Energy Efficiency in Wireless Sensor Networks Using Clustering and Fuzzy Logic

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***Abstract*— A wireless network consisting of a large number of small sensors with low-power transceivers can be an effective tool for gathering data in a variety of environments. The Wireless Sensor Network (WANs) have become major in both industrial applications as well as personal use. With the advent of Internet of Things (IoT) there has been a re-emphasis on research, development and application of WSNs. WSN nodes are characterized by low processing power, limited lifetime, and lack of mobility. So the major challenge is to design a high quality WSN irrespective of these constraints. In this paper we have presented an in depth analysis of one of these constraints i.e., limited power availability in WSNs. So in this paper, we have proposed a Fuzzy Logic based energy efficient approach for Wireless Sensor Network with efficient cluster head replacement scheme and simulate it and show the comparative results. The results show that it minimizes the total energy spent in the network when all sensors report data through the cluster heads to the base statiion.**

Keywords—WSN, sensors, wireless sensor networks, energy efficiency, power optimization

I. INTRODUCTION

A WSN is a network consisting of sensor nodes that communicate wirelessly and are deployed over a large geographical area. Each node in WSN consists of atleast 3 subcomponents- a sensor to sense the environment in which it is deployed, a processor for processing and/or analysing sensed data, storage- for storing data temporarily untill it is sent to a base station and a wireless transiever for transmitting and recieving data from peer nodes or from base station. In order to power the above mentioned components WSN nodes usually also have an embedded battery inside them[14]. The capacity of this battery is very limited and it is also very incovinient or sometimes even impossible to frequently replace the battery because of the harsh environment in which the WSNs are usually deployed. So it is of paramount importance to conserve as much energy as possible.

The general architecture of WSN is shown in figure 1. The WSN consists of a sink node which is sometimes also referred to as base station. WSNs also consists of a large number of sensors that are distributed above a large geographical area. They are over which the sensor nodes are spread is also called sensor field. The sensors as well as the sink can be stationary or moving. The sink is usually also connected with internet or some other form of WAN. Users operate and monitor the entire WSN remotely using the sink node[1-2].

All the operations of WSN consume energy. However the highest percentage of energy is consumed in transmitting messages from sensor node to sink node (long distance communication). Other operations like sensing of environment or processing of data etc. normally consumes way too less energy than transmitting of data. Energy conservation techniques in WSNs usually follow two techniques- either reduce the frequency of data communication from sensor nodes to sink nodes or reduce the frequency or amount of data sensed by sensor nodes.

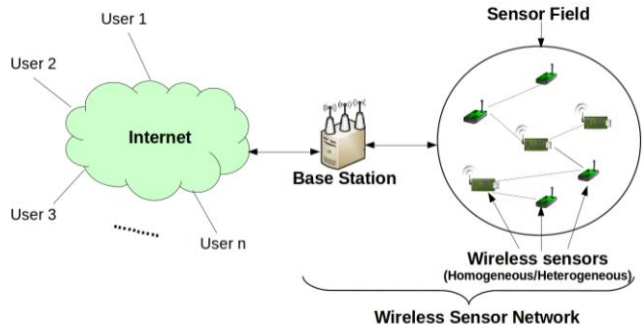

Fig. 1. Architecture of Wireless Sensor Network[14]

The rest of the paper is organized as follows- section two provides an overview of some related work done in this field, section three discusses Fuzzy Logic based energy efficient approach for Wireless Sensor Network with efficient cluster head replacement scheme . Section four describes the simulation results that shows the actual reduction in the energy consumption by sensor nodes. Section five concludes the paper and give future direction to our work.

II. RELATED WORK

In [1], researches have provided us with a broad survey of various energy conservation techniques present in WSNs. They have given taxonomy of traditional energy efficiency techniques as well as the under-development energy efficiency techniques of WSNs. At the most fundamental level, there are three energy conservation techniques- duty cycling, data driven

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approaches and mobility based approaches. In duty cycling technique, a node goes into off-state or sleep state whenever a communication is not required. Since communication is required very rarely so putting a node in sleep state saves lots of energy. In data driven approaches, the major focus is how the data is sensed which also considerably impacts the energy consumption of WSN. There are lots of samples sensed which are not at all required. Also unnecessary computation in the power constrained WSN node also impacts its battery life. Mobility based approaches focus on the mobility of WSN nodes. If a sensor node is mobile then it focus on how to collect its data, how it will relay the message, how it will impact the overall network etc.

I.F. Akyildiz et al. in [2] provides a study on modern day WSNs.They first discuss some basic terminologies used in WSNs and then explore various sensing tasks. Next they discuss various applications of WSNs. They also enumerate various factors that impact the overall design of a sensor node. They also discuss the communication architecture of WSNs along with various alogorithms and protocols that facilitate te working of WSNs. Finally they discuss come research challenges in realization of WSNs.

In [3] Ameer Ahmed Abbasi et al. gave a survey of various clustering algorithms that are specifically designed for WSNs. They discussed about various convergence time algorithms where convergence time is the time required before all the routers/cluster heads reach an agreement about the topology of the WSN. They classified clustering algorithms in two categories- variable convergence time algorithms, constant convergence time algorithms. Variable convergence time algorithms are useful when number of nodes in WSN is low while constant convergence time algorithms are useful when number of nodes in WSNs is high.

A detailed performance evaluation of data aggregation in clustering based WSNs is provided by Adwitiya Sinha et al. in [4]. They have clustered sensor nodes based on their entropy. Firstly, nodes sensing similar kind of data are placed in distinct clusters. In the worst case if no more cluster can be formed, then divergence of a node is calculated with respect to each cluster then nodes are placed in least divergent clusters. Lastly they evaluated performance of their scheme based on various parameters like convergence rates, average packet drop, transmission cost etc. using NS2 simulator. Their result demonstrate that their proposed scheme outperform various current energy conservation schemes of WSNs

Dervis Karaboga et al. [5], proposed one more scheme for clustering in WSNs using bee colony algorithm. In bee colony algorithm, we try to simulate the behaviour of honey bee swarms. The researchers have proposed new algorithms called ICWAQ to create cluster and select cluster heads. Their proposed ICWAQ algorithm not only prolongs WSN lifetime but also improves QoS of the WSN. Their experimental results show that ICWAQ works respectably with respect to other algorithms.

A fuuzy logic based clustering technique is proposed by Jin-Shyan Lee et al. in [6]. They have augmented fuzzy logic in LEACH algorithm for WSNs. In their technique called LEACH-ERE, the cluster head is selected using a fuzzy approach which focuses on expected residual energy which is the residual energy left in a sensor node if it will be selected as cluster head and complete its round. Thus the overhead of becoming the cluster head is more appropriately distributed among the various nodes in a cluster. Their simulation results show that the proposed scheme is more efficient than most of other distributed algorithms for WSNs including LEACH and CHEF.

In [7], the researchers have proposed yet another fuzzy based scheme for cluster head selection. However, unlike other schemes, the selection of cluster heads will be carried out in the base station. The fuzzy inputs chosen by them are energy level of sensor nodes and physical distance to base station. Their experimental result prove that their proposed scheme is able to reduce energy consumption in First Node Dies (FND) round as well as it has also increased the throughput of the base station before FND.

III. FUZZY LOGIC BASED ENERGY EFFICIENT APPROACH IN WSNS

In this section, we have proposed a novel fuzzy logic based energy efficient approach that will help us to achieve energy optimization with a variety of state of the art energy optimization WSN techniques. Basically, we introduce two techniques to raise network life time and throughput. To understand our proposed scheme, we have to understand mechanism given of clustering in WSN. Normally during clustering, the cluster head is changed at and once a cluster head is formed, it will not get another chance for next 1/p rounds. For every round, cluster heads are replaced and whole cluster formation process is undertaken.

We, in this work, introduce an "efficient cluster head replacement scheme". It is a threshold in cluster head formation for very next round. If existing cluster had not spent much energy during its tenure and has more energy than required threshold, it will remain cluster head for the next round as well. This is how, energy wasted in routing packets for new cluster head and cluster formation can be saved. If cluster head has less energy than required threshold, it will be replaced according to fuzzy logic based k-means algorithm.

Algorithm

1. Begin
2. Create clusters and select cluster-head based on residual energy of each node
3. **For** each round do
4. nodes transmit sensed data to the cluster-head using TDMA
5. cluster-head aggregate data received from nodes for a given time period

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6. cluster-head compress and transmit the data to the base station
7. **If** existing cluster-head has not spent much energy during its tenure and has more energy than required threshold
8. Continue with existing cluster and cluster-head
9. **Else**
10. Create new cluster and select new cluster-head using fuzzy C-means clustering
11. end **for**
12. End

Besides limiting energy utilization in cluster formation, we also introduce two different levels of power to amplify signals according to nature of transmission. Basically there can be three modes of transmission in a cluster based network.
1) Intra Cluster Transmission
2) Inter Cluster Transmission
3) Cluster Head To Base Station Transmission
Intra Cluster Transmission deals with all the communication within a cluster i.e. cluster members sense data and report sensed data to cluster head. The transmission/ reception between two clusters heads can be termed as inter cluster transmission while a cluster head transmitting its data straight to base station lies under the caption of cluster head to base station transmission.

IV. SIMULATION ENVIRONMENT AND RESULTS

Simulations are conducted using MATLAB (R2009a) and to get precise plots, confidence interval is taken. We have also used the fuzzy logic toolkit for our simulation to use built in Fuzzy C means algorithm. We have assumed following network parameters for our simulation:

TABLE I. NETWORK PARAMETERS

Network Parameters	Value
Network Size	400 * 400 m^2
Total Nodes	100
Initial Energy of Sensor Nodes	2.5 J
Packet Size	4000 bits
Transceiver idle state energy consumption	50 nJ/bit/report
Maximum Number of rounds	2500

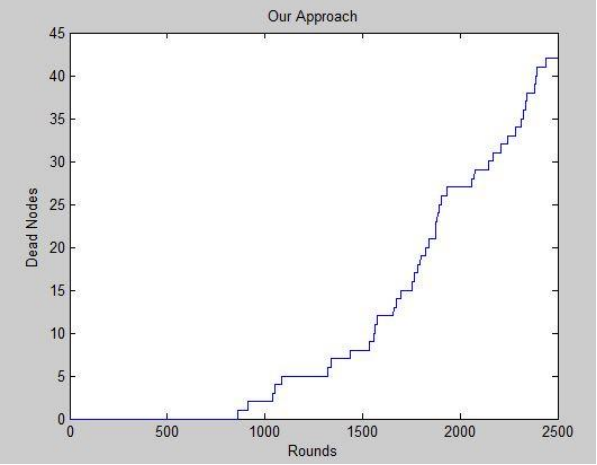

Fig. 2. The number of dead nodes in WSN

Fig 2. Above shows the cumulative number of dead nodes with respect to number of rounds in the simulation. We can see that until around 750 rounds, all the nodes are alive. After that, nodes start falling dead but with a very low rate. However the rate of death of nodes increases around 1700 rounds. At the end of 2500 rounds about 38 % of nodes die which is a very acceptable level.

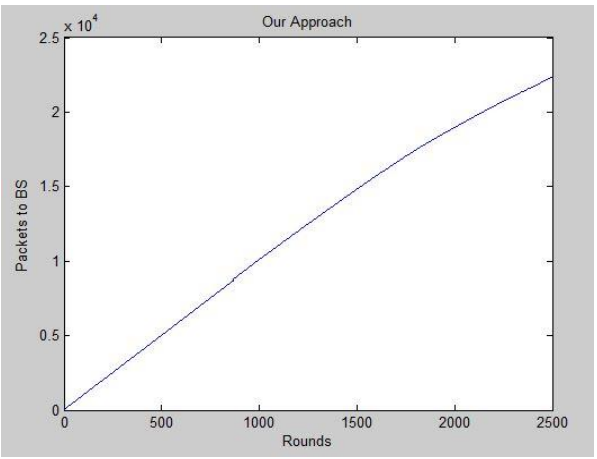

Fig. 3. The number of packets sent to the BS during each round

Fig 3. Above shows the number of packets sent to the BS (base station) during each round. We can easily deduce from the figure that after around 1100 rounds the number of packets sent to the BS becomes nearly constant.

Fig 4. Shows the total number of cluster-head in the WSN during each round is shown. This number is truly random and depends on the current state of the entire WSN including the total energy left in each node after a single round, which node belong to which cluster in the previous round (membership of nodes), the state of the cluster-head (whether its energy is greater than predefined threshold or not) etc. It can also be observed from the figure the average number of cluster heads

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in the end rounds is below average number of cluster heads in initial rounds.

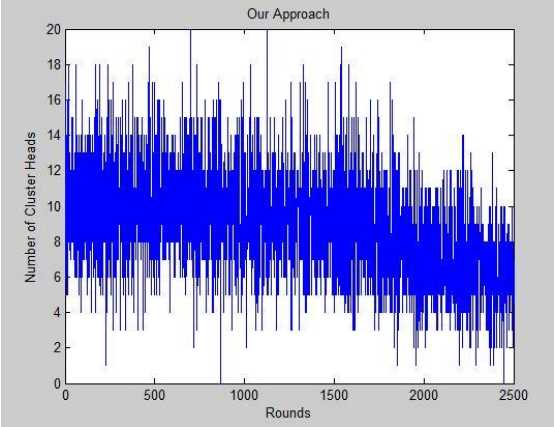

Fig. 4. The total number of cluster head during each round

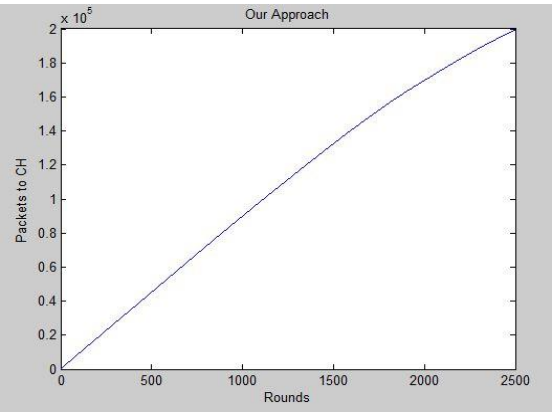

Fig. 5. The total number of packets sent to cluster-head during each round

Fig 5. above shows the cumulative number of packets sent to the cluster-heads during each round. As depicted in the figure the number of packets sent to the cluster-heads is increasing linearly with each round.

Fig 6. Shows the total energy of entire WSN (sum of energy left in each alive node) after each round. Initially the total energy of entire WSN was 250 J (since each node is assumed to have 2.5 J initial energy and there are 100 nodes). After each round the energy of WSN starts decreasing linearly. At the end of simulation, i.e. after 2500 rounds, the total energy left in the WSN is around 50 J.

Fig 7. Demonstrates the amount of energy saving achieved by using our approach with respect to using no energy optimization technique. As seen from the figure there is considerable amount of energy saving using our approach. This energy efficiency will further increased when we the WSN will be deployed over a large physical are such that energy required to transmit message from a node to BS is very high.

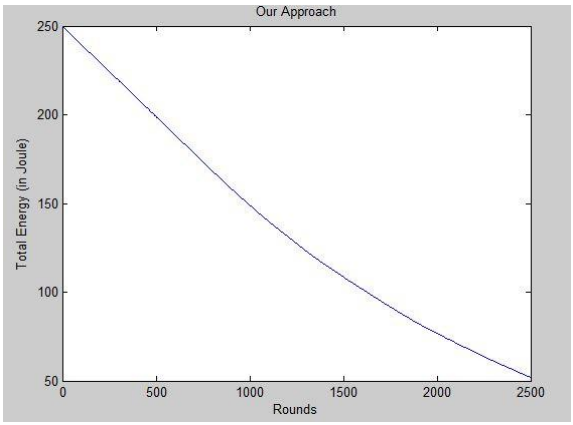

Fig. 6. The total energy of WSN during each round

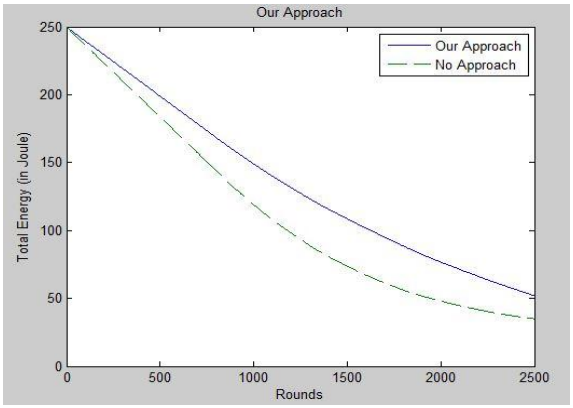

Fig. 7. Energy efficiency achieved using our approach vis-à-vis using no approach

V. Conclusion and Future Scope

In this paper, we give a brief discussion on emergence of cluster based routing in wireless sensor networks. We also propose novel approach, that can further be utilized in other clustering routing protocols for better efficiency. Our approach tends to minimize network energy consumption by efficient cluster head replacement using fuzzy logic after very first round and dual transmitting power levels for intra cluster and cluster head to base station communication. In our approach, a cluster head will only be replaced when its energy falls below certain threshold minimizing routing load of protocol. Hence, cluster head replacement procedure involves residual energy of cluster head at the start of each round. And the simulation results shows our approach consumes less energy as compared when we use no approach for transmitting the sensing information.

In future, we will carry our work to calculate routing load of our proposed scheme analytically and apply more sophisticated cluster head replacement mechanism along with

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dual transmission power levels in other clustering routing protocols of wireless sensor networks to study their impact in a broader sense.

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