Role of Heterogeneity in Clustered Wireless Sensor Network

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Abstract—WSN Technology has been widely used in many fields, such as monitoring, security,defense and so on. Nodes in the wireless sensor network require lots of energy in transmission and reception of information then required in sensing and processing. Hence, all the designing protocols and applications for wireless sensor network should be energy aware in order to increase the lifetime of the network. Generally all the real time applications are heterogeneous in nature rather than homogeneous. This paper analyzes the effect of heterogeneity of nodes, in terms of energy, on lifetime and throughput of wireless sensor network that are hierarchical clustered. Simulations shows the effect of heterogeneity on Low Energy Adaptive Clustering Protocol (LEACH) which is basically a heterogeneous-oblivious clustering protocol and then compare the result with the Stable Election Protocol (SEP) which is heterogeneity aware protocol. Simulation results show that heterogeneity increase the lifetime of the network and reduce the energy consumption. Simulation analysis with SEP shows significance increase in stability region than LEACH.The key contribution of this paper is to show that how the heterogeneity improves the performance parameters of WSN like lifetime and throughput in significant manner.

Keywords: *LEACH,Network Lifetime SEP, Routing Protocols, Throughput, Wireless sensor Network*

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I. INTRODUCTION

Wireless Sensor Networks are networks of small, battery powered sensor nodes with limited in-built processing, storage and radio capabilities [1]. Nodes sense and send their reports toward a processing centre which is called “sink.” The design of protocols and applications for such networks has to be energy aware in order to prolong the lifetime of the network, because the substitute of the embedded batteries is a very difficult process once these nodes have been deployed. The Base station is having unlimited battery power. So the base station should implement the algorithm and protocols by which it can enhance the life time of the sensor node as well as save the battery power.For this reason, clustering [2] in WSN is done. In clustering techniques, to reduce the amount of data transmission, information aggregation mechanism is used on cluster head level so that the total energy consumption in communication can be reduced.

LEACH [9] is a hierarchical clustering protocol that uses the mechanism of cluster-head rotation, selects cluster heads randomly, and each node has an equal chance. So LEACH algorithm balances the energy consumption of the entire network, prolongs the lifecycle of the whole network in compare to multi-hop routing [3] algorithm and static algorithm.

Most of the simulation results for LEACH-type schemes[8] are obtained assuming that the nodes of the sensor network have equal energy and that is called a homogeneous sensor network in terms of energy. On the other hand, heterogeneous sensor network consist of sensor nodes with different capabilities, such as different energy level, sensing Range and Computation power. Assuming that with the current technology the cost of a sensor is tens of times greater than the cost of embedded batteries, it will be effectual to examine whether the lifetime of the network could be increased by simply distributing extra energy to some existing nodes without introducing new nodes. This paper studies the impact of heterogeneity (in terms of node energy)on lifetime and throughput of sensor network. For this it is assumed [4] that a percentage of the node population have more energy than the rest of the nodes in the same network.

The rest of the paper is organized as follows. Section II describes the heterogeneous WSN Model. Section III shows the LEACH in Heterogeneous model. Section IV defines the energy-aware SEP protocol. In Section V Radio energy dissipation model is described. In Section VI Simulation results are discussed. Finally Conclusion is given in Section VII.

II. HETERGENEOUS WSN MODEL

In this section we describe our model of a wireless sensor network with nodes heterogeneous in their initial amount of energy. Consider the case [4] where a percentage of population of sensor nodes is equipped with more energy resources than the rest of the nodes. Let q be the fraction of the total number of nodes n, which are equipped with p times more energy than the others. Thesenxqpowerful nodes are referredas advanced nodes, and the rest (1−q) ×n as normal nodes. This model follows the same procedure as normal LEACH protocol.

Let assume all random deployed nodes are distributed uniformly over the sensor field and in this randomly deployed network:

Number of normal nodes = (1-q) × n
Energy per normal node = E_0

Number of advanced nodes = q× n

Energy per advanced node = $E_0 \times (1 + p)$

Hence the total energy of the network:

$((1\text{-}q) \times n) \times E_0 + (q \times n) \times (E_0 \times (1 + p)) = n \times E_0 \times (1 + p \times q)$ **(1)**

Total energy of the network is increased by afactor of (1+ p·q).Further section describes behaviourof the heterogeneity-oblivious protocol in heterogeneous WSN.

III. LEACH IN HETEROGENEOUS WSN

LEACH is a kind of cluster-based routing protocols, which uses distributed cluster formation [9], [10]. LEACH randomly selects a few sensor nodes as cluster heads (CHs) and rotates this role to evenly distribute the energy load among the sensors in the network to balance the energy spent by each sensor node. The idea is to form clusters of the sensor nodes based on the received signal strength and use local cluster heads as routers to the sink. In LEACH, the Cluster Heads compress data arriving from member nodes and send an aggregated packet to the BS in order to reduce the amount of information that must be transmitted to the BS. In order to reduce inter & intra cluster interference LEACH uses a TDMA/code-division multiple access (CDMA) MAC. The operation of LEACH is done into two steps, the setup phase and the steady state phase. In setup phase the nodes are organized into clusters and CHs are selected. These cluster heads change randomly over time in order to balance the energy of the network. This is done by choosing a random number between 0 and 1. The node is selected as a cluster head for the current round if the random number is less than the threshold value T (n), which is given by

$$T(n) = \begin{cases} \frac{P}{1-P.\left(r \bmod \frac{1}{P}\right)}, & if\ n \in G \\ 0 \quad , & otherwise \end{cases} \quad (2)$$

Where P is the optimal probability [9], G is the set of nodes that are involved in the CH election means these nodes have not been selected as cluster head in last 1/p round, and r is the current round number. In the steady state phase, the actual data is transferred to the BS. To minimize overhead the duration of the steady state phase should be longer than the duration of the setup phase. The CH node, after receiving all thedata from its member nodes, performs aggregation before sending it to the BS. After a certain time period, the setup phase is restarted and new CHs are selected. Each cluster communicates using different CDMA codes to reduce interference from nodes belonging to other clusters.

The original version of LEACH does not consider the heterogeneity in nodes in terms of initial energy. But if we make the network heterogeneous by giving more energy to some nodes LEACH protocol treats same the advanced node as it treats the normal nodes because it is a heterogeneity-oblivious protocol. So the stability period is the same in bothhomogeneous and heterogeneous network lifetime ofnetwork will be increased in heterogeneous network.

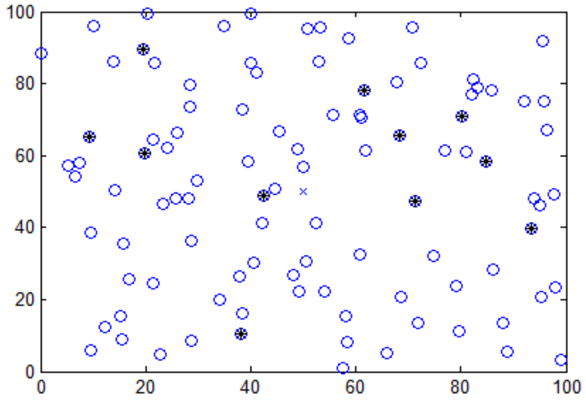

Fig. 1 HomogeneousWireless Network

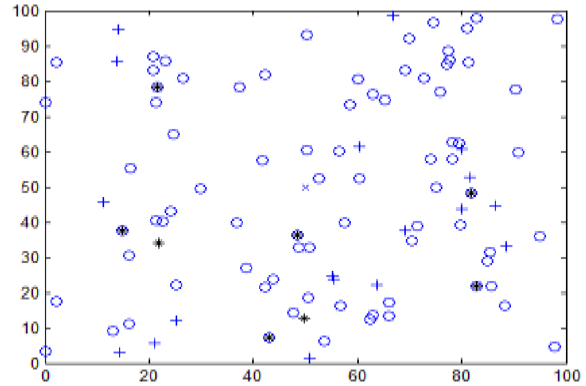

Fig. 2 HeterogeneousWireless Network

The LEACH protocol does not take into consideration the heterogeneity of nodes in terms of their initial energy, and as a result the consumption of energy resources of the sensor network is not optimized in the presence of such heterogeneity. The reason is that LEACH depends only on the spatial density of the sensor network.

IV. HETEROGENITY AWARE SEP PROTOCOL

In this section we describe how heterogeneity aware SEP protocol [6] increases the stable region of the clustering hierarchy process using the keynote parameters of heterogeneity, namely the fraction of advanced nodes (m) and the accrual energy factor between advanced and normal nodes (α). In order to prolong the stable region, SEP attempts to maintain the constraint of well-balanced energy consumption. Artfully, advanced nodes have to become cluster heads more oftenthan the normal nodes to maintain the balance of energy. SEP (Stable Election Protocol) based on the initial energy of the nodes assumes that each node knows the total energy of the network and then adapts its election probability to become a cluster head according to its remaining energy [7]. Hence in SEP there are two probabilities P_{nrm} and $P_{adv.}$ Here P_{nrm} is the weighted election probability for normal nodes and Padv is the weighted election probability for advanced nodes. The weighed probabilities for normal and advanced nodes are, respectively:

$$P_{nrm} = \frac{P}{1+\alpha \cdot m} \quad (3)$$

$$P_{adv} = \frac{P}{1+\alpha \cdot m} \times (1+\alpha) \quad (4)$$

For normal nodes threshold will be $T(n_{nrm})$ and for advanced nodes threshold will be Tadv which is simply obtained by replacing the optimal probability P in equation (1).

Thus, for normal nodes, we have:

$$T(n_{nrm}) = \begin{cases} \frac{Pnrm}{1-Pnrm \cdot \left(r \bmod \frac{1}{Pnrm}\right)}, & if n_{nrm} \in G^{n} \\ 0, & otherwise \end{cases} \quad (5)$$

where r is the current round, G^n is the set of normal nodes that have not become cluster heads within the last 1/Pnrm rounds of the epoch, and $T(n_{nrm})$ is the threshold applied to a population of n·(1−m) (normal) nodes. This guarantees that each normal node will become a cluster head exactly once every 1/P·(1+α·m) rounds per epoch, and that the average number of cluster heads that are normal nodes per round per epoch is equal to n·(1−m)×Pnrm.

Similarly, for advanced nodes, we have

$$T(n_{adv}) = \begin{cases} \frac{Padv}{1-Padv \cdot \left(r \bmod \frac{1}{Padv}\right)}, & if n_{adv} \in G^{m} \\ 0, & otherwise \end{cases} \quad (6)$$

Where G^m is the set of advanced nodes that have not become cluster heads within the last 1/ Padv rounds of the epoch, and $T(n_{adv})$ is the threshold applied to a population of $n \cdot m$ advanced nodes. This guarantee that each advanced node will become a cluster heads exactly once every $\frac{1}{P} \times \frac{1+\propto m}{1+\alpha}$round.Having an understanding that the wireless communicationcomponent of a sensor node is responsible for the energy draining activities, proposed algorithm uses the first order radio model. Next section describes the assumed radio model which is same as described in [9].

V. FIRST ORDER RADIO ENERGY MODEL

The first order radio model offers an evaluation of energy consumed when transmission orreception is made by a sensor node at each cycle.The transmission cost E_{TX} (l,d) and the receiving cost E_{RX}(l) of l bits of message between two nodes where their distance is d are given by the following equations:

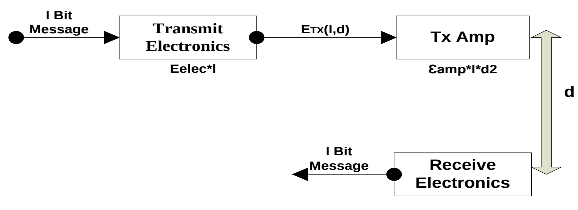

Fig. 3 First Order Radio Model

$$E_{TX} = \begin{cases} E_{elec} * l + \epsilon_{fs} * l * d^2, & if\ d < d_o \\ E_{elec} * l + \epsilon_{amp} * l * d^4, & if\ d \geq d_o \end{cases}$$

$$E_{RX} = E * l$$

The parameter Eelec is the per bit energy dissipations for transmission and reception. We also use the free space and two-ray models according to the distance between the transmitter and receiver. d_0 is a threshold transmission distance and $d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{amp}}}$, where ϵ_{amp} and ϵ_{fs} are the amplifier parameters of transmission corresponding to the free-space and the two-ray models respectively. Additionally, data aggregation operation will consume the energy EDA.

VI. SIMULATION ANALYSIS AND RESULTS

Simulations are conducted using MATLAB and results show that a heterogeneity aware protocol performs better considering metrics of network lifetime and throughput. Resultscompare the performances of LEACH, LEACH (Heterogeneous), and Heterogeneous-Aware protocol.

A. *Network Model*

- Nodes are deployed randomly in a known area.
- The base station is constant and localized in the middle of sensor area.
- There is no any mobile node.

B.Parameters for Simulation

Simulations are done of all three clustering algorithm for WSN with same parameters to see effect of heterogeneity. Simulation Results from 1200 runs of each algorithm are recorded for random distribution of nodes. The basic parameters used are listed in Table I.

For simulation environment we randomly deployed 100 nodes in 100*100 m^2 area. Location of base station is kept at (50, 50).

TABLE I

SIMULATION PARAMETERS

Parameters	**Value**
Number of Nodes	100
Area	100*100
Position of Base Station	(50,50)
Size of the Data Packet	4000 bits
Initial Energy of Node	0.1 J
Eelec	50nJ/bit
E_{fs}	10pJ/bit/m2
E_{DA}	5nJ
$\mathcal{E}_{amp}$	0.0031pJ/bit/m^4

For heterogeneous network wemake 10% nodes more powerful than normal nodes. These advanced nodes are given 30 % more energy than the normal nodes. So for heterogeneous network we assume (m=0.1 and α=0.3).To avoid complexity we assume P=0.1 which means 10 nodes become cluster Heads per round.

Figure 4 shows the comparative analysis of all three algorithms in terms of network lifetime. As it is clear from Figure 4 that sensor network performs longer with heterogeneity in comparison to homogeneous network.

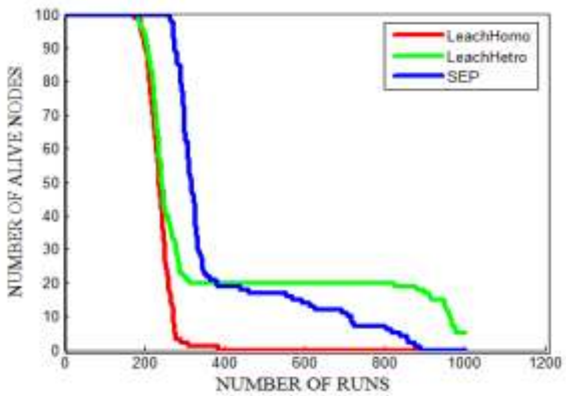

Fig. 4 Comparison of Lifetime of network

Stability period (time period from the start of network operation until the death of the first sensor node) which is important in practical applications is same for both homogeneous and heterogeneous LEACH. This period is longer in heterogeneity aware SEP protocol.

Figure 5 shows there is a trade-off between lifetime and reliability in homogeneous and heterogeneous LEACH. In the unstable region of heterogeneous LEACH throughput of the network is not certain so the network is not reliable in this region. But SEP maintains the network throughput up to the 1200 run.

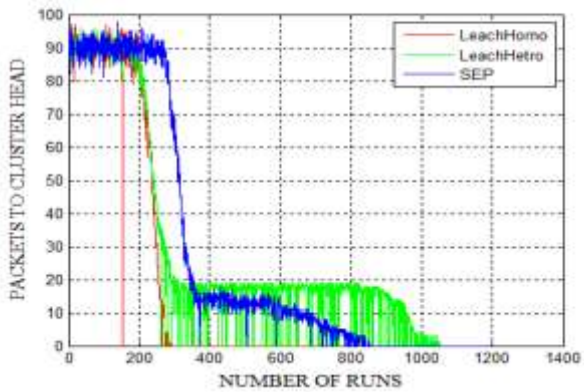

Fig. 5 Comparison of Throughput

VII. CONCLUSIONS

This paper presented the effect of heterogeneity on clustered wireless sensor networks. Simulation results prove the improvement in the performance in the original LEACH protocol in terms of network lifetime after adding heterogeneity. It is found that SEP protocol have 20 % more stable region and more reliable throughput than heterogeneous LEACH.

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