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Residual Energy Aware Adaptive Clustering for Multimedia Data in Wireless Sensor Network

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Abstract— **Wireless Sensor Network consists of large number of Sensor Nodes. The main aim is to increase the lifetime of the network as the sensors are deployed mainly to perform unattended operations like Environmental Monitoring, Seismic activity Detection, Industrial Monitoring and Control etc. All these activities require Robust Wireless Communication Protocol with low power consumption. This paper describes how the optimal numbers of Cluster Heads (CH) are elected among the sensor nodes so that energy is optimally consumed for the cluster members to interact with Cluster Heads. The role of the Cluster Head is rotated so that the energy consumption can be distributed evenly and the lifetime of the Wireless Sensor Network can be extended. The experimental results shows that the life time of the network is extended as compared to other approaches like Low Energy Adaptive Cluster Hierarchy LEACH.**

Index Terms— **Wireless Sensor Networks, Cluster Head, Base Station, Clustering, Network Lifetime and Energy Efficiency**

I. INTRODUCTION

WITH the advancement in the field of highly integrated digital electronics technology and wireless communication, a new class of distributed system called Wireless Sensor Network (WSN) has come into existence. Wireless Sensor Networks are used for gathering high precision data where the setting up of Wired infrastructure is not possible i.e. too difficult or too costly. Wireless Sensor Network Consists of large number of sensor nodes with limited communication, computational, sensing capability & irreplaceable power resources. Some applications of WSN include environmental monitoring, military control and communications, forest fire detection, surveillance, traffic monitoring, home applications and control and agricultural applications [2]. A typical Wireless Sensor Network consists of sensor nodes which send data directly or indirectly to the sink or Base Station (BS).

In most of the Wireless Sensor Network Applications the sensor nodes are deployed randomly on the fly for unattended operations. Once these sensor nodes are deployed, they are inaccessible to the users, therefore the replacement of these nodes is not feasible and it becomes costlier to replace every node which becomes dead. The sensor nodes works together in order to achieve a common goal of sensing the physical parameters of the environment in which they are deployed.

Sensor nodes have constraints like limited power resources and bandwidth. Thus different innovative techniques which overcome the inefficiencies are required so that the lifetime of the network can be functional for a longer time and the life time of the network can be extended. Thus, the main aim is to evenly distribute the consumption of energy load among the sensor nodes in order to overcome the problem of overly utilized sensor nodes that will run out of energy as compared to other sensor nodes.

In order to minimize the energy consumption, some of the previous research works focused on the low energy hardware design of the digital circuits which include micro sensor, low power transceivers etc. But this only reduced the energy consumption up to certain level. However, the energy consumption is mainly due to the communication over the network. Thus the primary focus should be more on design and architecture of the Wireless Sensor Network. For this several research works have proposed energy efficient protocols on Clustering, Routing, Data aggregation etc.

These protocols work on the evenly distribution of the energy consumption among the sensor nodes of the Wireless Sensor Network. The communication protocols can be classified into three domains [3]. These domains are: (i) Direct [4], (ii) Multi-Hop [5] and, (iii) Clustering [1]. Clustering is one of the efficient methods to reduce the energy consumption in the Wireless Sensor Network [6]. In Direct communication, each sensor nodes transmits the sensed data directly to the Base Station or Sink. In this type of communication, huge amount of energy is consumed if the distance between the Base Station and the Sensor Node is large.

In Multi-Hop architecture, data is transmitted from one sensor node to another (Hop by Hop) so as to reach the Base Station. In this, the energy consumption is reduced but the sensor nodes nearer to the Base Station die prematurely due to the over burden of transmitting the data to the Base Station. In the Clustering scheme, every sensor node actively participates in the communication. Thus, the energy dissipation is even which leads to extension of the lifetime of the network.

In this paper we have proposed residue energy based clustering protocol which makes use of clustering in order to extend the life time of the Wireless Sensor Network. It includes two phases: Setup Phase (selection of Cluster Head (CH)), and the Steady Phase (transfer of sensed data from the environment to the Base Station or Sink).

The rest of the paper is organized as follows- Section II, summarizes the previous works. In Section III the network model of the protocol is discussed. In this all the assumption made in the protocol are listed. In Section IV, the proposed protocol is explained in detail. In Section V we show the experimental setup and simulation results. Finally we conclude our paper in the Section VI.

II. RELATED WORK

In the past few years, a large number of energy efficient protocols have been proposed. Some of them emphasized on Centralized approach, some emphasized on the Distributed approach and some on the Hybrid approach. Clustering basically involves a set of Cluster Heads which are chosen from a pre defined criterion. The functionality of the CH is to synchronize and gather data from the cluster members. After aggregating the data, the CHs transmit this data to the Base Station. Some of the Cluster based energy efficient protocols are LEACH [1], LEACH-C [7] PEGASIS [8], HEED [9], EECS [10]. In LEACH, every node generates a random number between 0 and 1. If the random number generated by the sensor node is less than the threshold value, then that node is nominated for the Cluster Head. The number of CHs in LEACH is not fixed or optimal. The data aggregated at CHs is transmitted to the Base Station. In this approach the CHs are rotated after every round so that the energy dissipation is even. LEACH-C is a centralized protocol which involves the Base Station for the selection of CH.

All the sensor nodes send their location and energy to the Base Station. The Base Station forms the cluster using annealing algorithm and associate members with the CHs. In PEGASIS, the cluster formation is done on the basis of location of every sensor. In HEED, the cluster formation is on the basis of probability of residual energy of each node as well as the cluster radius for intra cluster communication. The Cluster Heads are elected on the basis of intra cluster communication cost. In EECS, the cluster sizes are uneven i.e. the cluster nearer to the Base Station will have less number of nodes as compared to the cluster farther from the Base Station.

In Energy Aware routing Protocol (EAP)[11], a ratio is find out between the average energy and the residual energy of each sensor node's neighbor which are cluster members. The node which has higher ratio has more probability of becoming the Cluster Head. In Base Station Controlled Dynamic Clustering Protocol (BCDCP) [12], the Base Station divides the network into certain number of cluster and then chose two nodes as Cluster Heads which have maximum distance. Now the Base Station assigns the clusters members so as to make balanced clusters. Some other algorithms make use of graph properties for cluster formation [13].

III. NETWORK MODEL

A. Assumptions

In our protocol architecture, we assume that N number of Sensor Nodes are scattered randomly over the network. A snapshot of the random network is shown in Fig. 1. These nodes are static and homogeneous in nature and the Base station is far away from the network and is fixed. Moreover, following assumptions are made for the underlying network model:

i). The energy of the Base Station is infinite.

ii). Every sensor node is capable of communicating with every other sensor node and to the Base Station if needed.

iii). Each sensor node has power control for communication i.e. range of the transmission can be controlled.

iv). Each sensor node has a Unique Id for its identification.

v). The locations of the sensor nodes are not known but they can calculate the distance with the help of received signal strength.

vi). Every sensor node has always data to be sent to the end user and the data is correlated with nearby nodes.

vii). The links are symmetric i.e. two nodes can communicate with the transmission power level.

viii). Sensor nodes are capable of working in low power sleeping mode.

B. Energy Consumption Models

In our network architecture we use a simplified model for the energy dissipation in communication [13]. In this model, free space power loss and multipath power loss are accounted depending upon the distance between the receiver and the transmitter. The energy consumed for L bits of data is calculated from the Eq. (1).

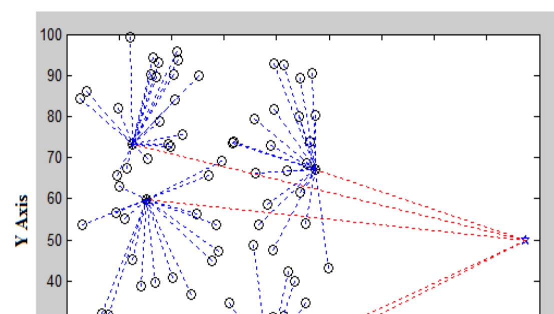

Fig. 1: 100 nodes random network

$$E_{Tx}(L,d) = \begin{cases} L * E_{node(Tx)} + L*\in_{fx}*d^2, & d \le d_0; \\ L * E_{node(Tx)} + L*\in_{mp}*d^4, & d > d_0. \end{cases} \quad (1)$$

Here E is the Energy and d is the distance. Finally d_0 can be calculated from the Equation (2)

$$d_0 = \sqrt{\frac{\in f_x}{\in_{mp}}} \quad (2)$$

Since it is assumed that the data is correlated, the Cluster Head aggregates the data in a single packet and sends it the Base Station.

IV. PROPOSED PROTOCOL

In our proposed protocol, there are two phases: (i) Setup Phase, (ii) Steady Phase. Table 1 describes the difference between the proposed protocol and the LEACH protocol.

The operations performed in each of the phases of proposed protocol are explained below.

A. Setup Phase

In the LEACH [5] protocol, every node generates a random number between 0 to 1. This random number is then compared with a threshold in Eq. (3). Here N is the number of nodes and k is the desired number of Cluster Head, r is the Rounds. If the number generated by the sensor node is smaller than the threshold (3) then the node is nominated as Cluster Head.

Table 1: Proposed Protocol vs. LEACH

Characteristics	LEACH	Proposed Protocol
Deployment of Sensor Nodes	Random	Random
Cluster Head Selection Criteria	Random number + Energy	Residual Energy
Number of Cluster Heads	Not Fixed	10% of Alive Nodes
Chance to become CH	Every node will get a chance	Higher energy nodes will get chance
First Round	Any node can be selected as CH based on Random number generated	Any node can be selected
Subsequent Rounds	Identification of Past CHs + Random number generated + Residual Energy	Only the Residual energy of node is under consideration
Rounds with No Cluster Head elected	Possible in LEACH because of randomness	Not possible as CH's election is based on residual energy

But in this selection criteria, some problem may arises [3] like (i) the number of CHs in one of the round may be zero i.e., no Cluster Head is elected which may lead to loss of information, (ii) there may be some rounds in which the number of Cluster Heads are very few which may lead to more energy consumption, 3) there may be some Cluster Heads which are having energy greater than the threshold level [5] but less than other nodes.

$$T(n) = \begin{cases} \dfrac{P}{1-P*(r \bmod \frac{1}{P})} & \text{If } n \in G \\ 0 & \text{Otherwise} \end{cases} \tag{3}$$

In order to ensure that all the nodes should dissipate energy evenly, we present new Cluster Heads selection criteria which will take into account the residual energy of the nodes. First step of our protocol for selection of Cluster Head is to find out the energy levels of every alive node. In the second step, every node will be having different amount of energy at different rounds. So, all the nodes are arranged in decreasing order of Energy levels. Now the question of number of Cluster Heads arises. In our protocol we have experimentally chosen 10 % of the nodes which are alive in the network as the maximum number (CH_{max}) of Cluster Heads in a round for each round. All those nodes which are having highest levels of energy will be selected as the Clusters heads. In this Selection phase, a key point is kept in mind that no two or more Cluster Heads will be there in the nearby region. If it happens, then the Cluster Head with the highest Energy level will be chosen as Cluster Head and rest of the competitors will be discarded for that round. This will also ensure that Cluster Heads will be dispersed evenly in the scenario so that the energy consumption can be evenly distributed as much as possible to prolong the network lifetime.

B. Steady Phase

After the selection of Cluster Heads, all the Cluster Heads will announce their selection as Cluster Heads using a non persistent carrier sense multiple access (CSMA) MAC protocol [13]. The announcement or advertisement message will consist of Node Id of the Cluster Head. All the nodes in the network will send a message to the Cluster Head for along with the Node ID to associate themselves with the Cluster Heads whose received signal strength is strongest i.e. Stronger the received signal strength, shorter is the distance between them. Now the Cluster Head will set up a span of time and will transmit the slot to the cluster members based of Time Division Multiple Access (TDMA) mechanism.

In the communication phase, since all the nodes have power control, the radio frequency of the cluster members is set to minimal so as to reach only to the Cluster Heads. In our network architecture, all the nodes are assigned with the TDMA slot, so only the cluster member which has the slot to send data to the Cluster Head will be awake and rest of the cluster members will go in low power sleeping mode. The Cluster Head will collect data from the cluster members and will send this data after diffusion to the Base Station using a fixed spreading code and CSMA [5]. Whenever the Cluster Head needs to send data to the Base Station, it will sense the channel to check if other Channel Head is using the channel or not. If the channel is busy, the Cluster Head will wait and then again sense the channel after some time and will send the data if the channel is found free.

V. PERFORMANCE EVALUATION

In this section we will evaluate the performance of our proposed protocol. Simulations are carried out in MATLAB version 7.8. The simulation parameters are listed in Table 2. The simulation is carried out in a network grid of 100mX100m. There are two scenarios where the position of the Base station is varied. In one scenario, the location of the Base station is (50, 50) and in another scenario, the Base station is at (175, 50). The numbers of nodes are 100. The packet size is set to 500 Bytes. The energy levels of each node are also varied in both the scenario. The energy levels are set as 0.25J, 0.50J, and 1J. Different topologies are generated randomly for simulation. Each simulation result shows the average of independent experiments.

Table 2: Simulation Parameters

Parameters	**Values**
Network grid	From(0,0) to (100,100)
Number of Nodes	100
Base Station Location	(175,50)m/ (50,50)m
Initial Energy	0.25J/0.50J/1 *J*
$€_{fs}$	$10pJ/bit/m^2$
$€_{mp}$	$0.0013pJ/bit/m^4$
d_0	$87m$
E_{elec}	$50nJ/bit$
E_{DA}	$5nJ/bit/signal$

Table 3 summarizes the simulation results for three different initial energy levels for the network structure. In this table, two terms are used FND (first node death) and LND (last node death). The FND determines how long all the nodes in the network are alive and LND determines the last round when the network gets disconnected. The difference between these two terms determines the energy dissipation for the network i.e. if the difference between these two terms is least, then it means the energy dissipation is evenly distributed and if the difference is larger, then it means the energy dissipation is uneven.

We have chosen LEACH protocol for comparison because this protocol almost works in similar fashion except for the Cluster Head selection. From the results in the table-2, we can see that the death of first node in our protocol is always at later rounds than in LEACH. For any protocol it is necessary that the death of first node should be extended as much as possible so that network should be connected and provide the required information to the End user. Our protocol is capable enough to extend the life time of the Wireless Sensor Network as compared to LEACH. The energy dissipation in LEACH is also uneven as we can see that the difference between the death of first node and the last node is larger whereas in our proposed protocol, the energy dissipation is evenly distributed among the sensor nodes.

Fig. 2 depicts the number of alive nodes at a regular round interval. In this, we can see that all the sensor nodes were alive till round 690 in our proposed protocol where as in LEACH it was up to 470 only. The number of nodes alive in the network of the proposed protocol lasts for more than 700 rounds where as in other protocol it is near about 550. Thus, the life time of the proposed protocol is comparatively greater than the LEACH protocol. Figure-3 shows the number of packets delivered to the Base Station per round. It is clear from the figure that the number of packets delivered by proposed protocol is more as compared to LEACH protocol. This concludes that our protocol sends more information to BS for longer period.

Fig. 4 depicts the Average energy level of the network per round. The network is initiated with 1 J of energy for every sensor node. As the number of rounds increases, Average energy level of the network also decreases. We can see in the Fig. 3 that the average energy level of the LEACH protocol is decreasing more rapidly as compared to our proposed protocol. The Average energy level in LEACH lasts for less than 550 rounds where as in our proposed protocol it is more than 700 rounds. Hence, we can say that our protocol dissipates less energy per round as compared to LEACH protocol thereby increasing the lifetime of the network.

Table 3: Timing of death of Nodes

Energy (J)	Protocol	Base Station (50,50)		Base Station (175,50)	
		FND	LND	FND	LND
0.25J	LEACH	217	277	20	155
	Proposed	344	364	56	167
0.5J	LEACH	469	532	78	275
	Proposed	700	719	195	326
1.0 J	LEACH	988	1047	171	520
	Proposed	1409	1430	438	597

VI. Conclusion

In this paper, energy optimized clustering protocol is proposed for Wireless Sensor Network. Clustering of sensor nodes leads to less consumption and evenly distribution of energy. We have proposed a Cluster Head selection criteria based on which clusters are formed. From the experimental results, we conclude that in the proposed protocol, the death of first node is extended in terms of round as compared to LEACH and the difference between death of first node and the last node indicates that the energy dissipation of the network is also evenly distributed in the proposed protocol. The life time of the network is also increased comparatively.

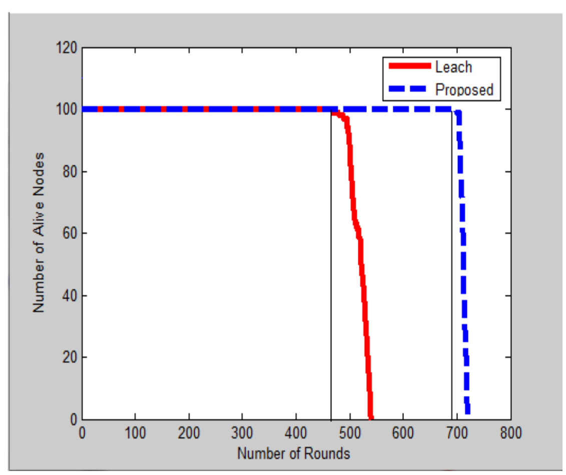

Fig. 2: Number of Alive nodes per round

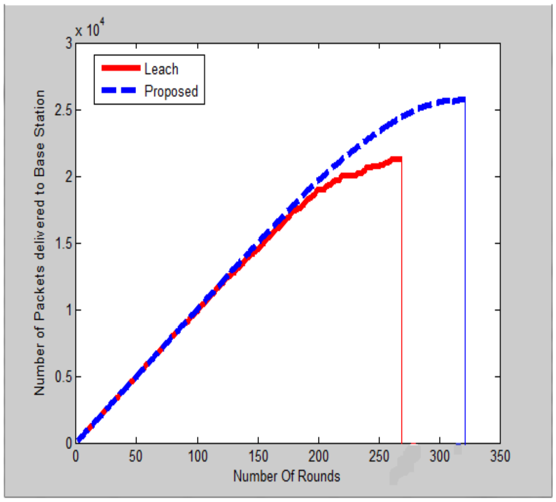

Fig. 3: Number of Packets delivered to BS per round

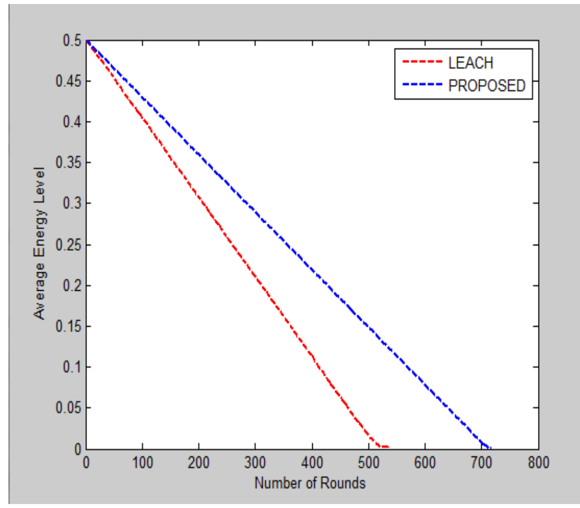

Fig. 4: Average Energy level of Network per round

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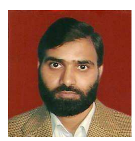

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