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Energy Efficient Routing in WSNs: Three Soft Computing Based Approaches

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Abstract: This paper presents three new soft computing based energy efficient optimal cost path based routing approaches to optimize the life time of WSNs. These routing approaches are BBBC, PB3C and 3PGA based approaches. The BB-BC and 3PGA based approaches are single population approaches whereas PB3C is a multi-population based approach.All the three approaches use ANN based integrated link cost based optimal cost metric to measure the path cost. The proposed approaches were implemented on MATLAB and simulated on a 10 clusters WSN. We compared the performance of BBBC, PB3C and 3PGA based approaches along with AODV for the energy efficiency in terms of enhanced lifetime of WSN. We observed the performance of various approaches under timing constraints for optimal path evaluation as well as we allowed adequate time for optimal path evaluation. Such observations were necessitated to assess the application of WSNs under certain time critical applications. It was observed that for given network scenario and similar radio and processing capabilities of WSN nodes, PB3C based approach is the most energy efficient routing approach offering the longest network life time to a given WSN followed by 3PGA and BB-BC based approaches.
Keywords: Wireless Sensor Networks, Network Lifetime, Energy Efficiency, BBBC, PB3C,3PGA, AODV.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are gaining popularity due to exceptional capabilities and wide range of control, command and communication applications. A WSN consists of sensor nodes deployed over a geographical area for substantial range of applications ranging from military to farming, healthcare, measuring temperature, humidity etc. The sensor nodes monitor the parameters of interest from the environment, process data if necessary and send/receive processed data to/from sensing nodes. The cost of these sensors is very low due to which these could be deployed in diverse fields.WSNs are energy constrained networks due to the limited energy of the node batteries. Hence, network life improvement/ enhancement through optimal use of power sources is a hot research area. Researchers are making all out efforts to improve the average lifetime of WSNs. Sometimes the routing protocol chosen for data transmission creates an excessive overhead to implement their algorithm which affects the energy of sensor nodes. The chosen routing protocol must have high quality of service, long lifetime, energy efficiency, good packet delivery ratio and gives high throughput which leads to increased network lifetime.

It has also been observed that for long distance communications, the sensor nodes should avoid direct communication with the sink node; instead multi-hop communication can further optimize the power usage and can result into an enhanced network life. Direct communication means requirement of high transmission power in order to achieve reliable transmission which leads to more energy usage**.** Multiple paths should be chosen at different times since the single optimized path will lose its energy if the same path is chosen repeatedly for all the transmissions.In this way the energy is saved by using multi hop communication. To decrease the energy consumption, the distance between the transmitter and the receiver is estimated before transmission and the lowest transmission power needed is calculated and measured. If the distance between two sensor nodes is long, then energy consumption is also high. There is excess energy consumption in transmitting data via longest path with many nodes. So, shortest paths with less number of nodes should be chosen to minimize energy consumption. In WSNs for that matter in any data network optimal cost path based adaptive routing leads to enhanced network life time.Number of hops based shortest path is perfectly acceptable provided our WSN is able to transfer data packets to sink node within an acceptable time constraint. This may not be the case always. In delay sensitive WSNs the packet though, transferred over shortest path may violate critical time constraint due to excessive traffic on the shortest path. Hence, we need some other approach that uses the minimum energy and also transports the packet within a given time frame. To tackle this issue we use an integrated path length measure that takes into account the residual energy as well as the end to end packet delay into account. This type of path length metric helps optimize the power usage while keeping the end to end delay within stipulated limits. Further, for time critical applications we can use optimal cost path based routing rather than shortest path based routing. This needs designers to impose a timing constraint to evaluate optimal path and rather than working with least cost path.

This paper proposesthree new energy efficient routing approachesfor WSNs. The three approaches arebig bang big crunch (BB-BC) algorithm based approach [1], parallel big bang big crunch (PB3C) based approach[2] and three parent genetic algorithm (3PGA) based approach [3]. BB-BC is based upon the theory of evolution of the universe. This is a single population based approach. PB3Cis the extension of BB-BC approach butunlike BB-BC, PB3C is a multi-population approach. Shakti et al. [3] introduced the concept of three parent genetic algorithm (3PGA). 3PGA is single population based unconstrained global optimization algorithm.All the three approachesare incorporatedwith the ANN based integrated route cost metric. We implemented these approaches along with AODV routing approaches in MATLAB and tested the performance of thesethree soft computing based approaches for optimal cost route evaluation for routing in WSNs. The results were found to be very encouraging.
This paper is divided into V sections. Section I presents the motivation behind the paper.Section II focused on prior work. Section III proposes the new energy efficient routing approach to WSNs. Section IV presents the simulation results of the proposed approach on a 10 cluster WSN.

This section compares the BBBC, PB3C, 3PGA and AODV based energy efficient routing approaches. Section V concludes the paper.

Prior Work:

Sharma et al [4] proposed the ANN Based Framework for Energy Efficient Routing in Multi-Hop WSNs. Theytargeted large scale WSNs and proposed a soft computing based approach for optimal cost path routing. The proposed approach works in two phases; initialization phase and the operational phase. In order to evaluate route costs, we proposed an ANN based integrated link cost (ILC) measure. ILC is a function of residual sensor node energy and average end to end delay (EED). In the initialization phase the framework sets up and self-organizes the WSN and creates routing tables and initial set of source-terminal 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 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. They 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 optimalcost path, hence, keeping track on residual node energy and end to end delay thus, improving the life time of WSN.

III. SOFTCOMPUTING BASED ENERGY EFFICIENT ROUTING APPROACH FOR WSNs

We define the life time of a WSN as the time period upto which the communication takes place between a given source and sink (destination) pair. The network fails when the communication between source-sink node pair is disrupted. We assume that communication disruption takes place only due to power supply reaching a level where it is not able to send or receive information. Nodes are assumed to be 100% reliable.In this section we propose three new soft computing based energy efficient routing approaches for routing in WSNs. The Energy efficiency is a major issue in WSNs due to the limited battery energy of the network nodes. The working of the proposed approaches is shown in Algorithm 1. In the proposed approach, first of all we initialize the network and construct an adjacency matrix for each of the nodes. For a given pair of source to terminal nodes we evaluate the total number of cut-sets for a given WSN. These cut sets help us to evaluate the instance when the WSN will fail. This way we can compute the life of the WSN. We discover the optimal cost path from each node on the network to the destination node using BB-BC/PB3C/ 3PGA based approaches [5,3]. Using the discovered paths, we cause the traffic to flow from each node to the destination node for the 5 round. After each set of 5rounds we check if the cluster head needs to be changed and rediscover the optimal cost routes.On the completion of eachof the rounds,we update the energy of each node. If the energy of any cluster-head node falls below the given threshold then the algorithmselects another cluster node from the cluster that has the energy greater than the given threshold. Further, if no node is having the energy greater than the specified threshold then consider the cluster head for that cluster as having failed and we record that clusterhead in the blocked list. If the blocked node list matches with any of the cutset then we understand that communication between the desired source-sink pair has been disrupted and the network has failed as there is no path alive between the given source and the terminal node, otherwise the creation of adjacency matrix and optimal route cost paths are computed again. We continue with communication process. This process is repeated until the WSN fails.Number of round communication takes place before the source to terminal communication fails is defined as the life of the WSN.

To evaluate the link cost of a path, the literature is rich with number of path cost evaluation metrics. Some of these are; minimum hop count, cross layer link quality and congestion aware (LQCA) metric[6], Per-Hop Packet Pair Delay (PktPair) [7], Effective Number of Transmission (ENT) and Modified Expected Number of Transmissions (mETX) [8], Expected Transmission Time (ETT), Weighted Cumulative ETT [9], Expected Transmission on a Path (ETOP) [10], Expected Transmission Count [8], Metric of Interference and Channel Switching (MIC) [12], Bottleneck Link Capacity path metric [13], per hop Round Trip Time [14]. A novel interference aware low overhead routing metric was proposed by Liran Ma et al. [15]. Integrated Link Cost (ILC) for Wireless Mesh Networks (WMNs) was defined as follows [5, 16, 17]:

$$ILC = f(\text{throughput, delay, jitter, node\_residual}_{\text{energy}})$$

In our work wehave modified the above ILC. We compute the Integrated Link Cost using an 2-input Single output ANN system as shown in figure 1. The ANN based ILC consists of two input variables as given below:

ILC = (EED, RE)

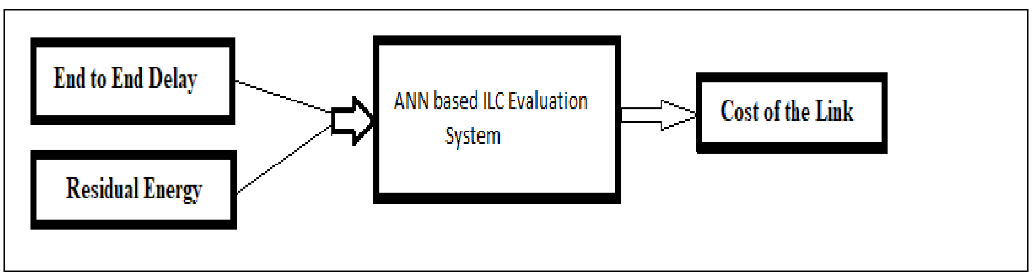

Figure 1: ILC function evaluation using ANN Based System

Where EED is End to End Delay and RE is Residual Energy of the node.

Algorithm 1: Soft Computing based energy efficient Routing Approach
Begin **Step 1**: Set Round = 0, block_list = 0, network_failure_status = false, Initialize energies of all nodes. **Step 2:** Construct adjacency and ILC for the sensor network. Adjacency matrix is a N×N matrix that contains the information about the adjacent/ neighborhood nodes. **Step 3:** Evaluate s-t Cutsets. **Step 4:**Using BBBC/PB3C/3PGA Algorithm evaluate the optimal cost path. **Step 5:** For round_counter = 1:10 **Step A:** Carry out data collection and flow the traffic from each node to terminal node.. **Step B**: Update the residual energies of all cluster-heads and client nodes according to number of packets received and transmitted. **Step C: While average energy of cluster nodes**> Minimum required average threshold. **If the cluster head node energy < Current average energy of cluster nodes then select next cluster head node randomly from amongst the cluster nodes whose energy is > current average energy.** **Step D**: if the energy of any cluster goes below the predefined threshold and no client in the cluster is having residual energy above the threshold then append the current cluster into block_list. **Step E**: Round = Round +1 **Step 6**: End for **Step 7**: compare all computed cutsets with block_list. **Step 8**: if blocked list nodes matches with any computed cutest then set network_failure_status = true. **Step 9**: If network_failure_status == false then Goto Step 2. **Step 10**: Print WSN life in number of rounds **End**

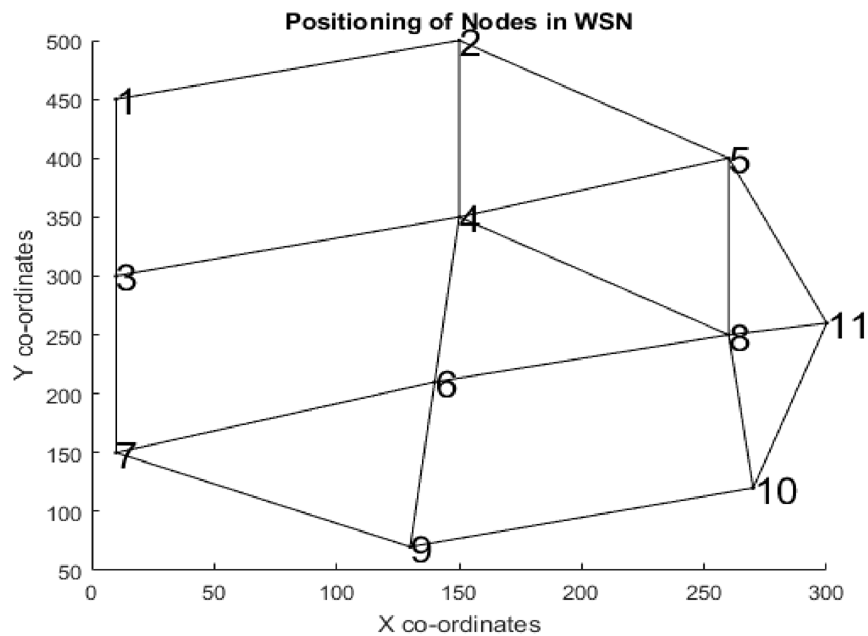

Figure 2: Deployment of clusters in WSN

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IV. SIMULATION, RESULTS AND DISCUSSION

In order to validate our approaches we implemented the proposed approach using MATLAB. We used the node radio battery and associated processing characteristics as given in table 1. For simulation purpose, wehave considered 10 clusters in the network and one sink (server base station)node that collects the data from every cluster as shown in figure 2. The 11th node in the figure 2 is the base station that acts as sink node or destination node. Each cluster consists of 10 nodes, Out of these 10 nodes one of the nodesacts asthe cluster head and 9 nodes are client nodes. For this architecture,we tested the all three proposed approaches along with AODV on total number of 100 node WSN with onesink node/ base station. Further, we have assumed that there is no direct link between any cluster-head to the base stationexcept for the cluster-head adjacent to sink node/base station. All the clusters use hop to hop communication approach. To validate the proposed approach we caused the traffic to flow from each node towards the base station on the optimal cost routes.The network is said to fail if the traffic is interrupted between the specified source-sink node pair and weterminate the program. To test the performance of the proposed approaches we conducted total number of 6 sets each with 10 trialsusingall the 3 proposed optimal cost route evaluation approaches i.e. BBBC, PB3C and 3PGA based approach along with AODV.The average simulated performance of each of the trial set for the 4 approaches is placed in table 3.

Table 1 Battery and Radio and processing Characteristics of a node

Parameter	**Value**
Number of nodes	100
Network size	100m × 100m
Initial energy, E_0	1 J
Radio electronics energy, $E_{Tx} = E_{Rx}$	50 nJ/bit
Energy for data-aggregation, E_{DA}	5 nJ/bit
Radio amplifier energy, ε_{friss_amp}	100 pJ/bit/m^2
Radio amplifier energy, $\varepsilon_{two\_ray\_amp}$	0.0013 pJ/bit/m^4
Temperature range on the field	0°F − 200°F
Hard threshold	50°F
Soft threshold	2°F
Packet Size	4000 bits

Table 2: Lifetime of WSN with timing constraint of 0.005 Seconds

Trial No.	**3PGA**	**BB-BC**	**PB3C**	
1	610	605	610	0
2	605	605	605	0
3	610	610	615	0
4	605	600	610	0
5	630	630	630	0
6	610	605	605	0
7	605	605	620	0
8	615	600	620	0
9	605	605	610	0
10	620	605	620	0
Average	**611.5**	**607**	**614.5**	

Table 3: Average WSN life under various timing constraints

Algorithm	Timing Constraint (Seconds)					
	0.001	**0.002**	**0.003**	**0.004**	**0.005**	**0.007**
3PGA	617	611	611.5	611	611.5	612.5
BB-BC	616	608.5	609	610	607	608.5
PB3C	616.5	609	611.5	612.5	614.5	613
AODV	Failed	Failed	Failed	Failed	Failed	572(Failed 3 Time)

From table 3 we observe that initially at lower timing constraints of 0.001, 0.002 seconds 3PGA based algorithm performs better. At timing constraint of 0.003 seconds the performance of PB3C algorithm approaches that of 3PGA and for other higher timing constraints of 0.004, 0.005 the PB3C algorithm out performs all other algorithms. We also observe that AODV algorithm being reactive algorithm was not able to find any path for data traffic to flow. However, when the timing constraint was relaxed to 0.007 seconds the average performance was observed to be good but the performance was unreliable as AODV failed to discover the path 2 times in 10 trials. Though the performance of AODV is fairly good yet we don't recommend its use as its performance for lower timing constraints as well as for higher node networks is extremely unreliable and very poor.

Table 4: Simulated Life time of the given 10 cluster WSN

	WSN life in terms of number of rounds		
Trial No.	**BBBC**	**3PGA**	**PBBBC**
1	210	240	240
2	290	260	240
3	240	330	240
4	220	220	220
5	210	260	260
6	220	240	320
7	230	260	310
8	280	240	230
9	250	260	250
10	220	220	320
11	240	280	260
12	220	260	260
13	210	280	220
14	220	220	280
15	220	240	260
16	210	310	310
17	230	280	330
18	220	310	330
19	210	330	320
20	230	260	280
mean Number of Rounds/trial	**4610/20 =230.5**	**5300/20 =265**	**5480/20 = 274**

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We conducted another set of 20 trials with reduced node energy of 800 mJ and increased packet length with unconstrained time given to optimal path evaluation. With these parameters the performance of the network given in figure 1 is placed in table 4 and figure 3. From figure 3 we observe that out of 20 trials PB3C gave best performance in 8 trials, 3PGA followed it with best performance in 5 trials. BBBC based approach gave best performance in just one trial only. 5 times 3PGA and PB3C gave the same best performance. The table 4 shows that overall for 20 trials, with BBBC based approachWSN had the average life of 230.5 rounds of the data transfer, 3PGA extended this average life to 265 rounds and P3PGA optimized the mean WSN life to 274 rounds. Thus, we find that in this case, out of the three optimal cost path evaluation approaches PB3C based routing approach proved to be the most energy efficient of the three approaches followed by 3PGA and BB-BC based approaches.

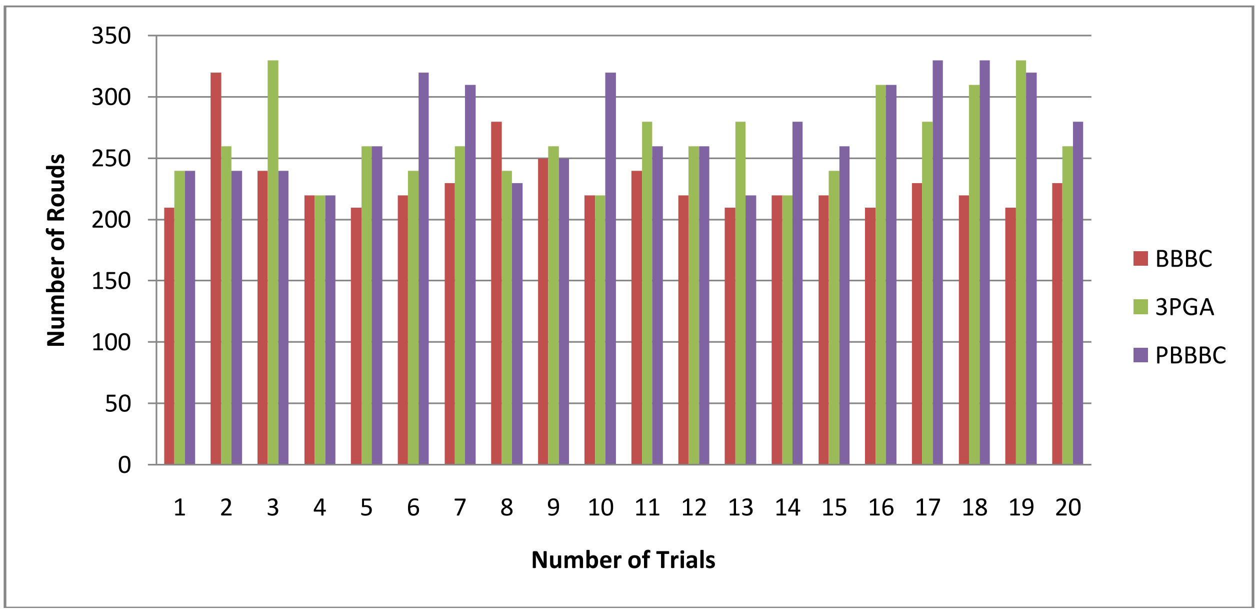

Figure 3: Performance of all algorithms for different number of trials

V. CONCLUSIONS

This paper proposes three new energy efficient optimal cost path based soft computingrouting approaches for WSNs namely BBBC, PB3C and 3PGA optimization algorithms based approaches. The performance of the proposed approaches have been compared with AODV, a reactive routing approach. We used an integrated link cost measure to evaluate the route costs. The link cost is a function of residual node energy and end to end delay.We used a ANN based system to get the integrated link cost. We tested the performance of all three proposed approaches along with AODV on WSNs with 10 clusters. Each cluster consists of 10 sensor nodes. From the simulation results we conclude that for lower timing constraints on optimal integrated cost route evaluation 3PGA gives the longest WSN lifetime. When more time is allowed to optimal path evaluation we found that PB3C based approach gave the longest WSN life time. In our second experiment we conducted 20 trial on reduced battery energy and increased packet size with adequate time to evaluate optimal path. We observed that the PB3C algorithm based routing approach gave the longest mean life time of 274 rounds as against 265 and 230.5 rounds provided by 3PGA and BBBC based approaches.We donot recommend the use of AODV, as the performance of this algorithm is highly unsatisfactory for lower timing constraints, also the performance of AODV for WSNs of size larger than 1000 nodes was observed to be very poor. Hence,from our observations of 7 sets of trials for optimized life time issue, we rank PB3C based approach as number 1, followed by 3PGA on number 2 and BBBC as number 3.

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