An Energy-Aware Protocol for Periodical Data Collection in Wireless Sensor Networks

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Abstract

In this paper we propose a protocol for periodical data collection applications in wireless sensor networks. The protocol is energy-aware in the sense that the way of energy consumption used here is evenly distributed. The protocol is chain-oriented and uses data fusion at every sensor node. Compare to other data collection protocols, this protocol shows better performance with respect to both latency and energy. It has been found that the proposed protocol outperforms PEGASIS with respect to latency in data delivery and performs better than that of LEACH with respect to energy. Furthermore, our protocol performs higher number rounds than that of PEGASIS in the case when the first node dies in the network. In a word the protocol shows an outstanding time-energy compromise.

1. Introduction

Tiny sensor nodes with wireless communication capability, small memory and processing power are deployed randomly to form ad hoc networks. These self-configurable networks emerged as new data gathering tool from remote inaccessible terrain. There are many applications of sensor networks including habitat monitoring, location tracking, industrial plant monitoring, combat field surveillance and medical monitoring [1, 2, 3]. But their promising scopes are constrained by the limited energy, bandwidth and computation power [4, 5]. Among those constraints, energy efficiency is the key research objective in most of the application scenarios because once deployed over the target field battery replenishment is often not possible [6]. Therefore, network lifetime is directly related to the lifetime of the energy source i.e., battery. In order to facilitate the efficient use of this precious energy source, energy awareness should be included in all layers of networking protocol stack. Also as data from sensor networks are generally delay sensitive, therefore, timely delivery of data is important [7]. Another important issue that must be taken care of in protocol design is data aggregation or data fusion. Since it is assumed sensors are deployed densely, there must be significant redundant data. Therefore, similar data can be reduced by applying simple data aggregation such as *min*, *max* and *average* [5, 8] or more advance signal processing technique such as *beamforming* of acoustic signal [9, 10] to reduce energy expensive transmission.

This paper is based on the work explained in [11] by giving a detailed explanations and simulation results of Chain Oriented Sensor Network (COSEN) protocol, an improved energy efficient hierarchical periodical data collection protocol for wireless sensor networks. COSEN is a chain-oriented two-layer protocol. The chains are formed in the way that the routes along which the information are sent by the sensors are near optimal. This is the reason behind the lower energy consumption. We propose to form several chains so that time required for data collection decreases significantly. We also propose data aggregation at every node level in order to leverage the benefit of reduced transmission cost. In our proposal data get fused at every node level when transmitted from one node to another node and finally transmitted to chain leader. On the other hand chain leaders form a higher-level chain; among that one designated leader chosen in a greedy way takes turn to transmit to the base station (BS). Data also get fused while routed among higher-level chain until it reaches the higher-level leader and finally transmitted to the BS.

The rest of the paper is organized as follows. Section 2 gives an overview of the background. We discuss the network and radio models used in the protocol in section 3 and 4 respectively. Section 5 presents a detailed description of the protocol. A comparative analysis is given in section 6. Simulation results are discussed in section 7. Finally conclusion and discussions are given at section 8.

2. Background

Collecting data from an application field and sending this information back to the remote BS is a traditional application area of sensor networks [2]. Various routing protocols have been proposed to carry out this work energy-efficiently. Among those protocols, Low-Energy Adaptive Clustering Hierarchy (LEACH) [9] and Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [12] provide elegant solutions. Our proposal is greatly influenced by both LEACH and PEGASIS. We strive to leverage the benefits of both protocols while eliminating the drawbacks.

In LEACH sensors are organized into local clusters and only one node in each cluster acting as cluster-head takes the responsibility to collect data, aggregate them and finally transmit to the distant BS. Authors in [9] showed that the network is optimal in the sense of energy dissipation while around 5 percent of the total nodes act as cluster-heads. The operation of LEACH is divided into rounds. Each round begins with a set-up phase followed by a steady-state phase. During the set-up phase each node calculates by itself with a given probability whether to become a cluster-head. After that each cluster-head broadcasts an advertisement message to the rest of the nodes. Depending on the received signal strengths, each non-cluster-head node decides to which head it wants to belong for that round. Each cluster-head then creates a TDMA schedule for all the member nodes in its cluster and sends this information back to the member nodes. During the steady state phase, member nodes start sensing and transmitting data to the cluster-heads according to the TDMA schedule. Cluster-head aggregates the received signals and then transmits the fused information to the remote BS. At the end of a given round, a new set of nodes become cluster-heads for the subsequent round and the whole procedure repeats again. As acting as cluster-head heavily drains energy from nodes, LEACH facilitated randomized rotation of cluster-head position in order to evenly distribute the energy extensive transmission to the BS. Though LEACH provides an excellent solution to the traditional data collection operation still there are some limitations. Firstly, the cluster set-up overload that needs to be carried by the network at every round. Secondly, as data transmitted directly from each cluster-head node to the remote BS, there are many long distance transmissions in the network. The number of long distance transmissions will increase with the increase in the network size so does the overall energy dissipation of the network

On the other hand, PEGASIS [12], an improvement over LEACH, is a near optimal chain-based protocol. Rather than forming several clusters, PEGASIS forms a single chain including all nodes of the network using a greedy algorithm so that each node transmits to and receives from only one neighbor. In each round, only one randomly selected node in the chain takes turn to transmit the aggregated information to the BS thus energy consumption reduces greatly. However, this achievement faded by the excessive delay introduced by the single chain for the distant node. The huge delay makes this protocol inconvenient for time critical operation.

3. Network model

Unlike the traditional wireless networks sensor networks are characterized as application dependent network due to the fact that in different situations they are intended to carry on different types of jobs depending on the nature of the specific applications. But in almost all cases the principle nature of work of sensors is to collect information from a targeted field, process the information, and send them for further processing to some sink or BS. Obviously network protocols vary according to the specific nature of the application [13]. In our experiment we consider periodical data collection problem from a remote target field in both energy efficiently and timely manner. We proceed based on the following network model:

- The BS is located far from the sensor network and fixed.
- All nodes are homogeneous and energy constrained.
- Data are transmitted periodically from the sensor network to the remote BS.
- Each node is capable to reach the BS directly.

4. Radio model

To keep the uniformity, we choose the same radio model used in LEACH. PEGASIS also uses this radio model. In LEACH it is assumed that the energy dissipated in the transmitter amplifier is E_{amp}=100pJ/bit/m^2 for an acceptable signal to noise ratio (SNR). In addition energy required in running transmitter and receiver electronics are equal and given by E_{elec}=50nJ/bit. Moreover, the energy cost for data aggregation is considered as 5nJ/bit/message [9]. The radio speed is considered as 1Mbps [4] and information processing time in a node is taken between 5 to 10 milliseconds [4].

Thus the total transmission cost for a k-bit message is given by the Equation 1.

$$E_{tx}(k,d) = E_{elec} * k + E_{amp} * k * d^2 \quad (1)$$

Here d is the distance between sender and receiver measured in meters.

In case of receiving message, the energy consumption equation is given by Equation 2.

$$E_{rx}(k) = E_{elec} * k \quad (2)$$

The medium assumed to be symmetric such that the energy required for transmitting a message from node

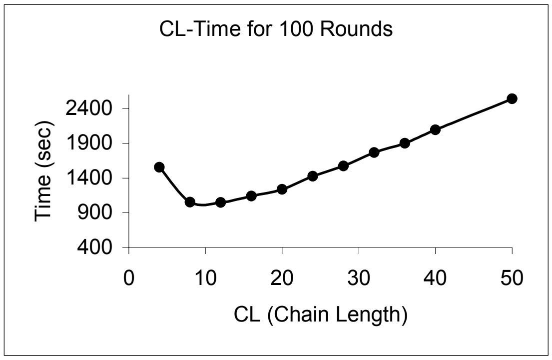

Figure 1: Time required vs. CL

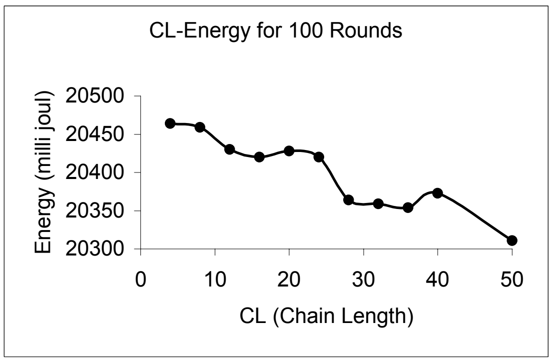

Figure 2: Energy required vs. CL

n1 to n2 and from n2 to n1 are same at a fixed SNR. So we can say, for free space propagation loss, energy dissipation is certainly dominated by the long distance transmission.

5. Chain Oriented Protocol (COSEN)

The operation of COSEN can be divided into two broad phases: chain formation phase followed by data transmission phase. In the chain formation phase, chains are formed and in the data transmission phase, information are transmitted along with the designated paths. Several chains are formed with the sensors deployed. In each chain, one node is elected as a leader. All nodes in a chain send messages to the leader node. Besides, all leader nodes form a higher-level chain where a member of the higher-level chain is elected as the higher-level leader. All leaders send the information to the higher-level leader. The higher-level leader is the node that transmits the information to the BS. In the following sub-sections we discuss the phases in details. We consider that sensor nodes are capable of dynamic power adjustment. Therefore nodes can adjust the amplifier electronics to adjust for any required distance. Also we assume nodes are aware of their location. Positions of the nodes may be obtained by methods based on triangulation [13, 14], where nodes approximate their position using radio strengths from a

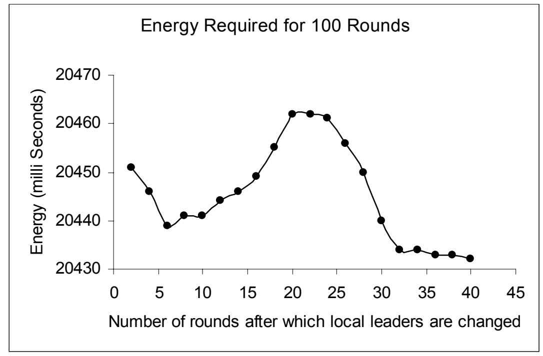

Figure 3: Energy dissipation vs. R

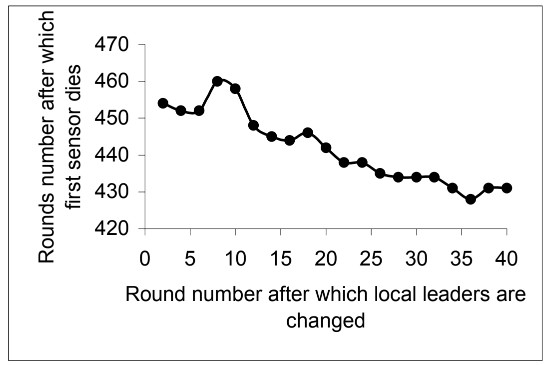

Figure 4: Number of Rounds when 1st node dies vs. no. of rounds after that local leaders are changed

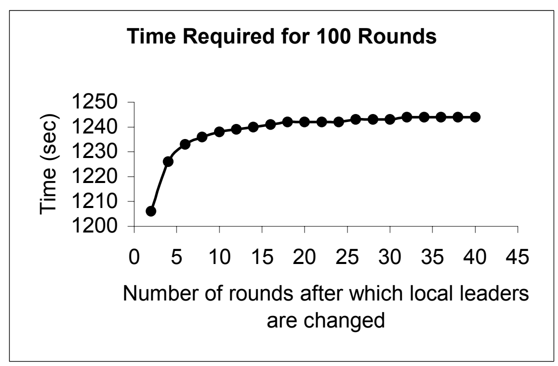

Figure 5: Time required vs R

few known points. Authors in [14] showed that algorithms based on *triangulation* or *multilateration* can work quite well under conditions where only very few nodes know their positions a priori. Certainly this extra negotiation consumes extra energy but as this process only takes place once at the beginning of network setup, it is negligible.

5.1 Chain formation phase

COSEN forms several chains along with the randomly deployed sensors on the target field. Each chain is of fixed length[1]. Let call this length CL. The chain formation starts from the furthest node from the BS. A node in a chain selects the nearest live node that is not already included in any other chain and adds it to the chain. If the chain length exceeds CL, new chain formation starts. This way chain formation continues until all the live nodes are grouped into a number of chains. We consider that the chain formation takes place again whenever 20% nodes of a chain die. This is due to the optimal length of chain and thus efficient distribution of energy dissipation.

After fixing the chains, next target is to identify the leader node in a chain. Unlike PEGASIS, where leaders are chosen randomly at every round, our protocol selects leaders for every chain based on the energy remaining in each sensor of the chain. In addition, COSEN does not change leaders at every round but at after R number of rounds. The benefits of using a slight larger duration for selecting leaders rather than selecting leaders at every round are i) less communication overhead ii) reduction of time required to select leaders at every round and iii) to maximize the utilization of higher-level chain. Once the leaders are selected, a higher-level leader is selected among the leaders using a greedy algorithm. The higher-level leader is the only node that sends information to the BS. For the higher-level leader selection the criteria our protocol considers are i) distance from the BS and ii) energy remains in the node. COSEN tries to ensure that nodes closer to BS take turn to transmit frequently than the nodes those are far from the BS. In this way our protocol can use the energy of the network optimally.

We consider several issues to choose the value of CL and R. At first, consider Figure 1. It shows the comparison for time required by our protocol for different CL values for 100 rounds. It is obvious from Figure 1 that if the CL value increases, required time also increases. The time differences are considerable enough. Figure 1 recommends that the value of CL should be in between 10 to 15. Now consider the Figure 2. It depicts the energy required by the protocol for different values of CL. But it is apparent that the differences between energy requirements are little. From Figure 1 and Figure 2 we conclude that the value of CL could be in between 15 to 20. Actually it depends on the application which value of CL should be chosen. In our work we consider CL=20.

Now come to the point about the value of R. The local leaders should be changed after some period of time to distribute the load. If the local nodes are changed frequently, it makes delay because it needs time to select the local leaders. On the other hand, if local leaders are not changed for long time, some nodes will die soon. Simulation results by changing the rounds after which local leaders are changed are given in Figures 3, 4 and 5. From these figures we find that the value of R can be used for optimal result is between CL/2 to CL.

5.2 Data collection and transmission phase

During the data collection phase each chain leader is responsible to collect data from other members in that chain. Leader node initiates the data collection operation by sending a small token signal toward the end nodes in the chain similar to PEGASIS. As the size of this token is very small its associated cost is also negligible. As shown in Figure 6 leader node, n3 sends token toward node n1. After receiving the token n1 transmits its data to node n2 which fuses n1's data with its own data and sends this fused data toward n3. Leader n3 then sends a token toward n5 and collects data in the same way from n5 through n4. This is how data propagate from the furthest node in the chain to the chain-leader. The similar approach is also taken to collect information at the higher-level leader in the higher-level chain. Data also undergo further processing while routed among the higher-level chain toward the higher-level leader. Finally, the higher-level leader sends the fused data toward the distant BS.

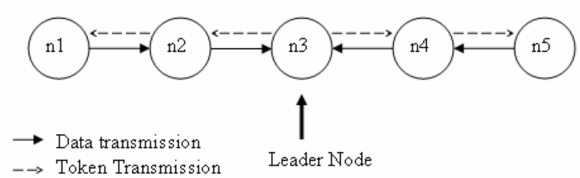

Figure 6: Token passing approach to collect data

6. Comparative analysis for required energy and time to complete single round

LEACH uses direct communications from cluster-heads to the BS. Therefore, with around 5% of nodes acting as cluster-heads in a 100-node network there are at least five long distance transmissions from five cluster-head nodes to BS. Time required to complete a single round can be estimated in the following way: if we consider that there are approximately 20 nodes per cluster for a 100-node network with 5% nodes acting as cluster-heads and if t unit of time is required for one node to transmit information to the cluster-head then with a TDMA schedule for 19 nodes requires approximately $19t$ unit of time to collect data from all the nodes in a cluster. After that with a CSMA MAC the last one among five cluster-heads may have to wait

[1] The very last chain of the network may not be of the same length with other chains in the case when N is not fully divisible by CL.

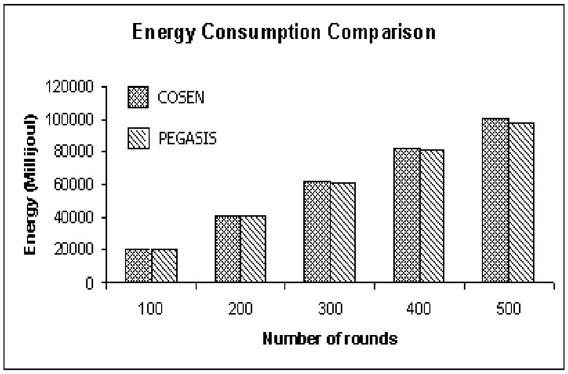

Figure 7: Energy dissipation comparison

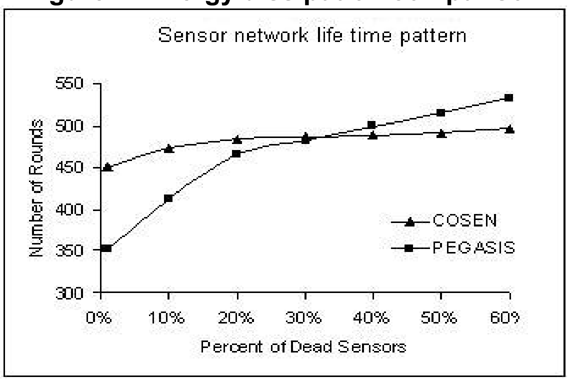

Figure 8: Lifetime of COSEN and PEGASIS

around 4t unit of time. In total 23t unit of time may require to before sending the last information from the network. This time requirement may vary due to the randomness of the network but we consider here the ideal case for the LEACH.

Whereas in PEGASIS, each node transmits to the next and receives from its previous nearest neighbor except the end two nodes in a chain. Only one node is responsible to collect and transmit to the BS during each round. So long distance transmission reduces to bare minimum i.e. only one. If we assume it needs approximately same unit time delay, t to transmit from one node to the next node, then for a N-node network, if the leader is the end node in the chain, other end needs (N-1)t unit of delay to reach the leader node. Therefore, for a 100-node network the delay yields 99t units.

In our proposal, we consider to form smaller chains of fixed length with the deployed nodes. The network is divided into N/CL chains where N is the total number of nodes and CL is the maximum number of nodes in a chain. As described above in our experiment we use CL=20. For a network of 100 nodes, we construct 5 chains each containing 20 nodes. Therefore, in extreme case, in order to reach the furthest node in a chain there are always a delay of (CL-1)t i.e. 19t units in each chain. There are some additional delay in the higher-level chain. For a 100-node network there are five leader nodes. Therefore extra (N/CL-1)t i.e. 4t unit of

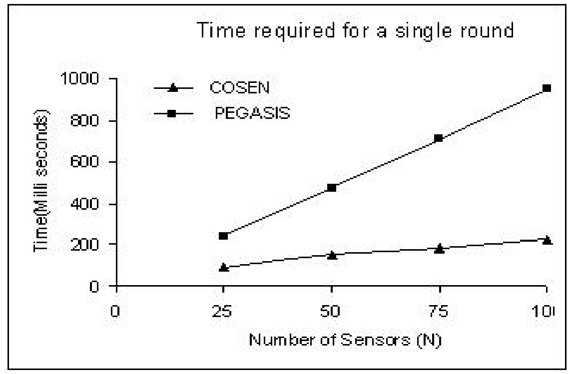

Figure 9 (i): Time requirement for single round

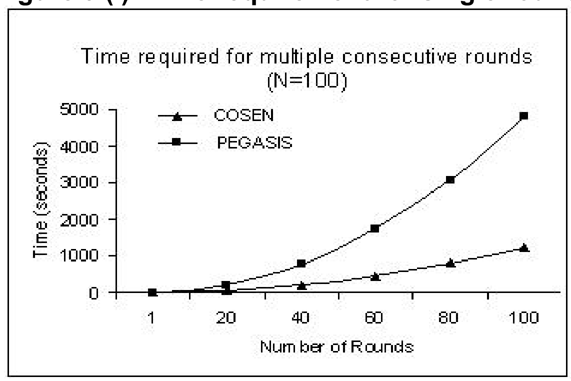

Figure 9(ii): Time requirements for multiple consecutive rounds

delay may occur in the worst case before sending the signal. In total there may be (N/CL-1)t + (CL-1)t units i.e. 23t units of delay for a 100-node network. Table-1 shows a comparison between LEACH, PEGASIS and COSEN in one round of data transmission for a 100-node network. It is clear from Table-1 that COSEN outperforms LEACH by avoiding many long distance transmission at the same time it causes much less delay to deliver information to the BS from distant nodes as compared to PEGASIS.

Table 1: Comparative analysis

Parameters	LEACH	PEGASIS	COSEN
No. of Long Distance Transmission	5	1	1
Unit Delay	23	99	23

7. Simulation results

We developed our own simulator written by object oriented programming language (C++). Similar to PEGASIS, we consider 100 nodes placed randomly in a place of 50 meter × 50 meter. We use Cartesian coordinates to locate the sensors. The BS is located at (25, 150). We assume each sensor has one Joule of initial energy. We mainly compare the performance of our protocol, COSEN with that of PEGASIS. As in [12] we find that, for the case of energy consumption, PEGASIS performs better than LEACH by about 100% to 300% when 1%, 20%, 50%, and 100% of nodes die for different network sizes and topologies, we limited the comparison only with PEGASIS.

It is shown in Figure 7 that after several hundreds of rounds in COSEN and PEGASIS, the amount of energy consumed is approximately same in both the cases. For example, after 100 rounds COSEN requires only 0.218 joules additional than that of PEGASIS, after 500 rounds COSEN requires only 2.833 joules additional than that of PEGASIS etc. But the significant point for COSEN is that, it spends the energy in a totally distributed way such that the network can operate higher number of rounds before the first sensor dies. The lifetime pattern of COSEN is depicted in Figure 8. Whereas the first node dies for PEGASIS at 350 rounds, the first node dies at around 450 rounds for COSEN. The definitive improvement of COSEN from PEGASIS is that, the latency in data delivery is greatly minimized. Figure 9 shows that where, for 100 rounds, PEGASIS requires around 5000 seconds, COSEN requires only one-fifth of that time.

8. Conclusions and discussion

In this paper, we propose an optimized two layer hierarchical routing approach for sensor network in an energy and time constraint environment. The proposed protocol routes information not only energy-efficiently to lengthen the network lifetime but also in a timely manner to meet the real-time need. Simulation results show that our protocol offers an outstanding time-energy compromise as compared to that of both LEACH and PEGASIS. Moreover, we find in the simulation that our protocol performs higher number of rounds than that of PEGASIS before the first sensor dies.

Here we bring some other issues concerning our protocol. The first issue is the reliability of our protocol. This may be assumed that, as one node is being elected as a coordinator for a chain, the protocol is a centralized one. And the problem of a centralized protocol is the single point of failure. But a careful look at the protocol refers that for every R rounds of propagation the coordinators are changing. Thus the probability of crashing a node while it is a coordinator is negligible. The second issue is about multiple hierarchy levels. Although in this paper we described our protocol as a two-layer protocol, for a huge size of sensor networks out protocol can be extended to multiple hierarchical layers, remaining the protocol constitution unchanged.

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