses only residual energy. Multi-parameter efficient routing decision used in the proposed technique chooses less congested path.

An energy efficient congestion control algorithm is presented in Antoniou et al., [6] using flocking behavior of birds. Congestion is detected using node loading indicator which measures the buffer occupancy and is controlled in a hop-by-hop manner. This algorithm provides suboptimal solutions of longer path length and suffers with more control packet overhead. Static hierarchical topology used in the proposed technique yields suboptimal solutions of shorter tour length.

In Lalwani et al., [7] and Manshahia et al., [8] authors have implemented a general firefly algorithm for route establishment and congestion control. They considered some solutions among *n!* permutations to initialize the population. This increases the searching complexity and selection of inappropriate solutions. Proposed technique overcomes it by choosing fewer appropriate permutations.

In the WSN literature, we have explored some of the intelligent protocols which are focused on energy efficiency. One such algorithm is developed in Ho et al., [9]. A ladder diffusion algorithm uses *ACO* to reduce power consumption. It uses backup routes to avoid energy wastage. This requires processing time in building and updating routing table where as proposed technique does not require routing table.

A hierarchical routing based on honeybees swarm intelligence is designed in Ari et al., [10]. In this approach a cost function is derived on energy and hop counts to make routing decision. The algorithm is found to be a centralized control algorithm. An evolutionary tabu search routing protocol is proposed in Orojoo et al., [11]. This method integrates energy and hop counts to make routing choice. The drawback lies in maintaining the tabulists for multiple paths. A number of nature-inspired routing algorithms based on swarm intelligence have been reported for congestion control, energy efficient routing and hotspot problems but, they found to be not suitable for large networks, ignores the energy factor and of slower convergence rate.

A. System Model and Notations

The assumed network model used for the proposed technique and notations used in cluster and routing algorithms is discussed in this section.

I. System Model

We consider a WSN in a target area of $X \times Y$ dimension. A set of *n* heterogeneous sensor nodes $S = \{s_1, s_2, \ldots, s_n\}$ are deployed randomly in the target area. All the sensor nodes become stationary after deployment. A set of clusters $C = \{c_1, c_2, c_3, \ldots, c_m\}$ are formed from the zones $Z=\{z_1, z_2, \ldots, z_k\}$ where n>k>m. A set of leaders chosen to the clusters are $CH = \{CH_1, CH_2, CH_3, \ldots CH_{m-1}, BS\}$.All the communications are over symmetric wireless links which are established between two nodes if they lie within the communication range. The approximate distance between the nodes is computed based on the received signal strength.

II. Notations

The notations used in cluster formation and routing algorithms is defined as in TABLE 1.

TABLE 1 : Notations used in the proposed algorithm

Notation	Definition
δ_{zi}	Represents the total number of nodes in the i^{th} zone
δ_{avg}	Is the average node density of the network
$zone_{type}$	Indicates the type of the zones L, M and H
E_{resi}	Is the remaining energy of the node s_i
Dist (s_i, s_j)	Euclidian distance between sensor nodes i and j
I	Represents the brightness of the firefly
B_{ML}	Maximum queue length initialized in a node
B_{CUR}	Number of data packets buffered in a node at any time instance t
Q_{ideal_th}	The threshold value used to vary the queue buffer
R_{max}	Is the maximum transmission range
PacketLoad $=B_{CUR} / B_{ML}$	Represents queue length
Nexthop(s_i)	One hop neighbor node
TransCost	Transmission cost for sending one data packet

III PROPOSED TECHNIQUE

The proposed technique consists of two phases namely cluster formation and route establishment. The cluster formation process is explained in III-A and routing is presented in III-B.

A. Cluster Formation

The operation of the cluster formation in the proposed technique is as follows. At the beginning , target area is partitioned into equal sized zones. Then, the network undergoes bootstrapping process in which base station BS assigns unique z_{id} to all the zones as $z_i\,(\,i,a,b\,)$ where $i = \{1,2,3,...,k\}$, where *a* and *b* are zone co-ordinates and *i* is the z_{id}. Using the z_{id} all the sensor nodes are mapped to unique zones. The reader is referred to Sunitha G P et al., [12] for assigning z_{id} and node mapping algorithms. Example of assigning z_{id} is shown in Fig. The distance between any two zones z_i and z_j can be calculated as $l = \max\,(\,|z_i.a - z_j.a|, |z_i.b - z_j.b|)$. The zone are classified as low *(L)*, medium *(M)* and high *(H)* density zones based on their node density. Static unequal sized clustered topology is designed by merging horizontally or vertically adjacent *(L,L)* and *(L,M)* zones.

The reason for excluding the merge of diagonally adjacent zones is illustrated with the Fig.1. Let the maximum distance between any two arbitrary nodes in horizontally adjacent zones be *x* and is *y* for vertically adjacent zones. Then, the distance between the diagonal zones is calculated as $d = \sqrt{x^2 + y^2}$. As, the distance between the nodes in the diagonal zones is more, they are not considered for merging. Two adjacent zones merging guarantees communication between any two arbitrary nodes from the zones.

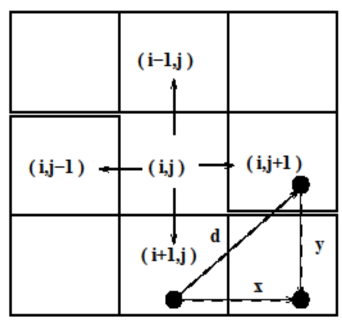

Fig 1: Zone Merging

This clustered topology is significant for the following reasons:

- Avoids redundant data transmission in adjacent sparse regions and preserves energy consumption
- Eliminates isolated node problems.
- Increases the node availability near and around the sink and minimizes hotspot problem.

The cluster head *(CH)* selection is a crucial task in clustered architecture as the overall network performance is dependent on leaders. These *CHs* are responsible for transmitting data from their group members and neighbor *CHs* to the *BS*. The node in the cluster that has maximum residual energy and minimum distance from the sink is selected as *CH*. The cluster formation process and *CH* selection is presented in Algorithm 1. The output of cluster formation is shown in Fig.

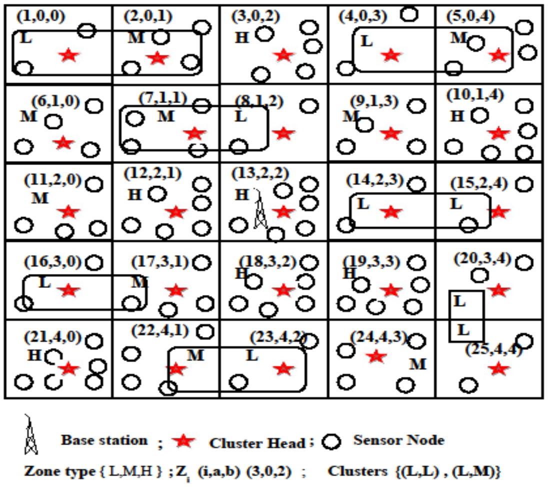

Fig 2: Cluster Formation

Algorithm 1: Algorithm for Cluster Formation and Cluster Head Selection

---

Input : Target_area $X \times Y$ and R transmission range
Output : Dividing the target area into m clusters
$C = \{ C_1, C_2, C_3, \ldots, C_m \}$
/* Divide the target_area into equal sized zones */
1. k $\leftarrow \frac{Target_{area}}{\frac{R}{\sqrt{2}}}$
2. Map all the nodes to unique zones
3. Determine the number of nodes present in each zone δ_{zi}
4. $\delta_{avg} \leftarrow \frac{\sum_{i=1}^{k} \delta zi}{k}$
/* Classify the zones into L, M and H zones */
5. **for** i $\leftarrow$ 1 **to** k **do**
6. **if** $\delta_{zi} < \delta_{avg}$ **then**
7. $zone_{type} \leftarrow$ L
8. **else if** $\delta_{zi} >= \delta_{avg}$ && $\delta_{zi} < \delta avg + 0.25 * \delta avg$ then
9. $zone_{type} \leftarrow$ M
10. **else**
11. $zone_{type} \leftarrow$ H
12. **end**
13. **end**
14. Merge (L,L) and (L,M) horizontally and vertically adjacent zones into clusters
15. m $\leftarrow$ k - cnt
/* Where cnt is the total numbers of clusters formed */
16. **for** i $\leftarrow$ 1 **to** m **do**
17. $CH_i \leftarrow \frac{max(Eresi)}{min(dist(si,BS))}$
18. **end**

B. Firefly based Routing

The proposed firefly based route establishment in inter CHs and intra clusters has the ability to make path selection in the network through multiple parameters like energy consumption, buffer occupancy and hop distance to BS. This technique allows to determine the least resource conserving path to the destination at any instance of time. in this technique, local optimal parameter values controls traffic balancing throughout the network thus minimizing congestion and energy consumption. This technique ensures valid route decisions in searching paths with energy efficiency. The general description of the firefly algorithm (FA) is explained in Section III-a and the proposed technique is presented in Section III-b.

a. General Description of Firefly Behavior

Firefly algorithm is a recently evolved meta-heuristic algorithm. Social behavior of fireflies leads to the nature inspired FA. Most fireflies produces short and rhythmic flashes and uses this flashes to attract other fireflies. All the FAs uses the following three idealized C Yogarajan et al., [12] rules:

- Regardless of the gender fireflies attracts other fireflies.
- Firefly with less brightness move towards the brighter ones and
- Value of the objective function determines the brightness of the firefly.

b. Proposed Firefly Routing Algorithm

A discrete firefly algorithm proposed in Jati G et al., [13] is used in this paper to establish uncongested path for data transmission. In this technique, there are *n* fireflies in total with each firefly denoted by $x_i = \{ x_{i1}, x_{i2}, \ldots, x_{iD} \}$ in which D is the space dimension of the situation. The initial population is taken as some random permutations of n. Light intensity of the fireflies determines its movement. The fitness function used to derive intensity is formulated as in Eq. (2).

$$A = \alpha \times \text{TransCost} + \beta \times \text{PacketLoad} \ \ldots. \quad (2)$$

Where α and β are weighted parameters with $\alpha + \beta = 1$

The objective is to minimize A subjected to

C1 : $dist(S_i, nexthop(S_j)) \leq R_{max}$

C3 : TransCost $\leq E_{res}$

C2 ensures the avoidance of congestion, C1 and C3 ensures the reduction of transmission cost.

Firefly intensity is calculated as in Eq. (3)

$$I = \frac{1}{\sum An + \sum \text{dist}(s_i, s_j)} \ldots. \quad (3)$$

To establish the route, random firefly solution set is initialized from total *n*! population. Light intensity of each firefly in a solution is calculated. More brighter firefly attracts the less brighter one. Movement of one firefly to other is based on edge swap movement. The best solution is selected after all fireflies move. The solution selected is considered as the population for next generation. The procedure is repeated for suitable number of iterations. The global best firefly obtained is the optimal path chosen for data transmission. The algorithm steps are given in Algorithm 2.

Algorithm 2: Firefly routing algorithm

Input : n, no_of_iterations
Output: Routing path

From source node find all possible paths P[u] on applying DFS algorithm
/* To initialize the population keep source and destination constant and generate permutations of intermediate nodes of all paths */
IS ← [ ]
for i ← 1 **to** u **do**
    t ← randomperm(P[u])
    IS ← IS **U** t
end
calculate the intensity $I(F_i)$ of each firefly
p ← 1
while p < = no_of_iterations **do**
    for i ← 1 **to** n **do**
        for j ← 1 **to** n **do**
            if $I_{Fi} < I_{Fj}$ **then**
                move F_i towards F_j
                update the intensity of new solution obtained
            end
        end
    end
        Find the current best solution
    p ← p + 1
end
Process the obtained global solution for route establishment

The optimal route establishment steps are illustrated with an example in Fig. 3.

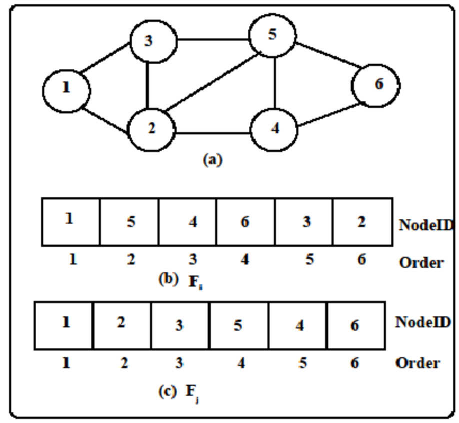

Fig 3: Firefly Representation

A WSN consisting of 6 nodes as in Fig. 3(a) is considered for illustration. A sample firefly is represented in Fig. 3(b) where *nodeID* represents the *id* of the node and order represents node sequence. One firefly represents one path for data transmission i.e one solution. For *n* fireflies *n!* is the total number of solutions. If source and destinations are fixed then there are *(n-2)!* solutions exists. The solution size is still reduced on taking the permutations in depth first search *(DFS)* paths. In the proposed algorithm the solution size is reduced to fasten the convergence rate. In the example Fig. 3(a) there are *6!* solutions if, source and destinations are fixed then solution set size is reduced to *4!*. If permutations of the *DFS* paths are chosen then size is still reduced. For example, *DFS* paths chosen for Fig 3(a) are *P[] = { P[1]=(1,2,3,5,4,6), P[2]=(1,3,2,4,5,6) }*. For *P[1]* keeping *1 and 6 constant , 2,3,4 and 5* are permuted to generate other solutions. Same procedure is repeated for P[2]. These permutations are used to initialize the population.

For each firefly intensity value which depends on total length of the route, average payload and transmission cost is calculated. Brighter firefly attracts the less intensity firefly. Suppose firefly F_i has to move towards F_j the distance between the fireflies is calculated. It is the number of mismatches in the permutation sequence. The hop swaps or edge swaps has to be performed on F_i to obtain F_j. The distance between F_i and F_j shown in Fig 3(b) and 3(c) is 5. To move F_i to F_j hops (5,2), (4,3) and (5,6) are swapped. Each swapping leads to new solution and is considered as an updating value. The best updated value is selected as the best solution. The next iteration is continued in the similar way considering the current solution as best local solution. When the maximum number of iterations are completed best global solution is obtained. The global solution obtained represents the optimal path.

c. Congestion Mitigation

The congestion in the proposed algorithm is detected through fitness function as in Eq. (2). The congestion is detected in terms of buffer occupancy and transmission cost. It is defined as the total energy required for packets transmission. Higher the value of A indicates the congested node. A firefly representing a path with such nodes results with minimum intensity. In the algorithm such fireflies are avoided while finding the optimal path. In this manner the proposed algorithm mitigates the congestion in an efficient way.

III EXPERIMENTAL EVALUATION

The proposed technique is implemented using MatlabR2013. The experiments were conducted for target area of *100m × 100m*. Random deployment of *100 to 150* nodes is used to analyze the technique. The transmission range is varied from *40m to 60m*. The value of γ taken for the experiment is *0.01*. Initial population of fireflies considered is *30*. We have extensively tested the proposed technique and depicted results by combining congestion control and energy efficiency. Proposed technique is compared with ant colony optimization *(ACO)* [9] and existing firefly algorithm for congestion control [8]. We have obtained impressed results through the proposed algorithm than other two protocols in terms of packets received at *BS*, energy consumption, network lifetime, average path length and packet delivery rate.

1. **Network lifetime:** Network lifetime is strongly reflected by the survival of individual nodes. The nodes of *ACO* starts to die first followed by those of existing firefly and proposed technique. The energy saving strategy of the proposed technique delays the death of *CHs* at early stages. Minimizing data transmission at sparse region of the network conserves energy of the nodes. Fig 4 shows that at later part of the simulation time the proposed technique outperforms the existing algorithms. The survival rate is 2.8% and 11.7% better than the existing *FA* and *ACO* algorithms respectively.

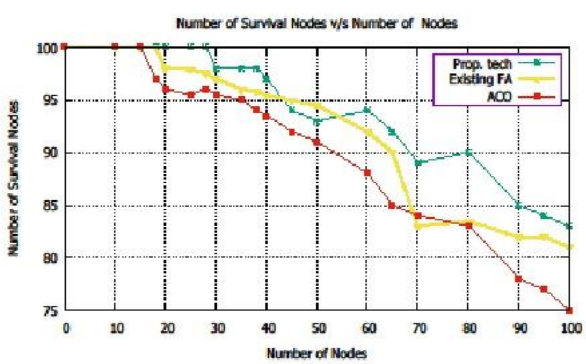

Fig 4: Network Lifetime

2. **Packet received at BS:** We have evaluated the performance of the proposed technique with other two algorithms in terms of packet received at BS. The proposed technique always chooses uncongested path for data transmission providing reliable data delivery. Therefore, it has shown better performance than the other two algorithms. From Fig 5 we can observe that the proposed technique shows 15% and 22% improvement over existing FA and ACO respectively.

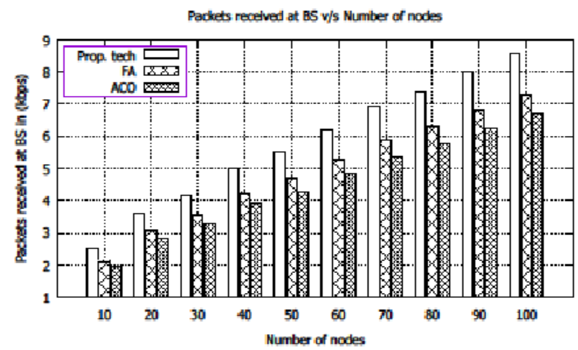

Fig 5: Packets received at BS

3. **Total energy consumption:** From Fig 6 we claim that proposed algorithm gives promising results than other two. The reason is because of hierarchical topology and merging of sparse region nodes. This energy balancing both at inter and intra cluster levels minimizes the energy consumption of the proposed technique.

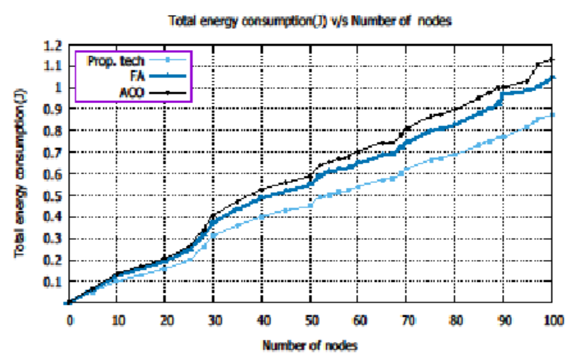

Fig 6: Total energy consumption

4. **Packet delivery ratio (PDR):** The *PDR* is studied by increasing the number of sources in the network. Increasing the sources reduces *PDR* as it increases network traffic and probability of network congestion. In case of our proposed technique, the rate of decrease in *PDR* is small when compared to other algorithms. This is due to the avoidance of hotspots and bottleneck nodes. Multiple parameters in routing decision selects uncongested path and reduces packet loss and improves *PDR*. Fig 7 shows *PDR* of proposed technique is 20% better than *FA* and 25% better than *ACO*

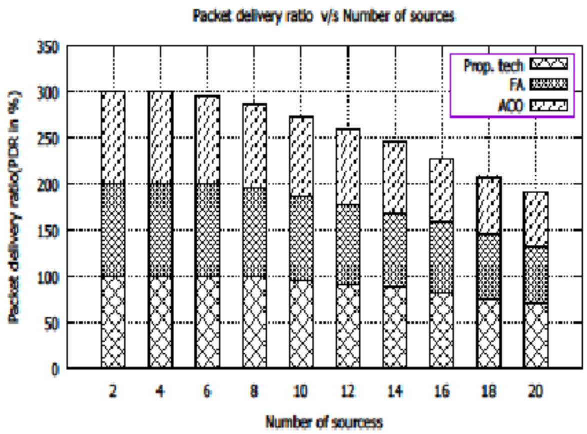

Fig 7: Packet delivery ratio

5. **Average path length:** Nature inspired routing protocols gives optimal as well as suboptimal paths as solutions. Proposed technique reduces the average hops as it uses hierarchical structure. It shows the steady behavior on increasing the network size. From Fig 8 we can infer that the proposed algorithm outperforms the other two methods. It reduces path length by 2.2% by existing *FA* and 2.5% by *ACO.*

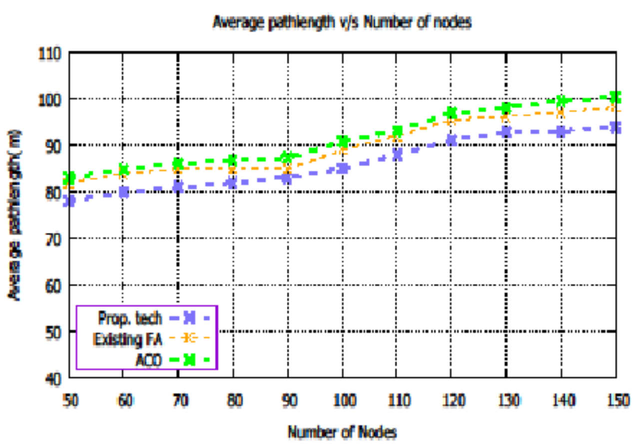

Fig 8: Average pathlength

6. **Average queue length:** The number of packets accumulated at queue determines the degree of congestion. It effects on energy-utilization as well as data transmission. Proposed technique considers both buffer occupancy and energy consumption for deriving fitness function. From Fig 9 we can conclude that the proposed technique buffer management is better than other two methods. It is achieved through efficient maintenance of queues on avoiding packet accumulation at *CHs* and nodes.

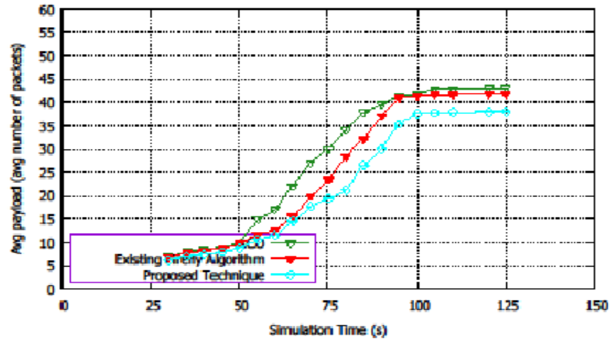

Fig 9: Average pathlength

7. **Fitness function value :** From Fig 10 we can analyze the variation of fitness function with respect to payload and residual energy. The minimum fitness function gives maximum intensity. For minimum payload and maximum energy, minimum fitness value is obtained. For maximum payload and minimum energy maximum fitness value is obtained. We have chosen α = 0.5 and β = 0.5 in our experiments.

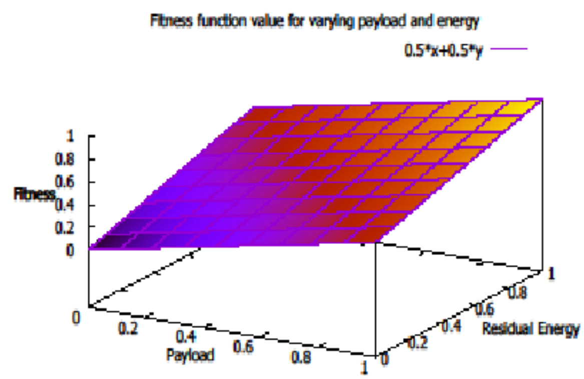

Fig 10: Fitness function value

V CONCLUSION

To solve congestion and energy efficiency problem in WSN a nature-inspired hierarchical routing is proposed in this paper. This technique is centered on the idea of simulating firefly behavior for communication. In the proposed technique, a static clustering based on node density is designed to achieve energy balancing. Congestion in the network is detected through a fitness function in terms of energy, buffer and distance. Route establishment decisions are determined by firefly movements. All firefly movements towards one firefly generates global optimal solution. Simulation results shows the proposed technique performs better than direct diffusion algorithm using *ACO* and existing firefly algorithm, for congestion control in terms of *PDR*, network lifetime, energy consumption and pathlength. This ideally makes the proposed algorithm suitable for diverse *WSN* applications.

REFERENCES

[1] Imran Ali Khan, Syed Afsar Shah,Babar Nazir, "Congestion control algorithms in wireless sensor networks: Trends and opportunities", Journal King Saud Universit,y Vol.29, Issue.3, pp.236-245, Elsevier 2017.

[2] Muhammed Saleem, Gianni A Di Caro, Muddassar Farooq "Swarm Intelligence based routing protocol for wireless sensor networks: Survey and future directions", Information Sciences, Vol.181, Issue 20, pp.4597-4624, 2011.

[3] Guo,Wenjing and Zhang wei "A survey on intelligent routing protocols in wireless sensor networks",Journal of Network and Computer Applications, Vol.38, pp.185-201, Elsevier 2014.

[4] Mukhdeep Singh Manshalia, Myank Dave and Satya Bir Singh "Computational intelligence for congestion control ad quality of service improvement in wireless sensor networks", Transaction on Machine Learning and Artificial Intelligence, Vol.5, Issue 6, pp.21, 2017.

[5] Jia Dongyao, Zou Shengxiong Li Meng and Zhu Huaihua "Adaptive multi-path routing based on an improved leapfrog algorithm", Information Sciences, Vol.367, pp.615-629, 2016.

[6] Pavlos Antoniou, Andreas Pitsillides, Tim Blackwell, Andries Engelbrecht and Loizos Michael. "Congestion control in wireless sensor networks based on bird flocking behavior", Computer Networks Vol.57, Issue 5, pp.1167-1191, 2013.

[7] Praveen Lalwani, Isha Ganguli and Haider Banka "FARW: Firefly algorithm for routing in wireless sensor networks", In Recent Advances in Information Technology(RAIT), pp.248-252, IEEE 2016.

[8] Mukhdeep Singh Manshalia, Myank Dave and Satya Bir Singh, "Congestion control in wireless sensor networks based on bioluminescent firefly behavior", Wireless Sensor Networks Vol.7, Issue 12, pp.149, 2015.

[9] Jiun-Huei Ho, Hong-Chi Shih, Bin-Yih Liao and Shu-Chuan Chu " A ladder diffusion algorithm using ant colony optimization for wireless sensor networks", Information Sciences, Vol.192, pp.204-212, 2012.

[10] Ado Adamou Abba Ari, Blaise Omer Yenke,Nabila Labraoui,Irepran Damakoa and Abdelhak Gueroui, "A power efficient cluster-based routing algorithm for wireless sensor networks: Honeybees swarm intelligence based approach", Journal of Network and Computer Applications, Vol.69, pp.77-97, 2016

[11] Hameed Orojloo and Abolfazl T Haghighat "A tabu search based routing algorithm for wireless sensor networks", Wireless Networks, Vol.22, Issue 5, pp.1711-1724, 2016.

[12] G P Sunitha, S M Dilip Kumar and B P Vijaya Kumar "Energy balanced zone based routing protocol to mitigate congestion in wireless sensor networks", Wireless Personal Communications, Vol.97, Issue 2, pp.2683-2711, Springer 2017.

[13] G Yogarajan and T Revathi,"Nature inspired discrete firefly algorithm for optimal mobile data gathering in wireless sensor networks", Wireless Networks, pp.1-15, Springer 2017.

Jati Gilang Kusuma and others,"Evolutionary discrete firefly algorithm for travelling salesman problem", In Adaptive and Intelligent Systems, pp.393-403, Springer 2011.