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Low-Energy Aware Routing Mechanism for Wireless Sensor Networks

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***Abstract* - Wireless Sensor Networks are a collection of several hundred nodes that together sense some physical quantity and transmits the same to a central node, known as the base station. These sensors are miniature electronic circuits or devices that are capable of sensing data and establishing connection in between themselves. Due to the frequent transmission and reception of data in these sensor nodes, the overhead of these nodes are sinusoidal. Hence, increasing the network lifetime without disrupting the topology and the functionalities of the system is one of the main challenges in WSN. Moreover, due to the existence of cyclic events such as election of Cluster Heads (CH), energy is wasted. In this paper, a methodology is proposed to eliminate the cyclic execution of such events in order to conserve energy for more important functionalities. The proposed methodology yields an energy aware routing protocol accounting the residual energy of every participant node in a cluster and forecasts the next cluster head based on the energy parameters to select the most suitable CH. The proposed methodology eradicates the simultaneous selection process of new cluster heads after each cycle, and in terms, saves substantial amount of energy that is later on used by the participant nodes to transmit and receive data. Performance analysis of the system is carried out with programming tools and the results are shown.**

***Keywords* — Wireless Sensor Networks, Protocol Design, Network Protocols, Network Resource Management**

I. INTRODUCTION

Rapid technological developments have been made in WSN, which has led to a stable, cost effective, low power consuming and efficient communication mechanism. Several enhancements have also been made in routing protocols to reduce the routing overhead and reliability issues. In this paper, an energy optimizing mechanism is proposed. The proposed mechanism concentrates on increasing cluster life cycle by eliminating the cyclic process of determining individual cluster heads of each cluster. An alternate approach to Cluster Head Selection is proposed in this paper, in which, an Energy Utilization table is maintained by the base station and a probabilistic model is used to select the next most suitable CH. The conventional process in a wireless sensor networks is as follows-

1. The Base Station initiates the network by broadcasting a hello message to all the sensor nodes in the domain.

2. The sensor nodes receives the Broadcast message and replies its current configuration to the Base Station.

3. The Base Station then selects a suitable from the aggregated data.

4. The selected CHs broadcasts a beacon message to all its neighboring nodes for forming a cluster.

5. The recipient nodes then respond to the message and becomes a member node of a cluster.

6. The member nodes transmits information in cycles to the CH until a new CH is formed.

7. The collected information is directed to the Base station.

Several efficient Routing protocols have been previously proposed to reduce routing overhead issues, packet collision, re transmission delay etc. Some of these protocols are Low Energy Adaptive Clustering Hierarchy (LEACH), Dual Homed Routing (DHR), Informer Homed Routing (IHR), Neighbor Knowledge based Probabilistic Routing (NKPR) protocol.

In LEACH Protocol, the CHs are chosen in a random manner based on limited decisions. Information is collected from surrounding nodes and transmitted to the nearby CH, which is later on aggregated and forwarded to the Base Station (BS). Information Loss is inevitable when packet transmission occurs between the nodes in the routing network. Also, Broadcasting in the network is highly costly as it may lead to packet collisions, redundant re -transmissions and communication overhead, which in turn reduces the overall lifetime of the network. To overcome such anomalies in the protocol, a new methodology is proposed in this paper. Dual Homed Routing (DHR) for Wireless Sensor Network, consists of two CHs associated with an individual cluster. During data transmission, the data is sent to both the CH continuously. The data is then aggregated by the CH and then sent to the Base Station. Due to multiple CHs in a network, some nodes are unable to find a nearest CH to join which causes reliability issues. This is an important difficulty in DHR protocol. Informer Homed Routing (IHR) consists of two CHs efficiently transmitting packet from sink to destination. However, a non-cluster head (member node) cannot select nearest CH to join in the routing process. This leads to communication overhead between the nodes in a cluster. This issue may seem negligible when considering small wireless sensor networks, but this drawback may lead to a critical reliability issue for large scale Wireless sensor networks, where the member nodes are scattered randomly and are separated with large distance.

II. RELATED WORK

Efficient Neighbor Coverage Routing Protocol (ENCRP)- Neighbor Coverage based Routing concentrates on effective broadcasting and limited rebroadcasting through flooding approach. Rebroadcast delay assists in efficiently developing knowledge of neighbor clusters and establishes a rebroadcast order to maintain coverage ratio accuracy. Using Rebroadcast delay, packets are transmitted to higher number of neighbors. Node ri receives a RREQ (Route Request) packet from the previous node rp. Afterwards, node rp checks the RREQ packet by using the Neighbor List and determines the uncovered neighbor in the RREQ message. The node ri uncovers more number of neighbors by the RREQ packet from rp.Then, the node ri rebroadcasts the RREQ packet.

$$Un(r_i) - Ne(r_i) - [\, Ne(r_i) \cap Ne(r_p) \,] - \{r_p\} \qquad (1)$$

Where, Ne(ri) is the neighbor set for node ri
And Ne(rp) is the neighbor set for node rp

The neighboring nodes in node ri might receive duplicate RREQ packets. A rebroadcast delay should be set and adjusted with time to exploit channel. The rebroadcast delay can be calculated as

$$Tp\,(r_i) -1 - \frac{|Ne(r_p) \cap Ne(r_i)|}{|N(r_p)|\; Td\,(r_i) - maxdelay * Tp\,(r_i)} \qquad (2)$$

Where $Tp(r_i)$ is delay ratio for node ri and maxdelay is a constant ratio.

Neigbor Knowledge based Probabilistic Routing Protocol (NKPR) - NKPR protocol is the combination of neighbor coverage and probabilistic approaches. Maintaining redundant re-transmissions and network connectivity is important and a factor called connectivity metric is introduced which defines the number of RREQ packets that is received by the neighbor. Combining the calculated coverage ratio and connectivity metric gives the probability of rebroadcasting that is utilized for decreasing the rebroadcasts of RREQ packets. NKPR method efficiently increases the routing performance and solves reliability issues.
If a duplicate RREQ packet is re-transmitted to node ri from neighboring node rj, then the number of neighbors from node rj covered by RREQ packet can be estimated. The uncovered neighbor set for node ri is as follows

$$U_n\,(r_i) - Un\,(r_j) - [\, U(r_i) \cap Ne(r_j) \,] \qquad (3)$$

After adjusting the node Un (ri), received RREQ packet form node ri is discarded. When the rebroadcast delay timer expires, then the node obtains the last uncovered knowledge set. If a node in a network does not receive RREQ duplicate packet from its neighbors implies that an uncovered neighbor set need not be changed which is treated as initial knowledge. Additional coverage ratio is calculated as follows:

$$\mathbf{R(r_i)\text{-}|Un(r_i)| \,/\, |Ne(r_i)|}$$

III. PROPOSED METHODOLOGY

The existing method called NKPR and ENCPR uses a cyclic process for CH selection. The execution of such cyclic processes leads to wastage of energy. In this paper, a new methodology is proposed which uses an Energy Utilization Table and avoids repetition of redundant processes in the network. The Energy utilization table is structured and maintained by the Base Station, and any frequent changes are sent as update messages to the recipient node.

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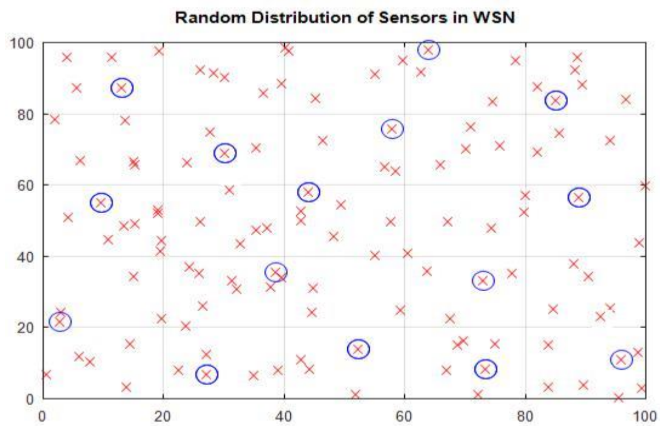

Figure 1.1 – Wireless Sensor Network

- Cluster Head   - Sensor Nodes

Figure 1.1 shows a Wireless Sensor Network with several wireless sensor nodes with selection and formation of 15% of CHs from the total number of nodes.

3.1.1 Energy Utilization Table

Energy Utilization Table for WSN				
Node_ID	Avail. Energy (in Joules)	Avg. Energy Consumption (µJ / min)		Avg. Energy Depletion (µJ / min)
		Transmitting	Receiving	
r_i	0.0025	0.13	0.07	0.53

Table 1.1- Energy Utilization characteristics

The above information is recorded and the energy statistics of the entire WSN is maintained by the BS in order to select/predict the set of suitable CHs for the next cycle. The term “Energy Metric” is introduced in this paper. The metric indicates a calculated score for a node ri based on the tabulated factors mentioned above. At every cycle, the Energy Statistics of the set of CHs are revised with the current configuration of the nodes and the next set of suitable CHs are predicted. These operations are solely performed by the BS and the participation of individual sensor nodes/CHs are restricted to conserve energy, which increases the lifetime of the entire network.

3.1.2 Energy Metric Calculation

The Energy metric introduced in this paper acts as an alias of the overall statistics related to an individual node. The energy metric is calculated as follows-

$$E_{metric}(r_i)=E_{avail}(r_i) - \frac{[\, E_{transmit}(r_i)+E_{receive}(r_i)\,]*T_{cycle}}{T_{cycle}}$$

where Tcycle denotes the average time of a cycle.

Energy involved in node-to-node transmission, bit processing and rebroadcasting should not be accounted for this statistical approach.

3.1.3 Energy statistics based Selection Algorithm:

After the initial node distribution has occurred, LEACH protocol is activated within the network. After every cycle, a new CH is selected within the cluster and process is repeated. A further optimized algorithm to reduce energy utilization of the network and increase the network lifetime is stated as follows:

Definitions:

$\sum_{r(i)}^{r(n)}$ ❑ : superset of all the nodes in the WSN,

$\{CH_m\}$: set of CH for the m^th cycle,

Timer (r_{base} ,T_i) : timer for base station, set to T_i seconds.

1. $\sum_{r(i)}^{r(n)}$ ❑ r_{base} : receive initial node info;
2. select $\{CH_m\}$ = { r_a } randomly from the received data; initiate first cycle; (m =0).
3. Set Timer (r_{base} ,T_i); $\sum_{r(i)}^{r(n)}$ ❑ r_{base} : receive data;
4. while (Timer (r_{base} ,T_i) not expires)
5. Compute { $\sum_{r(i)}^{r(n)}$ ❑ $E_{metric}(r_i)$ };
6. end while

7. if (Timer (r_{base} ,T_{i+1}) triggered)

8. select node r_b= min({ $E_{metric}(r_i)$ });

set { CH_{m+1} }={ r_b };

discard node r_b from { $E_{metric}(r_i)$ };

9. end if

10. set Timer (r_{base} ,T_{i+1}); $\sum_{r(i)}^{r(n)}$ ❑ r_{base} : receive data;

IV. SIMULATION CONSTANTS

The simulation observations are based on the Mica2 Specific energy consumption model proposed by Joseph Polastre. This model is reproduced in Table 1.2:

Radio Mode	Energy Consumption
Transmission (E_{tx})	4.60 µJ / 8 bits
Reception (E_{rx})	2.34 µJ / 8 bits
Amplification (ε_{amp})	100 pJ / bit / m^2
Idle state (E_{idle})	40 nJ / bit
Sleep state (E_{sleep})	0

Size of each Packet = 50 Bytes
Area of node distribution = 100 m x 100 m

Number of nodes in the network = 100
Initial energy given to each node = 25000 µJ

Time allotted for each cycle = 1800s
Table 1.2 – Radio characteristics, Classical Model
The classical energy consumption model considers a low power consumption radio and has slightly better advantages over standard definitions.

V. PERFORMANCE ANALYSIS

In order to analyze the performance of any proposed methodology, a simulation of the entire system is required. For this purpose, We used GNU Octave, which is an alternative analysis tool for MATLAB. The results are given sequentially with indices :

5.1.1 Residual Cluster Energy Per Cycle

The effective energy remaining in a cluster after the transition of the WSN from one cycle to another is defined as the residual cluster energy.

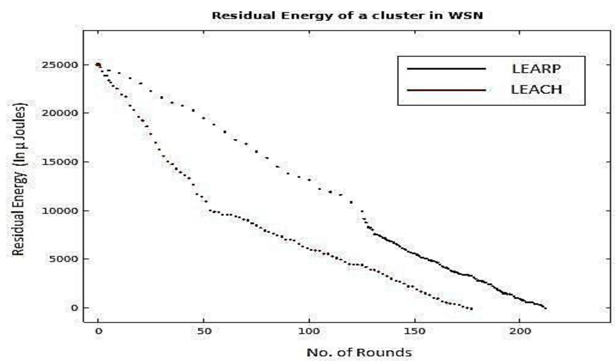

Fig 1.2 (a) – Avg. Residual Energy of a cluster , LEACH vs Proposed Methodology

Fig 1.2 (a) shows the residual cluster energy observed for the most nearby cluster from the BS. Since the packets transmitted from nearby clusters do not participate in rebroadcasting and routing operations, the energy consumed by these clusters are lesser and the endurance of such clusters are higher than the distant clusters. On the other hand, Amplification is mandatory for packets transmitted from distant clusters, which requires more consumption. The residual energy of a distant cluster is shown in fig 1.2 (b):

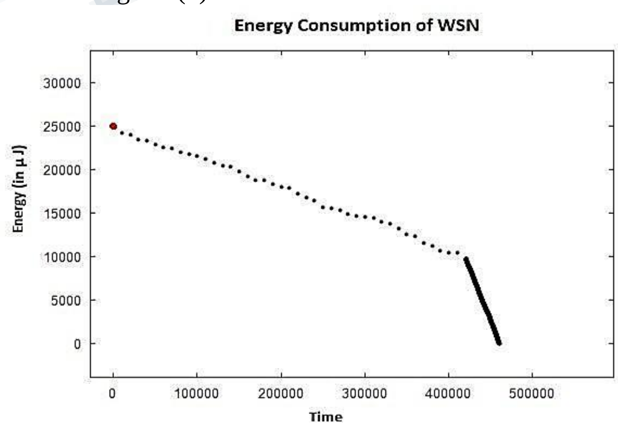

Fig 1.2 (b) – Avg. Energy Dissipation of the Network

5.1.1 Lifetime of the Network

The lifetime of the network is defined as the time upto which the network can remain alive and monitor the environment. Fig 1.4 shows some parameters that are involved in determining the lifetime of the WSN: C

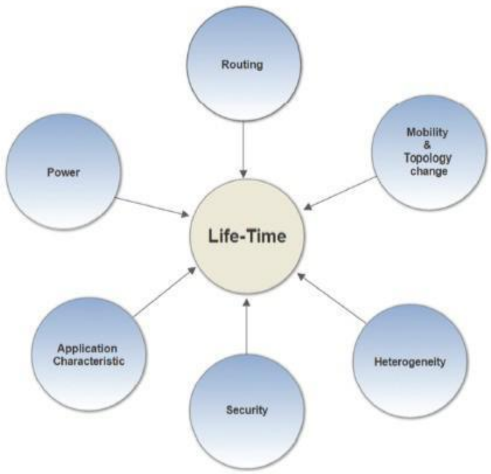

Fig 1.4- Parameters affecting Lifetime

The Lifetime of the network depends on the Power or the Energy consumption of the network. The energy required for various operations such as monitoring, transmission, reception, routing etc plays a vital role in determining the lifetime of the network. Thus, it is equally important to decide the hardware and configuration of the nodes while deploying the WSN. Routing on the other hand leads to redirection of packets to an intermediate CH for efficient delivery of packets. This increases the number of re-transmissions for a packet to reach from source to destination, which might lead to decreased lifetime. However, routing in WSN allows distant nodes to pass data efficiently by avoiding amplification and redirecting the packets to nearby neighbors. Security is also a parameter that impacts the lifetime of a WSN, Complex algorithms when used for encryption or decryption of data may lead to secondary consumptions.

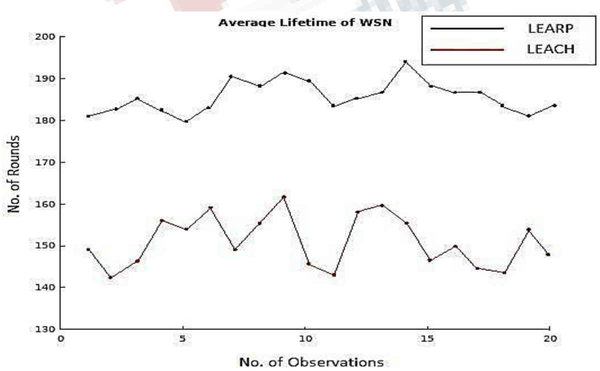

Fig 1.3 - Lifetime of the Network

In order to plot the lifetime of the network after deployment, we simulated the WSN and recorded the data for 20 observations. Fig 1.3 shows these readings. Due to the heterogeneity in the WSN, there is no linearity observed between the Lifetime of the network at different observations and it is very likely that the clusters can hold variant depletion energies. To verify the non-linearity of the energy depletion of individual clusters, we varied the initial energy and plotted the lifetime of a cluster for 20 observations. Fig 1.4 shows the Lifetime of the network with different initial energies:

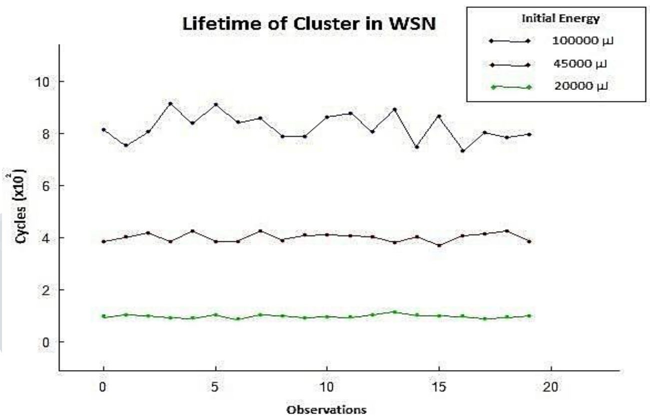

Fig 1.3 - Lifetime of the Cluster relative to Initial Energy

VI. CONCLUSION

Increasing the Lifetime and optimizing the energy consumption of the WSN is an important mechanism for deploying sustainable WSN. In this paper, an alternative methodology is proposed to eliminate the cyclic Cluster Head selection process which leads to wastage of energy and causes collision of redundant data in the network. The simulation results when compared with existing protocols proves that the proposed method reduces the depletion energy of individual clusters and thus, increases the overall lifetime of the WSN. However, this method is centralized and monitored by the BS, leading the BS responsible for the failure of the entire system. Any computational delay or hardware failures in the BS will interrupt the application of the WSN.

VII. FUTURE WORK

In this paper, the proposed methodology is centralized by the BS. With further advancements in memory and hardware configuration of sensor nodes, CHs will be able to compute and store the statistical data and the mechanism can be decentralized to the set of selected CH. Also, the proposed methodology is mostly suitable for heterogeneous WSN. A heterogeneous WSN can consist of several types of sensor nodes with different functionalities and different energy consumption. This increases the variance of the aggregated data in the energy utilization table. Whereas, due to low variance in homogeneous WSN, the complexity of the selection algorithm increases. Hence, Further advancements can be done to this methodology to provide a better and efficient CH selection algorithm for homogeneous WSN as well.

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