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A DISTRIBUTED ENERGY AWARE CLUSTERING APPROACH FOR LARGE SCALE WIRELESS SENSOR NETWORK

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Abstract- Wireless sensor networks consist of many micro sensor nodes that are dispersed in a limited geographical area. The nodes are wireless interconnected. Each node works independently and without human intervention and typically, it is physically very small with limitations in processing power, memory capacity, power supply and etc. The nodes in these networks carry limited and mainly irreplaceable energy resources. Given that a node acts also as a router, the node dysfunction eliminates them from the network topology and hence the network reorganization and rerouting the transmitting packet occurs. It will increase energy consumption and may also cause a part of the environment to get out of the supervision and control of the network. Since battery life virtually specifies the node life cycle, these network needs to work under energy-efficient protocols and structures. In this paper, a Energy Aware Clustering Approach (EACA) is presented for wireless sensor networks. To reduce overhead in this study, a multilevel and distributed clustering algorithm is proposed, that converts a flat network into a hierarchical multilevel structure and provides an appropriate infrastructure to rout and gather the data correctly. Also, In this protocol the best Cluster Head is selected periodically by considering a series of criteria, including the residual energy, lower communication costs and the minimum distance between the cluster head and the cluster members which consequently offers an energy efficient clustering protocol that increases the network lifetime. Our new approach uses the least amount of energy in the clustering process and will quickly terminate the clustering process. In addition, there is no assumption about the density, capabilities or synchronization of the node. The simulation results demonstrate that the clustering algorithm can effectively reduce the energy consumption and increase the system lifetime compared to the LEACH protocol, which is one of the most efficient clustering protocols.

Keywords: Wireless Sensor Networks, Clustering, Energy Consumption, Network Life Time, LEACH.

I. INTRODUCTION

The recent advancements on MEMS systems (Micro-Electro-Mechanical-Systems, smart sensors and wireless telecommunications have made it possible to build small, low consumption and low cost sensor nodes [1-4]. A sensor network is composed of many sensor nodes widely distributed in an environment, which gather information from the environment. The location of sensor nodes is not necessarily predetermined and specified. Such a feature makes it possible to leave them in dangerous or unavailable places. Each node contains sensor actor unit, the data processing unit, wireless transceiver and a power supply unit. The additional parts of the mobilizer, location finding system and power generation systems may also exist in the nodes, depending on their application.

The data processing unit includes a small processor and a limited capacity memory, which does a limited processing on the data received by sensors according to their application and sends them through transmitter. The transceiver unit connects the nodes to the network. The sensor unit consists of a series of sensors and analog-to-digital converter, which receives the analog data from the sensor and delivers it to the processor in digital. Energy supply unit provides the power consumed by all sectors; which is often a battery with limited power. Energy resource limitation is one of the major bottlenecks which affect everything in the design of wireless sensor actor network.

The location finding unit may also exist in each node. The location finding system detects the physical position of the node. Routing techniques and sensing tasks require the information of a high precision location. Each sensor node performs a limited processing on the received data by sensor and according to the type of data received from the environment, probably by its processing unit. Then, the data will be sent to the base station as single hop or multi hop. After that, all the information collected from different nodes in the base station will be processed to be used by a user or to perform specific operations.

In these networks, the nodes location is not predetermined, but the nodes are randomly distributed in the environment. This requires the protocols used in these networks to have the self-organizing capability [17, 18]. Wireless sensor networks have a wide range of applications. These applications can be divided into three main clusters according to their operation and capability: 1- monitoring, 2- tracking and 3 - controlling.

The monitoring applications, for example, includes habitat and environmental monitoring, forest fire detection, pollution monitoring, monitoring road traffic patterns and monitoring patient status. In monitoring applications, usually hundreds or thousands of sensors are distributed in an area where phenomena such as heat, pressure, noise, electromagnetic fields, vibration, and etc. are identified and monitored. According to data provision and the communication patterns between sensors and the base station (observer), the sensor network applications can be classified the following four classes:

* Continuous-time model in which each sensor node periodically sends reports to the observer on the physical parameters.
* Event-driven model, where the sensors transmit data only if a particular event has been identified.
* The observer-initiated model, in which the observer may be interested only in occurrence of an event in a determined geographical area. In such cases, the observer will send a clear and explicit request to the specific sensors.
* Mixed or composite model, in which some or all of the three above models work together in the network.

A sensor node consumes energy in three stages of sensing, processing and communication with other nodes or base stations. Since the data transfer costs too much energy, communication protocols have an essential role in the efficiency and the increase of longevity of wireless sensor networks. Therefore, it is essential for wireless sensor networks to design energy-efficient protocols [5], using which not only reduces total consumed energy in the network, but also it increases network lifetime.

Among the proposed protocol, the hierarchical (clustering-based) protocol notably saves the energy consumed by the network [6]. Clustering allows the majority of the sensors (in other words, other members of clusters) to establish data communication at a closer distance. In other words the cluster-heads around them and only a small number of nodes (in other words the cluster-heads) remain that communicates with distant base station or a relatively distant cluster head in the next step.

In these protocols, the entire network is divided into several clusters in each one of which cluster a node is selected as cluster head (CH). Cluster head is responsible for collecting the data received by the nodes of that cluster, probably a limit processing on them and then, sending this data to the base station. In the clustering protocols, selecting a node in each cluster as cluster head using local information greatly affects the increase of scalability and lifetime of the network [5]. So far, several clustering based protocols have been proposed for wireless sensor networks, but in none of these protocols ([8] SEP, [9] EBDEP, [10] EECH, [11] EECF, [7] LEACH, [12] HEED), the residual energy parameters in the nodes and the distance between the cluster head and the cluster members and communication costs have not been considered in the clustering process. In this paper, using the hierarchical LEACH protocol and interference of the residual energy parameters, the distance between the cluster head and the cluster members and communication costs, an energy-efficient communication protocol will be presented, by maintaining the scalability of the network and using only local information.

This protocol has several desirable features. First, it uses a step-based process rather than an iteration-based process with valuable energy. Therefore, it terminates the clustering process very quickly. Moreover, this protocol of network clustering has no needs regarding the number of required clusters, network congestion, and energy consumption patterns of sensors or synchronization of their hour and their capabilities. Further, the section II of this paper will briefly introduce some previous clustering protocol; section III will introduce some basic concepts regarding the proposed protocol. Section IV will introduce the proposed protocol. Section V will discuss the simulation results and finally, the conclusions will be reviewed in section VI.

II. RELATED WORKS

So many studies have been conducted on clustering in wireless sensor networks and any of these clustering have been performed for a specific purpose. Further, a few presented methods in this field will be described.

A. LEACH

It is a dynamic clustering protocol which uses random method to do a balanced distribution of the energy consumption among the nodes. In this protocol, the nodes organize themselves into some sets among which a node plays the role of a cluster head. LEACH algorithm uses the random rotation of cluster-heads to prevent the battery of a particular node from being immediately discharged. In addition, in LEACH algorithm, data fusion is locally used in order to compress the data sent from the clusters to the base station. This will reduce the energy required to diffuse the information, and consequently will increase the effective lifetime of the network.

In this protocol, time will be divided into some parts of equal length called round. Each round is divided into two phases; the first phase, called set-up phase, is the phase of cluster formation, and the second phase, called steady-state phase, is related to the data transfer. The second phase consists of a number of time frames in each one of which, all the cluster nodes send their data to the CH and CH sends the data received at the end of frames to the base station (BS). To reduce the information overload, the steady-state phase must be longer than the initial settings stage. LEACH protocol ensures that each node will become cluster head exactly once per $1/P$ of round.

In the set-up phase, each sensor selects a random number between 0 and 1, if this random number is less than the threshold $T(n)$, it will select its own node as a cluster head and the threshold function will be calculated as follows.

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

while, P is the percentage required by the cluster heads, r is the number of the current round and G is a fraction of nodes which have not become cluster head in the $1/P$ of the last round and thereby, will have CH capability for the current round. LEACH protocol ensures that each node will become cluster head exactly per $1/P$ of round.

If non-cluster head nodes receive a few cluster head becoming notices from the nodes around them, they will be joined the nearest node. After the clusters were identified and the members joined them, and TDMA program will be established and the data transfer can begin. Radio device of each non-cluster head node can be turned off until the time of sending the data of that node. To reduce the overload, the steady-state phase time must be much larger than the set-up phase.

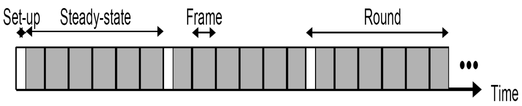

Figure 1. Two-pole permanent-magnet synchronous motor

B. LEACH-C Protocol

LEACH-C is another protocol which has been presented in [7]. In this protocol, a centralized cluster formation algorithm is used. In the setup phase of LEACH-C, each node sends the data about its situation (which it has achieved through GPS receiver) and its current energy level to the base station. Base station calculates the average energy level of the network nodes. The nodes, whose energy level is lower than the average, cannot be CH for the next round. The steady-state phase of LEACH-C is exactly the same as that of LEACH.

C. SEP

The SEP protocol [8] is the developed LEACH the main purpose of which is to use heterogeneous sensors in wireless sensor networks. This protocol performance is similar to LEACH, with the difference that in the SEP protocol, sensors have two different levels of energy (sensors are heterogeneous). In the protocol, assuming that the energy of some sensors is more, the probability of becoming a cluster head of higher energy sensors will be considered more and has been able to improve the performance criteria to LEACH in order to compare it with a similar case in LEACH protocol.

D. HEED

Unlike LEACH, HEED protocol [12] is a distributed clustering protocol that selects cluster heads periodically based on their residual energy criteria and other parameters such as the distance between the cluster heads and their members or the cluster head level. This algorithm has no assumptions about the distribution or density of nodes or the capability of nodes.

After a node began to implement HEED protocol, each sensor selects a random number between 0 and 1. If the produced number is smaller than or equal to the probability of CH, the node becomes an experimental cluster head and sends an announcement to its neighbors. It is the probability of becoming CH and is calculated as follows.

$$CH_{prob} = C_{prob} \cdot \frac{E_{residu}}{E_{\max}} \quad (2)$$

while E_{residu} is the residual energy of node and $E_{\max}$ is the maximum energy when the battery is completely filled, and C_{prob} is the initial percentage of the number of Cluster heads which will be set (5%).

Then all HEED nodes double themselves and repeat this step until the probability of node becoming cluster head will reach 1. If there are several candidates for becoming cluster head, the cluster head with a lower communication costs will be chosen.

E. BCDCP, BCSP

Another centralized mechanism is described in [13], namely the Base-station Controlled Dynamic Clustering Protocol (BCDCP). This technique forms balanced clusters, where each cluster has the same number of members to avoid cluster overloading. In addition to this, data from distant cluster heads is sent to the base station via other cluster heads. BCDCP outperforms LEACH both in terms of lifetime and of the number of delivered messages to base station. The Base-station Centralized Simple Protocol (BCSP), on the other hand, aims at extending the network lifetime by basing the clustering decision on the remaining energy of every node. The base-station redistributes the role of cluster head among the nodes from time to time. BCSP does not require location knowledge, like other algorithms, but each node should send its energy level information along with the sensing information, increasing the overhead. The drawback of two aforementioned techniques is that due to their centralized implementation, are not so appropriate for sensor networks with a large number of nodes.

F. FLOC

Fast Local Clustering Service (FLOC) [14] is a distributed clustering technique that produces non-overlapping clusters and approximately equal-sized clusters. FLOC achieves locality: effects of cluster formation and faults/changes at any part of the network within almost two units distance. FLOC exhibits a double-band nature of wireless radio-model for communication. A node can communicate reliably with the nodes that are in the inner band (i-band) range and unreliably with the nodes in its outer-band (o-band) range. Hence the iband nodes suffer very little interference communicating with the CH, thereby it is a reliable communication.

Messages from o-band nodes are unreliable during communication and hence it has the maximum probability of getting lost during communication. FLOC is fast and scalable, hence it achieves clustering in $O(1)$ time regardless of the size of the network. It also exhibits self-healing capabilities since o-band nodes can switch to i-band node in another cluster. It also achieves re-clustering within constant time and in a local manner. It also achieve locality, in that each node is only affected by the nodes within two units. These features stimulate FLOC algorithm to be suitable for large scale WSNs.

III. BASIC CONCEPTS

A. Energy Consumption Model

Here, the very energy consumption model presented in [15] for radio network components, will be used. In this model, E_{elec} (unit: nJ/bit) is the energy used at the transmitter or receiver electronic circuit to receiving or send a bit of data packet. ε_{amp} (unit: pJ/bit/mn) is also the energy consumed in the radio amplifier of the transmitter node to send one bit of data packet in the channel with length d, between the transmitter and receiver nodes. The calculated send and receive energy; we will have the relation (3):

$$E_{Tx}(l,d) = lE_{elec} + l\varepsilon_{amp}d^n \quad E_{Rx}(l,d) = lE_{elec} \qquad (3)$$

where l is the length of the sent/received packets in bits, d is the distance between the receiver and transmitter in meters. The energy consumed by an amplifier to send a bit of a data packet is proportional to the square of the distance between transmitter and receiver, i.e. d^2. While, the energy consumed in transmitting one bit of data packets at longer distances (e.g., from a cluster head to the base station) will be proportional to d^4.

Using this model, the energy consumed in transmitting L bit of data at long distances, i.e. D, will be as follows.

$$E_{TX} = lE_{elec} + l\varepsilon_{2r}d^4 \qquad (4)$$

while, E_{elec} is the radio electronic energy and ε_{2r} is the amplifier energy. On the other hand, the energy consumed in sending L bits of data along a short distance is defined as follows:

$$E_{TX} = lE_{elec} + l\varepsilon_{fs}d^2 \qquad (5)$$

while, ε_{fs} is the amplifier energy. The energy consumed to receive a packet with length of L bits is as follows:

$$E_{RX} = lE_{elec} \qquad (6)$$

In addition, CH in LEACH protocol is responsible for combining data of (signals of) the cluster members in which, as a result of a complete solidarity, a representative signal will be obtained from combining the node signals. The required energy to combine the data of each signal received by the CH is set equal to lEDA, to which 5 nJ/bit/signal is assigned during all tests. In this regard, EDA is the required energy for the combination of data and l a few bits of the received signal.

B. Network Model

The network model we have considered for our own approach is as follows:

- The set of n sensors are uniformly distributed on a land.
- The location of the base station and sensors is fixed and not moving.
- Sensors are aware of their position on Earth.
- Each sensor has a unique number.
- All sensors have the same features and capabilities.
- The sensors have single hop communication with their own cluster heads.
- All sensors have the same range of sensing R_s.
- All non-cluster head sensors have a transmission range R_t, all of which consume the same energy to transmit a bit of data. Also, all CHs have transmission range of $R_{t\text{-}ch}$ which are usually $R_{t\text{-}ch} >> R_t$.

C. The Main Objectives the Protocol Design

1- The clustering will be completely distributed so that each node locally makes its decision based on the information exchanged with its neighbors within its radio range.
2- The clustering process will be quickly terminated.
3- The clustering should be implemented within the minimum processing time.
4- The clustering should be implemented through minimal message exchange.

IV. EACA PROTOCOL

In this section, EACA (Energy Aware Clustering Approach) protocol will be discussed in detail. First, the protocol will be describe and then, it will be studied that how the protocol fulfills the design objectives.

A. The Protocol Performance

In LEACH, each cluster head sends their data directly to the base station. While, some cluster heads are in a long distance from base station and some are in short distance. According to the mentioned energy consumption model, this will lead to the difference in the consumed energy for sending data to the base station and consequently, unbalance the energy load in the network. This energy difference is evident after a few rounds of working of the network well. If the nodes have started working with the same energy, the nodes that are at a further distance from the base station will lose their energy sooner. Therefore, the network will be divided into dead areas (those areas of the network that cannot be monitored due to the premature death of sensor nodes [16]) and living areas and thus, network performance will decrease.

The second issue in the LEACH is that in this protocol, nodes are randomly selected as CH. Moreover, since the node which is selected as cluster head, uses more energy than the other nodes, if the selected node has little energy, it has not become a good cluster head and at all and its energy will be quickly discharged. This will also lead to the energy load unbalancing in the network. Load balancing is one of the primary elements to prolong the network lifetime.

Therefore, clustering process should periodically begin to select a different set of the most appropriate cluster heads in each cycle. T_c is the clustering process time period that is the time period the EACA protocol requires for clustering the network and T_N the time period the network performance, which is a period of time between the end of a T_N and the start of next T_c.

To solve the problems in LEACH algorithm and select the best possible cluster head, i.e. to balance the energy consumption and prolong the network lifetime, the main parameters used in the proposed algorithm to select the node as a cluster head are:

1- Residual energy of nodes: A cluster head node consumes more energy than a non-cluster head node; therefore, the nodes with more residual energy levels are more likely to be selected as cluster head.

2- Distance from the neighbors: After the selection of cluster head, the nodes of each cluster member send the data received from the environment to their own cluster head; therefore, knowing that the consumed energy is directly related to the distance for sending data, then, the less the total distances of the candidate node from its neighbors for becoming cluster head, the more likely the node will be to become cluster head and this will reduce the energy consumption in the cluster member nodes.

The protocol process will be as follows:

1- First, each node sends a HEELO packet, including the data on its location, to its 1-hop neighbors of before the clustering process.

2- Receiving each message from its neighbors broadcasting their own existence, the node increases the counter to determine the number of neighbors. In addition, receiving these messages, it can show the location of each neighbors, as well as its distance from the location of the node using the following relations:

$$Disanation = \sqrt{\left(X_{nig} - X_{node}\right)^2 + \left(Y_{nig} - Y_{node}\right)^2} \quad (7)$$

where, $\left(X_{nig}, Y_{nig}\right)$ shows the location of the neighbor node and $\left(X_{node}, Y_{node}\right)$ shows the location of its own node.

1- While receiving the HEELO messages and calculating the distance from that neighbor, each node should also calculated the sum of these distances, and measure the distance from its farthest neighbor. This will be calculated through a simple search.

2- After this stage, each node will have its own residual energy $\left(E_{current}\right)$, the total distance from its neighbors $\left(dis_{total}\right)$, the number of its neighbors $\left(count_{nig}\right)$, and its distance from its farthest neighbor.

3- Each node produces a random number between zero and one. If the produced number is less than $P(t)$, the sensor will broadcast itself as cluster head.

$$P_i(t) = \frac{P}{1 - P(r \bmod \frac{1}{P})} \cdot \left[\alpha\left(\frac{E_{current}}{E_{\max}}\right) - (1-\alpha)\left(\frac{Dis_{total}}{n.Dis_{\max}}\right)\right] \quad (8)$$

where, $E_{current}$ is Residual energy of each node, $E_{\max}$ is maximum energy of each node while its power source is fully charged, dis_{total} is total distance of each node from all its neighbors, $dis_{\max}$ is the distance of each node from its farthest neighbor, N is The number of its neighbor nodes and α is coefficient of each parameter

In this relation, the division operation is performed for normalization so that the value of any clause would be between 0 and 1. Because in this case, we will have $E_{current} \le E_{\max}$, $Dis_{total} \le n.Dis_{\max}$.

V. SIMULATION RESULTS

We simulated a cluster based wireless sensor network in an area with dimensions of 100×100 and with randomly uniformed distribution of one hundred sensors in it, by Jsim software. The initial energy of 90% of sensors is E_0= 0.5 J and the energy 10% of sensors is twice that of conventional sensors (this energy combination is due to the use of heterogeneous sensors and has no effect on the protocol behavior and SEP and LEACH protocols also follow this rule). We considered the length of the simulation implementation for 2500 rounds and the consumed energy is also calculated according to Table 1.

Protocol performance will be evaluated in this section. Simulation software has been implemented in JSIM environment in order to simulate EACA and LEACH protocols and study their efficiency. In our tests, we consider two types of wireless sensor networks with different configurations. In the first configuration, the base station is located in the middle of the sensor nodes, and in the second configuration, the base station is located within one hop at the outside the sensor network. The number of sensor nodes has been assumed 200 nodes for both tests. The parameters used in the tests are shown in Table 1.

Table 1. The network parameters used in the simulations of the first and the second tests

The second test (Base station is outside the network)	The first test (Base station within the network)	Parameters
(0, 0) to (200, 200)	(0, 0) to (350, 350)	The network range
200	200	N
87.7 m	87.7 m	D_o
(100, 300)	(175, 175)	The position of the base station
50 nJ/bit	50 nJ/bit	E_{elec}
10 pJ/bit/m2	10 pJ/bit/m2	ε_{fs}
0.0013 pJ/bit/m4	0.0013 pJ/bit/m4	ε_{mp}
1	1	The number of time frames in each round
20 s	20 s	The length of each time frame
5 nJ/bit/signal	5 nJ/bit/signal	EDA
0.5J	0.5J	The initial energy of each node
500 bytes	500 bytes	The packet size
3	3	The maximum number of pieces

In EACA protocol, the probability of becoming a cluster head for sensors can decrease or increase according to the energy level, the density of sensors and their distance from each other. However, in LEACH and SEP protocols, this probability is stable and cannot decide according to the position and energy levels of nodes in the network. The results related to the first and second tests are shown in Figures 2 to 10.

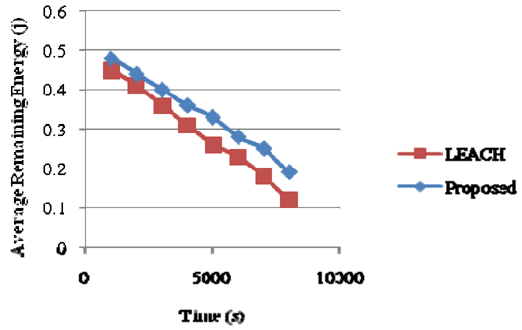

Figure 2. Average remaining energy whit execute LEACH and EACA protocol (the second test)

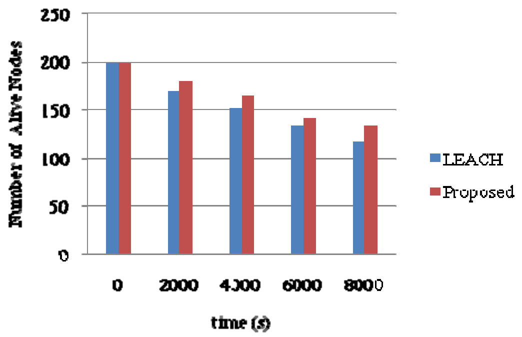

Figure 3. Number of alive node (the second test)

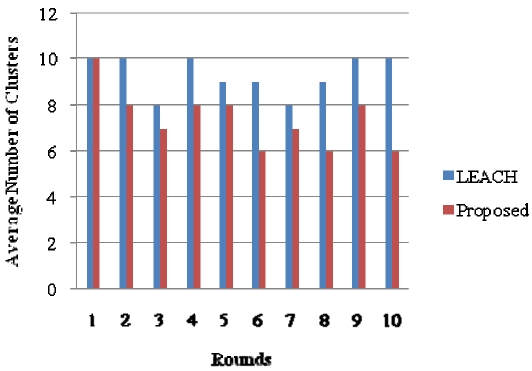

Figure 4. Average number of cluster head (the second test)

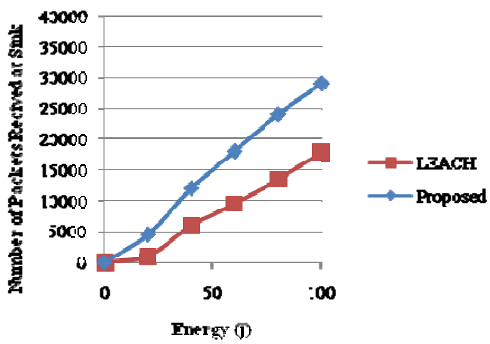

Figure 5. Energy consumed against packets received by sink (the second test)

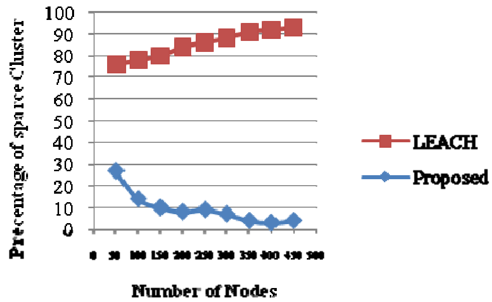

Figure 6. Percentage of empty cluster

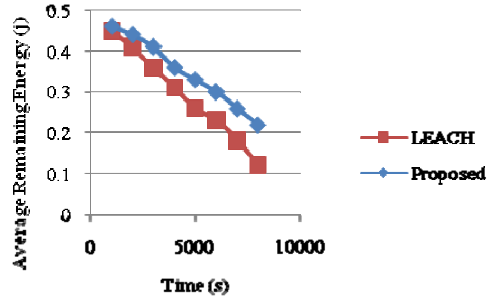

Figure 7. Network lifetime whit execute LEACH and EACA protocol (the first test)

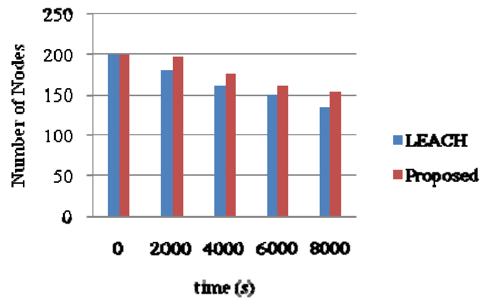

Figure 8. Number of alive node (the first test)

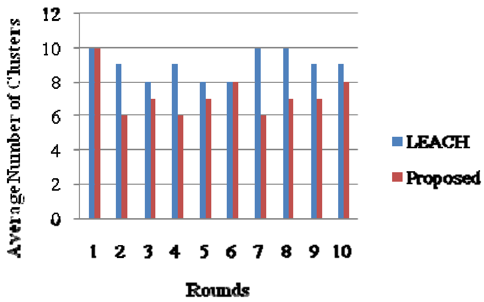

Figure 9. Average number of cluster head (the First test)

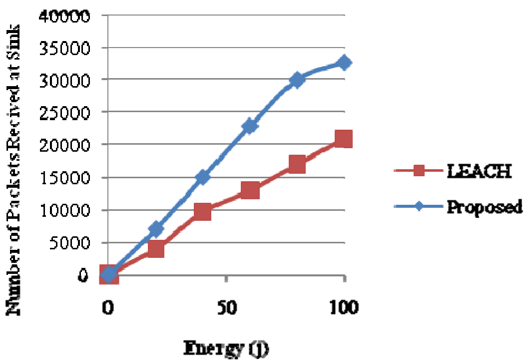

Figure 10. Energy consumed against packets received by sink (the first test)

VI. CONCLUSIONS

In this paper, a communication protocol was introduced for wireless sensor networks, called (EACA). In this paper, we proposed a hierarchical clustering method, in which the cluster head will be selected according to the parameters of the sensors residual energy, the distance between cluster head and the cluster members, and communication cost. Therefore, the entire network will be clustered hierarchically. Then, this method was simulated along with LEACH protocol, and the results were compared.

The simulation results show that our proposed solution prolongs the network lifetime about 23% more than LEACH protocol, and among these three parameters, the access level to the higher level cluster head of the sensor, has a greater effect on the improvement of the network lifetime than the other parameters.

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