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ENERGY EFFICIENT AND PROLONGED LIFETIME COMMUNICATION PROTOCOL FOR WSN

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Abstract- Wireless sensor networks consisting of nodes that are deployed to collect useful information from the sensor field. It is critical to operate the sensor network for a long period of time in an energy efficient manner for gathering sensed information. The paper proposes an improved LEACH protocol called Hetero-Residual-LEACH (Heterogeneous Residual Low-energy Adaptive Clustering Hierarchy), which is nearly optimal for this data gathering application in sensor networks. Most of the analytical results for LEACH-type schemes are obtained assuming that the nodes of the sensor network are equipped with the same amount of energy - *homogeneous* sensor networks. The key idea in hetero-LEACH is to study the impact of heterogeneity in terms of node energy. We assume that a percentage of the node population is equipped with more energy than the rest of the nodes in the same network - *heterogeneous* sensor networks. The lifetime of a sensor system is the time during which it gathers information from all the sensors to the base station. Given the location of sensors, the base station and the available energy at each sensor, the paper proposes an efficient manner in which the data should be collected from all the sensors and transmitted to the base station, such that the system lifetime is maximized. Further, the experimental results demonstrate that the proposed algorithm significantly outperform other methods (direct transmission protocol, minimum transmission energy protocol and LEACH protocol), in terms of system lifetime.

Keywords- WSN, clustering, LEACH, MTE, lifetime, sensor field, hetero-LEACH.

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Introduction

Advance research and technologies in the field of wireless and mobile communication led to the development of wireless sensor network. Wireless sensors, which are minute devices to collect information, are called nodes. CPU (for data processing), battery, memory and transceivers are the basic constituents of nodes. Therefore, the size of node is also affected by its application.

Sensor networks are the key to gathering information needed by smart environments where they are implemented. Recent advances in MEMS-based sensor technology, low-power analog and digital electronics, and low-power RF design have enabled the development of relatively inexpensive and low-power wireless microsensors [1, 2, 3].With their flexibility, fault tolerance, high sensing fidelity, low cost and rapid deployment characteristics, they find their application in various fields like in military for enemy tracking and battle field surveillance, for civil applications like habitat monitoring, environment observation, industries, transportation system and more where they are located very close to or even in the area where any phenomenon is to be observed.

To process the collected data meant for onward transmission to the sink, a lot of energy is consumed. And till date batteries were the only option to cater the energy requirements of the nodes of wireless sensor network. The applications of WSN were also restricted in many communication fields like surveillance, military etc. where it becomes highly expensive and impossible due to environment conditions, to replace the drained off batteries frequently. It is our objective to find an alternate enhanced power-aware, energy efficient system which can extend the life time of the network.

Energy Dissipation Radio Model

Energy dissipation models for radio propagation are focused on predicting the average received signal strength at a given distance from the transmitter. The models that predict the signal strength for a given transmitter-receiver separation distance are useful in WSN radio model. In this model, as shown in figure 1, the energy dissipation to run the transmitter or receiver circuitry is E_{elec} = 50 nJ/bit and ε_{amp} = 100 pJ/bit/m^2 for the transmitter amplification.

The received power decays as a function of the T_x-R_x separation distance (d). For relatively short distances, the Friis free space model is used in which the received power decays that are inversely proportional to d^2. For long distances, the received power falls off with distance raised to the forth power (two-ray ground reflection model). This is much more rapid path loss than is experienced in free space. Therefore, amplifier circuitry is required to compensate this loss by setting the amplification to a certain level.

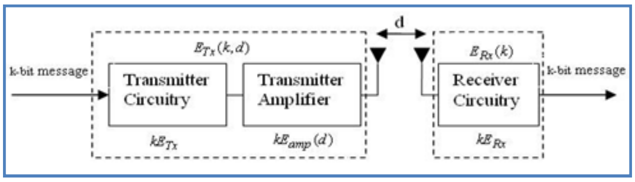

Fig. 1- Energy Dissipation Radio model.

The equations used to calculate radio energy transmission and reception costs for a *k*-bit message and the transmitter-receiver separation distance *d* are given by:

$$E_{Tx}(k,d)=E_{Tx}(k)+E_{amp}(k,d)$$
$$E_{Tx}(k,d)=kE_{Tx}+kE_{amp}(d) \qquad (1)$$

The term E_{Tx} denotes the per-bit energy dissipation during transmission. $E_{amp}(d)$, the per-bit amplification energy, is proportional to d^4 (two-ray ground reflection model) when the transmission distance exceeds the threshold d_0 and otherwise is proportional to d^2 (Friis free space model). $E_{amp}(d)$ is thus given by

$$E_{amp}(d)=\begin{cases}\varepsilon_{friss\_amp}d^2, & d\le d_o\\ \varepsilon_{two\_ray\_amp}d^4, & d>d_o\end{cases} \qquad (2)$$

The parameters ε_{friss_amp} and $\varepsilon_{two\_ray\_amp}$ denote transmit amplifier parameters corresponding to the free-space and the multipath fading models respectively. They depend on the required sensitivity and the receiver noise figure. The transmit power needs to be adjusted so that the power at the receiver is above certain minimum threshold. The value of d_0 is given by:

$$d_o=\sqrt{\varepsilon_{friss\_amp}/\varepsilon_{two\_ray\_amp}} \qquad (3)$$

The reception energy of the k-bit data message can be expressed by the equation:

$$E_{Rx}(k)=kE_{Rx} \qquad (4)$$

Where E_{Rx} is the energy dissipation of the receiver per-bit.

Communication Protocols For WSN

The expected lifetime of a WSN needs to be several years for a typical application. As, a WSN is composed of minute nodes, their energy resources are very limited. The amount of energy stored depends on the battery size. This imposes tight constraints on the operation of sensor nodes. The transceiver is the element which drains most power from the node. Thus the routing protocol plays a significant effect on the lifetime of the overall network. Also, sensors consume energy both in sensing data and in transmitting the sensed data to a base station. The power consumption for transmitting data is an exponential function of the distance from the sensor to the base station, while the power consumption for sensing data is determined by the type of sensor as well as the routing protocols.

Communication or routing protocols are the set of rules, according to which each sensor node has to play some roles, such as collecting information from neighboring nodes and transmit it to the destination or Base station. There are various energy aware communication protocols discussed in the literature [3,5,6].

Leach: Low Energy Adaptive Clustering Hierarchy

The current interest in wireless sensor networks has led to the emergence of many application oriented protocols of which LEACH is the most aspiring and widely used protocol [5]. LEACH can be described as a combination of a cluster-based architecture and multi-hop routing as shown in [Fig-2].

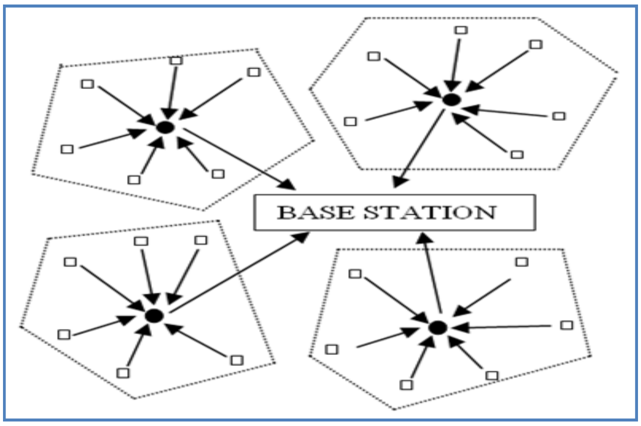

Fig. 2- LEACH Protocol Architecture.

The operations that are carried out in the LEACH protocol are divided into two stages:

(i) Setup phase and

(ii) Steady-state phase.

In the Set up phase, all the sensors within a network group themselves into some cluster regions by communicating with each other through short messages. At a point of time one sensor in the network acts as a cluster-head and sends short messages within the network to all the other remaining sensors. The sensors choose to join those groups or regions that are formed by the cluster heads, depending upon the signal strength of the messages sent by the cluster heads. Sensors interested in joining a particular cluster head or region respond back to the cluster heads by sending a response signal indicating their acceptance to join. Thus the set-up phase completes [3].

As soon as a cluster head is selected for a region, all the cluster members of that region send the collected or sensed data to the cluster head. The cluster head transmits this collected data to the base station which completes the second phase, called the Steady State Phase.

The above discussion describes communication within a cluster, where the routing protocols are designed to ensure low energy dissipation in the nodes and no collisions of data messages within a cluster. However, radio is inherently a broadcast medium. As such, transmission in one cluster will affect communication in a nearby cluster.

Hetero-Leach Protocol

Classical clustering protocols assume that all the nodes are equipped with the same amount of energy and as a result, they can not take full advantage of the presence of node heterogeneity. We propose a heterogeneous-LEACH protocol to prolong the time interval before the death of the first node (*stability period*), which is crucial for many applications where the feedback from the sensor network must be reliable. The proposed protocol is based on weighted election probabilities of each node to become cluster head according to the remaining energy in each node.

In WSN, sensor node assigns a dual role: it acts as a source for sensing information and as a relay. The death of some nodes may cause significant topological changes and may require re-organisation of the network. Therefore, routing algorithms has to employ some energy efficient routing tactics as well as approaches specific to WSNs, to minimize energy consumption.

Similar to LEACH, in heterogeneous LEACH each sensor node may elect itself to be cluster head at the beginning of a round. Probability of becoming a cluster head is set as a function of nodes energy level relative to the aggregate energy remaining in the network. The Sensor node is a cluster head if chosen random number is less than threshold T (n) given by

$$T(n) = \begin{cases} \dfrac{P}{1 - P * (r \bmod \frac{1}{P})} & if\ n \in G \\ 0 & otherwise \end{cases} \qquad (5)$$

where P: desired Percentage to become a Cluster head, r: Current Round, G: Set of nodes that have not been selected as Cluster head in last 1/P rounds.

In this paper, we describe heterogeneous LEACH protocol, which improves the stable region of the clustering hierarchy process using the characteristic parameters of heterogeneity, namely the fraction of advanced nodes (m) and the additional energy factor between advanced and normal nodes (α). In order to prolong the stable region, the protocol attempts to maintain the constraint of well balanced energy consumption. Intuitively, advanced nodes have to become cluster heads more often than the normal nodes, which is equivalent to a fairness constraint on energy consumption. Note that the new heterogeneous setting (with advanced and normal nodes) has no effect on the spatial density of the network so the a priori setting of p_{opt}, from equation 5, does not change. On the other hand, the total energy of the system changes. Suppose that E_0 is the initial energy of each normal sensor. The energy of each advanced node is then E_0(1+α). The total (initial) energy of the new heterogeneous setting is equal to:

$$n\,(1-m)\,E_0 + n\,m\,E_0 \,.\, (1+\alpha) = n\,E_0\,(1+\alpha.\,m) \qquad (6)$$

So, the total energy of the system is increased by a factor of 1+α. m. The first improvement to the existing LEACH is to increase the epoch of the sensor network in proportion to the energy increment. In order to optimize the stable region of the system, the new epoch must become equal to $\frac{1}{p_{opt}}(1+\alpha.m)$ because the system has α. m times more energy and virtually α. m more nodes (with the same energy as the normal nodes.)

We can now increase the stable region of the sensor network by α. m times, if (i) each normal node becomes a cluster head once every $\frac{1}{p_{opt}}(1+\alpha.m)$ rounds per epoch; (ii) each advanced node becomes a cluster head exactly 1+α times every $\frac{1}{p_{opt}}(1+\alpha.m)$ rounds per epoch; and (iii) the average number of cluster heads per round per epoch is equal to *n* x p_{opt} (since the spatial density does not change.)

Constraint (ii) is very strict- If at the end of each epoch the number of times that an advanced sensor has become a cluster head is not equal to 1+α then the energy is not well distributed and the average number of cluster heads per round per epoch will be less than *n* x p_{opt}. This problem can be reduced to a problem of optimal threshold T(s) setting with the constraint that each node has to become a cluster head as many times as its initial energy divided by the energy of a normal node.

If the same threshold is set for both normal and advanced nodes with the difference that each normal node Є G becomes a cluster head once every $\frac{1}{p_{opt}}(1+\alpha.m)$ rounds per epoch, and each advanced node Є G becomes a cluster head 1 + α times every $\frac{1}{p_{opt}}(1+\alpha.m)$ rounds per epoch, then there is no guarantee that the number of cluster heads per round per epoch will be *n* x p_{opt}. The reason is that, there is a significant number of cases where this number cannot be maintained per round per epoch with probability 1. A worst-case scenario could be the following. Suppose that every normal node becomes a cluster head once within the first $\frac{1}{p_{opt}}(1-m)$ rounds of the epoch. In order to maintain the well distributed energy consumption constraint, all the remaining nodes, which are advanced nodes, have to become cluster heads with probability 1 for the next $\frac{1}{p_{opt}}.m.(1+\alpha)$ rounds of the epoch. But the threshold T(s) is increasing with the number of rounds within each epoch and becomes equal to 1 only in the last round (when all the remaining nodes become cluster heads with probability 1). So the above constraint of *n* x p_{opt} cluster heads in each round is violated.

As a solution, assume heterogeneous LEACH Protocol, which is based on the initial energy of the nodes. This solution is more applicable compared to any solution which 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 [8].

Our approach is to assign a weight to the optimal probability p_{opt}. This weight must be equal to the initial energy of each node divided by the initial energy of the normal node. Let us define as p_{nrm} the weighted election probability for normal nodes, and p_{adv} the weighted election probability for the advanced nodes.

Virtually there are n.(1+α. m) nodes with energy equal to the initial energy of a normal node. In order to maintain the minimum energy consumption in each round within an epoch, the average number of cluster heads per round per epoch must be constant and equal to *n* x p_{opt}. In the heterogeneous scenario the average number of cluster heads per round per epoch is equal to *n*.(1+*α*.*m*). p_{nrm} because each virtual node has the initial energy of a normal node.) The weighed probabilities for normal and advanced nodes are, respectively:

$$p_{nrm} = \frac{p_{opt}}{1+\alpha.m} \tag{7}$$

$$p_{adv} = \frac{p_{opt}}{1+\alpha.m} \times (1+\alpha) \tag{8}$$

In Equation 5, we replace p_{opt} by the weighted probabilities to obtain the threshold that is used to elect the cluster head in each round. We define as $T(s_{nrm})$ the threshold for normal nodes and $T(s_{adv})$ the threshold for advanced nodes.

Thus, for normal nodes, we have:

$$T(s_{nrm}) = \begin{cases} \dfrac{p_{nrm}}{1 - p_{nrm}.(r \bmod \frac{1}{p_{nrm}})} & if\ s_{nrm} \in G' \\ 0 & otherwise \end{cases} \tag{9}$$

where r is the current round, G' is the set of normal nodes that have not become cluster heads within the last $\frac{1}{p_{nrm}}$ rounds of the epoch, and $T(s_{nrm})$ 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 $\frac{1}{p_{opt}}(1+\alpha.m)$ 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*)xp_{nrm}.

Similarly, for advanced nodes, we have:

$$T(s_{adv}) = \begin{cases} \dfrac{p_{adv}}{1 - p_{adv}.(r \bmod \frac{1}{p_{adv}})} & if\ s_{adv} \in G'' \\ 0 & otherwise \end{cases} \tag{10}$$

where G'' is the set of advanced nodes that have not become cluster heads within the last $\frac{1}{p_{adv}}$ rounds of the epoch, and $T(s_{adv})$ is the threshold applied to a population of n.m (advanced) nodes. This guarantees that each advanced node will become a cluster head exactly once every $\frac{1}{p_{opt}}.\frac{1+\alpha.m}{1+\alpha}$ rounds. Let us define this period as *sub-epoch*. It is clear that each epoch (let us refer to this epoch as "heterogeneous epoch" in our heterogeneous setting) has 1+α sub-epochs and as a result, each advanced node becomes a cluster head exactly 1+α times within a heterogeneous epoch. The average number of cluster heads that are advanced nodes per round per heterogeneous epoch (and sub-epoch) is equal to *n.m* x p_{adv}.

Thus the average total number of cluster heads per round per heterogeneous epoch is equal to:

$$n.(1-m) \times p_{nrm} + n.m \times p_{adv} = n \times p_{opt} \tag{11}$$

which is the desired number of cluster heads per round per epoch.

Residual-Hetero-Leach Protocol

The main idea is for the sensor nodes to elect themselves with respect to their energy levels autonomously. The goal is to minimize communication cost and maximizing network resources in other to ensure concise information is sent to the sink.

Deterministic cluster head selection introduces the heterogeneity to LEACH in terms of residual energy. It considers the residual energies of the sensor nodes in order to manage rational power consumption throughout the network. It follows the underlying mechanism of LEACH exactly. It has changed the equation of the threshold value only to incorporate the residual energy in cluster head selection process as follows:

$$T(n)_{new} = \frac{p}{1-p(r \bmod \frac{1}{p})} \frac{E_{current}}{E_{\max}} \tag{12}$$

where, $E_{current}$ is the current energy, E_{max} the initial energy of the node. The other parameters have the same definitions as of LEACH.

After a significant amount of time of operation, the residual energies of the sensors would become very low and then this threshold value will be very low. This can result in a situation where all the live sensors are one member cluster head. In this case the energy consumption rate will be very high. To break this stuck condition another modified equation of the threshold value is given by:

$$T(n)_{new} = \frac{p}{1-p(r \bmod \frac{1}{p})} \left[\frac{E_{current}}{E_{\max}} + (r_s div \frac{1}{p}) \left(1 - \frac{E_{current}}{E_{\max}} \right) \right] \tag{13}$$

Where p **=** the desired percentage of cluster heads (i.e. 5% as suggested by LEACH), r **=** the current round, and G is the set of nodes that have not been cluster-heads in the last 1/p rounds, r_s= number of consecutive rounds in which a node has not been cluster head.

Similarly, the effect of heterogeneity in terms of residual energy can be applied to hetero-LEACH protocol. Thus, for normal nodes, we have:

$$T(s_{nrm}) = \begin{cases} \dfrac{p_{nrm}}{1 - p_{nrm}.(r \bmod \frac{1}{p_{nrm}})} \times \dfrac{E_{current}}{E_{\max}} & if\ s_{nrm} \in G' \\ 0 & otherwise \end{cases} \tag{14}$$

where r is the current round, *G*' is the set of normal nodes that have not become cluster heads within the last 1/P_{nrm} rounds of the epoch, and T(s_{nrm}) is the threshold applied to a population of n*(1-m) normal nodes. Similarly, for advanced nodes, we have:

$$T(s_{adv}) = \begin{cases} \dfrac{p_{adv}}{1 - p_{adv}.(r \bmod \frac{1}{p_{adv}})} \times \dfrac{E_{current}}{E_{\max}} & if\ s_{adv} \in G'' \\ 0 & otherwise \end{cases} \tag{15}$$

where *G*” is the set of advanced nodes that have not become cluster heads within the last $1/P_{adv}$ rounds of the epoch, and T(sadv) is the threshold applied to a population of n*m advanced nodes

Experimental Results

The performance of various protocols is simulated using a random 100-node network as shown in [Fig-3].

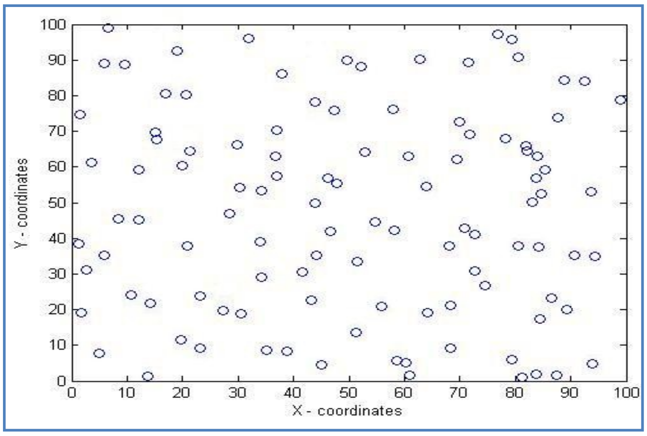

Fig. 3- A 100- node random network

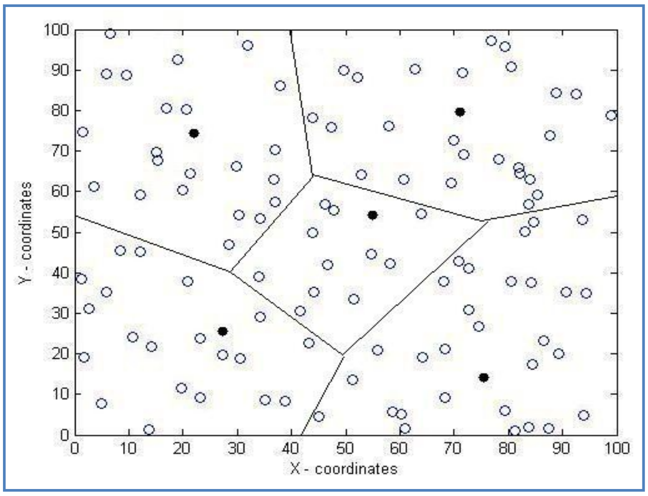

Fig. 4- Cluster head nodes and cluster formation at time t.

Table 1- Summary of the parameters used in the simulation experiments

Number of Nodes	100
Network size	100m * 100m
Base station location	-50,175
Radio propagation speed	$3*10^8$ m/s
Processing delay	50 μs
Initial node energy	0.25 J
Simulation time	900 sec

The results of LEACH, residual LEACH, hetero-LEACH and residual hetero-LEACH simulations are shown in figure 6 for m = 0.2 and a=1 with initial energy 0.25J. We observe that LEACH takes some advantage of the presence of heterogeneity (advanced nodes), as the first node dies after a significantly higher number of rounds (i.e. longer stability period) compared to the homogeneous case (m = a= 0). The lifetime of the network is increased.

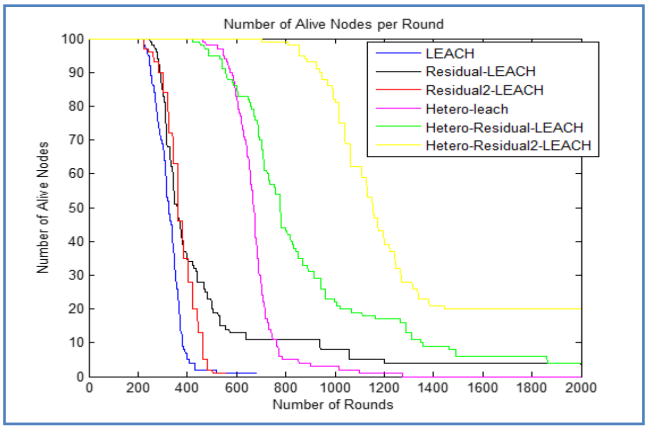

Fig. 5- Number of alive nodes using LEACH in the presence of heterogeneity with advanced nodes m=0.2 and normal nodes a=1 with initial energy 0.25J.

The simulations are performed to determine the number of rounds of communication when 1% (FND), 50% (HND) and 100% (LND) of the nodes die using LEACH, residual LEACH, hetero-LEACH and residual hetero-LEACH with each node having the same initial energy level. Once a node dies it is considered dead for the rest of the simulation. The nodes begin to die at a more uniform rate after about 20% nodes die. This is because the distances between the nodes become greater, and nodes have to become leaders more often causing the energy to drain rapidly. Figure 7 shows the number or rounds the complete sensor network take until 1%, 50%, and 100% nodes die with initial energy per node of 0.25J for a 100m x 100m network. It is clear that as the initial energy of the sensor node decreases then the nodes drain out quickly and follows the inverse square law.

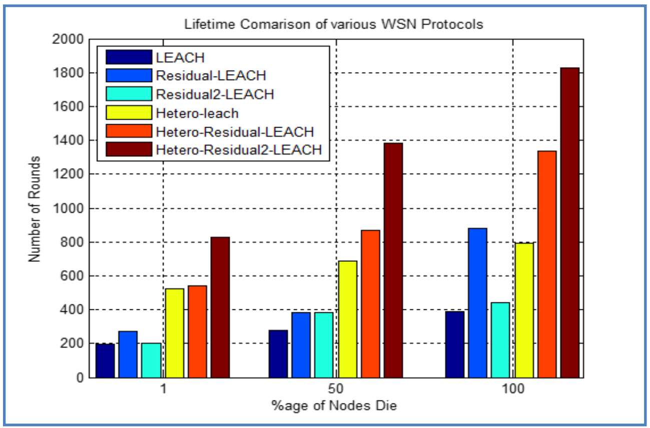

Fig. 6- Performance results with initial energy 0.25J/node for a 100m x 100m network

The simulation shows that residual hetero-LEACH achieves:

- Approximately 4x the number of rounds decreases compared to LEACH, when 1%, 50%, and 100% nodes die for a 100m x 100m network.
- Approximately 2x better than Hetero-LEACH for a 100m x 100m network.
- As the energy level doubles the number of rounds approximately doubles for all cases.

Conclusions

The simulation work performed according to the new proposed residual heterogeneous LEACH protocol approximately doubles the lifetime of network in comparison to heterogeneous LEACH. These type of networks are more useful in applications where network lifetime is critical. Our simulations also shows that the above said protocol performs better than LEACH and Hetro-LEACH by about 200 to 400% when 1%, 50%, and 100% of nodes die for different network sizes and topologies. The protocol shows an even further improvement as the size of the network increases. When energy of a node in network is double it becomes easy for any receiver to detect it so when deploying a network for some secure data collection a trade off in between the energy level can be tuned. This protocol is more efficient when number of nodes is greater. Thus this protocol also proves its efficiency when deployed over lager areas for sensing.

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