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ANN Based Framework for Energy Efficient Routing In Multi-Hop WSNs

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***Abstract* –** This paper proposes a soft computing based framework for optimal cost path routing in the large scale WSNs. The proposed approach works in two phases; initialization phase and the operational phase. In order to evaluate route costs, the paper first proposes an ANN based integrated link cost (ILC) measure. ILC is a function of residual sensor node energy, average end to end delay (EED) and network throughput. In the initialization phase the framework sets up and self-organizes the WSN and creates routing tables and initial set of s-t paths through cluster heads. In the operational phase optimal routes under given timing constraints are evolved using BB-BC optimization approach. Timing constraints are imposed due to dynamic conditions arising because of energy expenditure of the nodes. Once the near shortest path/optimal routes are available, data transmission for a predefined interval takes place in the WSN. The ILC based dynamic shortest path routing approach improves throughput, reduces average end to end delay and improves the life time of the WSN. We implemented the proposed framework in MATLAB and its performance on optimal path enumeration was simulated. The framework was observed to be working extremely efficiently by evaluating near least cost path, thus keeping track on throughput, end to end delay and energy efficiency of the given WSN.

Keywords - Wireless Sensor Networks, Integrated Link Cost, Artificial Neural Network (ANN), Big Bang- Big Crunch (BB- BC).

I. INTRODUCTION

Wireless Sensor Networks (WSNs) is an emerging field that has been target of recent research due to its ever growing popularity attributed to its wide range of applications. A WSN is the network of distributed and connected tiny wireless sensors nodes that have the ability to sense a variable of interest [1]. The sensor networks are different from other networks as these do not focus on human interaction but instead focus on interaction with the environment. A sensor node integrates sensing, computing, and Communication into a single unit. These sensor nodes have limited battery based capacity; are deployed in untethered and unattended environment and hence, it is not possible to improve battery life by replacing or recharging the battery [2][3][4]. Routing is a very challenging task in this unpredictable environment. Energy is a factor of utmost importance in wireless sensor networks and energy efficient operation is the fundamental need for WSNs. In WSNs, the network life time is considered to be equally important to their performance. The most challenging concern in WSNs is to reduce energy consumption and to increase the lifetime of the network to reasonable times without compromising with their performance. The most of the energy consumption take place in the transmission/ reception process which is dependent upon amount of communication and the distance of communication. The multi-hop communication reduces the burden of energy consumption on individual node by dividing this consumption into number of intermediate nodes but it also increases delay to reach the data from source to destination. So there has to be a trade-off between delay and distance while keeping power optimization as main criteria before selecting multi-hop or single hop in the wireless sensor networks [5]. Thus, choosing the least cost route in terms of energy usage has great impact on the life time of WSNs.

This paper is organized in V section. Section I highlights the motivation for the work, section II presents the related work, section III presents the framework. It explains the newly proposed ANN based integrated link cost evaluation metric that we use for the evaluation of the cost of a given source to terminal route. The section further explains how the optimal routes are evaluated using big bang big crunch optimization approach [6][7]. Section IV presents the implementation, simulation and discussion on the results. Finally section V concludes the paper.

II. RELATED WORK

Power consumption in WSNs has been critical concern as it determines the lifetime and performance of networks. Reduction in power consumption has been an area of research for long.

Shakti Kumar *et al.* [8] proposed an energy efficient communication approach for WMNs which could also be adapted for WSNs. The proposed frame work for optimal routing based on integrated link cost measure named ILC; which is a function of three network parameters i.e., throughput, jitter, delay and residual energy of the node. Authors used a fuzzy logic based approach to evaluate ILC. They also proposed that Big Bag- Big Crunch (BB-BC) optimization algorithm [6][7] is the potential candidate to evaluate the shortest path or near shortest path in wireless mobile networks (WMN) applications.

Heinzelman *et al.* [9] proposed a low energy efficient adaptive clustering hierarchy (LEACH) algorithm in which wireless sensor nodes are deployed in the form of clusters for data aggregation. In LEACH, cluster heads (CHs) perform the aggregation of data in periodic manner to reduce the redundancy in data to be communicated to Base Station. In setup phase, the rotation/selection of CHs is the function of two parameters: Percentage of CH selection and how many times a specific node has been elected as CH. To make a decision for election, a random number between 0 and 1 is chosen by the wireless sensor node. To become a winner as CH for a particular round, the random number picked by sensor node should be less than threshold value. In the steady state phase, transmission of data takes place between the cluster members to CH, and then finally data is transmitted to the Base Station.

Di Tang *et al.* [10] focused on lifetime optimization, Packet Delivery Ratio (PDR) and security concerns. They investigated that non uniform deployment strategy in terms of energy is more efficient, optimize lifetime and increases Packet delivery ratio (PDR) under the same requirements like energy resources and security as compared to uniform energy deployment strategy.

Jalal Habibi *et al.* [11] presented the framework in which they emphasize on optimal link cost assignment, extending network lifetime and provides optimal route strategy by implementing heuristic algorithm. In this work, the cost assigned are changing dynamically and re-computing the routes which are more energy efficient.

From the above discussion, we can summarize that optimal and energy efficient routes provided by different clustering techniques on the basis of earlier proposed integrated link cost measure still have several shortcomings that need to be addressed, for power optimization and to increase the life time of network. The approaches based on clustering increases robustness, scalability and provide data aggregation and load balancing [3, 4, 12-19]. The above discussion also shows that reducing the distance of communication strategically is a better option but energy efficiency and lifetime depends upon the cluster head selection method, number of hops and optimal route evaluation for data transfer between sources to destination or Base Station. Furthermore, the proposed technique not only is energy efficient but also performs better on load balancing, decreases delay, increases throughput and thus extends the lifetime of network when compared with state-of-the-art techniques.

III. THE WSN FRAMEWORK

In this section we propose an ANN based WSN routing framework and its constituent modules. The framework can be divided into cost evaluation module called ANN based ILC evaluation module, the node architecture and the BB-BC algorithm based optimal cost route evaluation module.

a) The ANN Based ILC Evaluation:

In order to find out the shortest route from amongst a number of alternatives available we need to find cost of the route. The cost of the route is the sum total of the costs of the links which form the route between source to destination node. There are a large number of cost measures available in the literatures which a designer could use [20]. In order to have an energy efficient routing protocol we use an integrated link cost (ILC) measure similar to the one defined in [8]:

Integrated Link Cost (ILC) = f(Residual Energy, Throughput, End to End Delay)

We propose the ANN based cost computing approach as shown in Fig. 1 to compute the link cost between two adjacent nodes. This cost computing system is part of the each WSN sensor node. The ANN is trained on the training data available for the ILC.

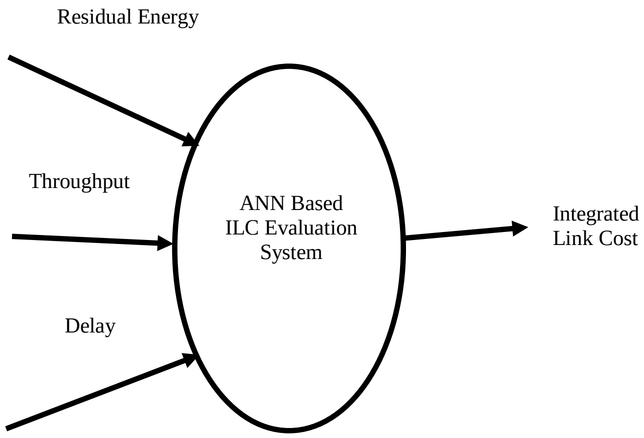

Fig. 1 ANN based Integrated Link cost computing system

The residual energy is the energy left in the sensor node after sensing, computation and communication. Most of the node energy is spent in communication for transmission and reception.

The energy consumption for transmission of data is expressed as [21]:

$$E_{Tx}(k,d) = E_{elec} * k + Camp * k * d^2, d > 1 \qquad (1)$$

The energy consumption for reception of data is expressed as [21]:

$$E_{Rx}(k) = E_{elec} * k \qquad (2)$$

Where K is expressed as data to be transmitted and “d” is the distance between the two intermediate nodes or from node to cluster head or base station. E_{elec} Represents the energy consumed for transmitting per bit.

Throughput is the rate of successful data delivery in a given time period from source to destination in the wireless sensor networks [22]. The end to end delay (EED) is the time taken by data packet to reach the destination point BS from source in WSN [23] and it also comprises all types of delays which are generally caused because of transmission, processing, buffering etc., at the time of route discovery and queuing at the specific interface. Mathematically, it is expressed as [24]:

$EED = T_p + T_q + T_T$

Whereas T_p = Processing Time

T_q = Queuing Delay

T_T = Transmission Time

b) The Node Architecture:

The architecture of a proposed WSN node is as given in figure 2. Each node contains an ANN based ILC evaluation module that computes the ILC between all adjacent node pairs of the WSN and conveys this information to every node of the network. Each node maintains a link cost table which helps in evaluating the route costs.

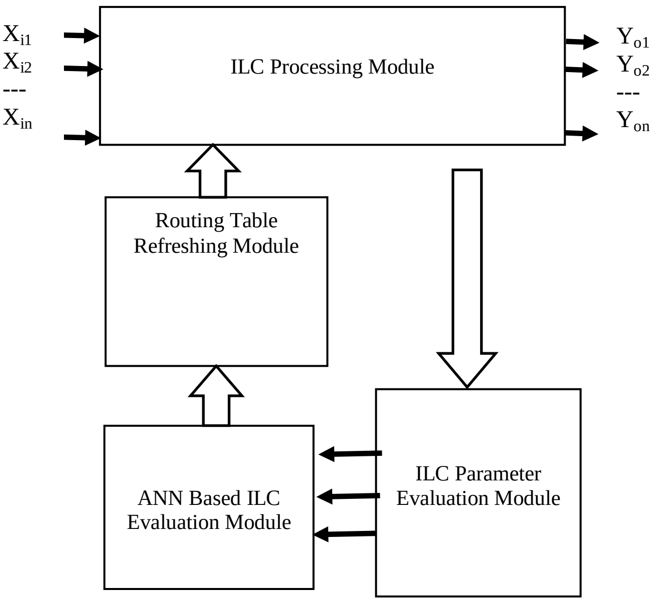

Fig. 2 Architecture of a Proposed WSN Node

c) Dynamic shortest path routing Algorithm for WSNs

The proposed algorithm for the framework for routing in WSNs consists of two phases. In the initialization phase it creates the adjacency matrix and routing tables whereas in operational phase it maintains the data routing between source-terminal node pair and updates the routing information periodically.

Assumptions:

1. All network nodes are similar in their radio characteristics.
2. Initially any of the WSN nodes can be assigned as cluster head (CH). Thereafter for next round, the sensor node with highest energy in a cluster shall act as CH.
3. Each node has a range to communicate to any other node of the adjacent cluster with additional power consumed. Nodes working as CH are allowed to consume energy twice of the energy when these are working as ordinary sensor nodes.
4. A given WSN is set up into a given number of clusters.
5. Nodes within a cluster communicate to CH directly.

Initialization Phase:

1. Organize entire WSN into clusters and assign a CH for every cluster.
2. For all Clusters, each CH senses neighborhood CH within its operating radio range in the WSN. Through control messages this information is conveyed to all the CHs to constitute a WSN wide adjacency matrix for each of the CH node. A sensor node whose energy level drops down to a minimum energy threshold required for it to be treated as CH can’t act as CH. This CH is allowed to exit network. In its place a new node with highest energy is allowed to join the network as CH. If more than one nodes have highest energy one of them is assigned randomly as the CH by the cluster. This sets up WSN wide communication network; it also allows the entry and exit of any CH in the communication network with most recent information.
3. From all source nodes of the cluster generate a very small percentage of rated traffic towards CHs. Assuming equal throughputs, permitted network delays, and full residual energy for every source-destination node pair.
4. For each cluster Compute ILCs based distance for each adjacent node pair.
5. For each cluster build cost matrix for each adjacent node pair.
6. For each source-BS pair, create the routing tables and allow the traffic to flow in the network.
7. For each of the source nodes of a cluster compute set of paths between source node-BS pair.

Operational Phase:

1. WSN wide, for each cluster:
   a) A cluster is maintained by allowing entry/exit of incoming/outgoing nodes.
   b) Allows the entry/exit of new CH/Old CH.
   c) ILC based distance/cost is computed between the sources sensor node-BS pair through a communication network formed by adjacent CHs for the current traffic. Update cost matrix at each node [25].

2. The shortest path/ near shortest path is evaluated for given source node–BS (terminal) pair, using a suitable soft computing approach [25]. To enumerate ILC based near shortest path, we adapted for WSNs, the BB-BC optimization algorithm based approach as given in [6].
3. Update the routing tables (for each source node-BS (terminal) node pair).
4. Continue with the data routing process for a pre-specified time/ as required by the network dynamics.
5. Go to step 1.

As stated in step 2 above we use the BB-BC approach to evaluate ILC based near shortest path. The path evaluated is not the shortest path but we term it as the "*near shortest path*" as this BB-BC based approach generates a good enough path that can be evaluated within a given time constraint. Hence, we have no option but to use this good enough/near shortest path in place of shortest path.

IV. SIMULATION, RESULTS AND DISCUSSION

In order to validate our framework we implemented the proposed framework in MATLAB and simulated the approach for various WSN scenarios as given in Table 1. The ILC was evaluated using the proposed ANN model. The optimized ANN model was identified using proprietary model identification software available with Computational Intelligence Laboratory (CI-Lab) at Baddi University of Emerging Sciences and Technology. We conducted 25 simulation trials for each scenario of the implemented framework. In all of the trials the software was able to generate the WSN successfully. Fig. 3 presents a WSN formed by one of the trials.

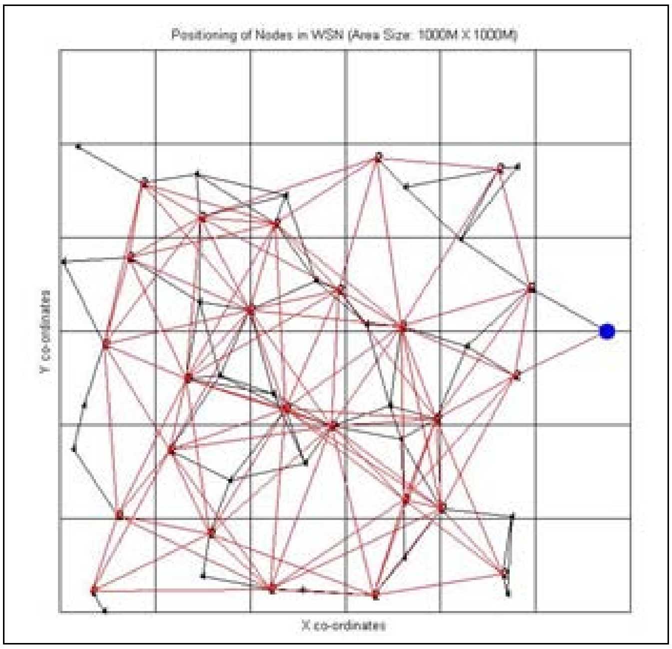

Fig. 3 Positioning of Nodes in WSN

Once the WSN was constituted, the framework then enumerated a set of initial routes between a given source node of a given cluster and the destination node which is the base station (BS) node. The frame work then applied a Big Bang- Big Crunch (BB-BC) optimization based approach to evolve optimal paths/near shortest path routes within the stipulated timing constraint. We have used a proactive routing approach in which an initial population of four routes between the source sensor node and the destination node (BS) was created.
The framework evolves a new population of routes from the given population. The BB-BC approach used to evolve new generations of routes from the current generation of routes has been adapted from [8]. The Figure 4 depicts the progress of near shortest path enumeration with the increasing iterations. We observed that in all the 25 trials which were conducted the frame work was able to establish a near shortest path within the specified time constraint.

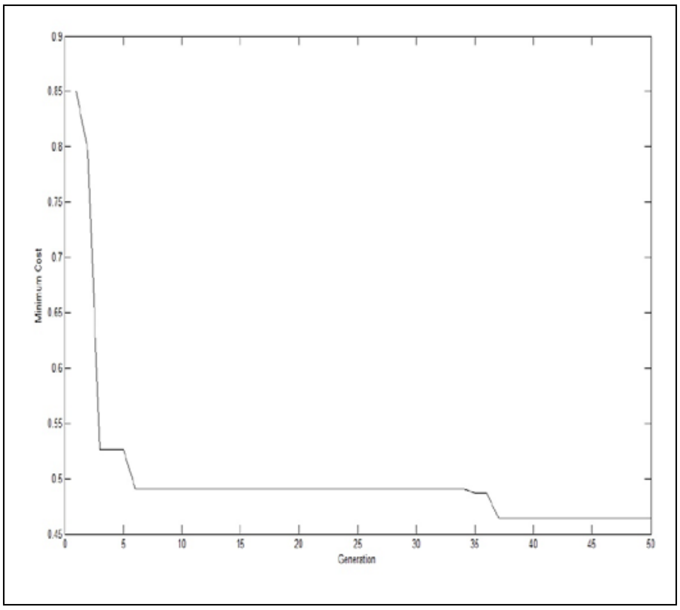

Fig. 4 Progress of shortest path evaluation process using BB-BC Approach

The simulation results under various network scenarios are presented in Table 1. A look at the percent error indicates that as the processing time constraint is relaxed with increased processing time constrain, the percentage error comes down. This reduction in route cost is not linear this is due to the fact that we used BB-BC algorithm based optimization approach. It is an approximate reasoning based approach which is a randomized guided process. Most often but not always higher processing times result into lesser cost routes. Figure 5 presents the ILC based route cost with increasing time constraint for a 2500 cluster WSN spread over an area of 5000× 5000 m^2.

If we have unconstrained processing time available to us we shall get minimum ILC routes. But given the dynamic nature of WSNs due to decreasing energy of the nodes we have no option but to evaluate optimal routes under timing constraints. Timing constraints have to be chosen in such a way that we use minimal time for route evaluation so as to get optimal time for data transmission. Since the routing is based upon node energy; this routing technique shall increase the life time of the given WSN

Table 1 Simulation results under various scenarios

Sr. No.	No. of Nodes/CH	Area (In Meter)	Timing Constraint	Path Cost	Shortest Path	% Error
1	25	100×100	0.1	0.5929	0.4728	20.254
			0.2	0.4401	0.3670	16.605
			0.5	0.5454	0.4791	12.161
			1	0.3815	0.3475	8.921
			1.5	0.3044	0.3044	0.000
2	400	500×500	1	3.6519	2.3217	36.425
			2	3.3393	2.2535	32.516
			3	3.2048	1.9668	38.630
			4	2.6537	1.9326	27.173
			6	2.9564	2.2037	25.461
			7	2.2473	1.7346	22.816
			10	2.4691	1.9190	22.279
			15	2.4395	1.9153	21.489
			20	2.2394	1.7524	21.747
			25	1.9803	1.5291	22.786
			30	2.4222	1.9892	17.876
			35	1.6687	1.3997	16.120
			40	2.3499	1.9777	15.837
			45	1.9060	1.6366	14.132
			50	1.8705	1.6239	13.184
3	900	900×900	5	6.1051	4.3953	28.006
			6	7.3060	3.6192	50.462
			7	5.3993	3.7771	30.044
			8	4.7300	4.2512	10.123
			9	4.7206	3.5452	24.900
			10	4.6430	3.5690	23.131
			20	3.8716	2.9500	23.804
			25	4.5277	3.5494	21.607
			30	5.7951	4.5755	21.045
			35	4.6628	3.8380	17.690
			40	4.1773	3.4645	17.065
			50	4.5440	3.7741	16.943
4	2500	5000×5000	7	14.5333	9.8395	32.297
			8	13.4710	9.8257	27.060
			9	13.4447	9.8460	26.767
			10	13.3975	10.3871	22.470
			15	11.7952	9.8257	16.698
			20	12.3105	10.5389	14.391
			25	11.2275	9.6500	14.051
			30	11.7727	10.2159	13.224
			35	10.9261	9.5562	12.538
			40	10.3556	9.1110	12.019
			50	11.3773	10.0610	11.570

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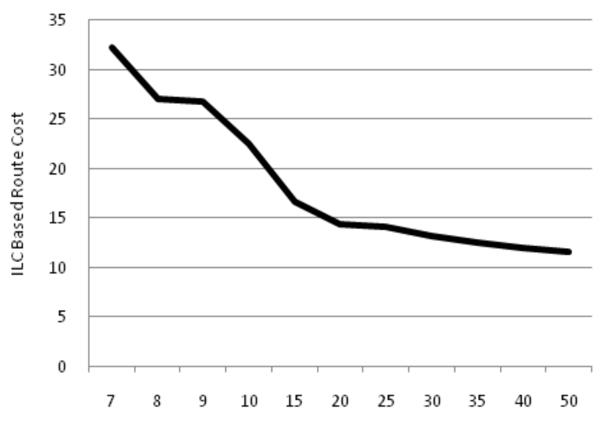

Fig5: Optimal Route Evaluation Timing Constraint (Seconds)

V. CONCLUSIONS

Routing and life time improvement are two challenging issues faced by WSN designers. In this paper we presented a new soft computing based framework for optimal path routing in the large scale WSNs. The first module of the proposed framework is an ANN based integrated link cost (ILC) measure evaluation module. The ILC is a function of residual sensor node energy, average end to end delay (EED) and network throughput/packets sent. The framework uses a near shortest path routing evaluation approach based upon BB-BC optimization based approach to improve the throughput, reduces the average delay and attempts to improve the average life time of the WSN. The framework first self-organizes itself to a WSN by using the radio ranges of its nodes. It is able to adjust to the new incoming and exiting nodes. Once the network is constituted it evaluates initial population of paths between a source sensor node and the destination node (base station) through a set of cluster heads by taking a proactive routing approach. Once the initial set of routes is established the framework evolves optimal routes using the big bang big crunch optimization approach through a series of big bang and big crunch operations. In order to keep an effective control over the node energies, the optimal cost paths are enumerated under given timing constraints. Once the optimal route evaluation phase is over, the data transfer takes place for a given interval of time called WSN operational phase. We implemented the proposed framework in MATLAB and its performance was simulated for various WSN scenarios. The framework was observed to be working extremely efficiently by evaluating near minimal cost paths, thus keeping track on throughput, end to end delay (EED) and energy efficiency of a given WSN. We conducted 25 trials for each of the WSN scenarios and observed that the framework was able to enumerate near minimum cost route under given timing constraints.

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