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Dynamic Hierarchical Communication Paradigm for Wireless Sensor Networks: A Centralized, Energy Efficient Approach

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Abstract

A Wireless Sensor Network (WSN) consists of a large number of randomly deployed sensor nodes. These sensor nodes organize themselves into a cooperative network and perform the three basic functions of sensing, computations and communications. Research in WSNs has become an extensive explorative area during the last few years, especially due the challenges offered, energy constraints of the sensors being one of them. In this paper, the need for effective utilization of limited power resources is emphasized, which becomes pre-eminent to the Wireless Sensor Networks. Organizing the network to achieve balanced clusters based on assigning equal number of sensors to each cluster may have the consequence of unbalanced load on the cluster heads. This results in an unbalanced consumption of energy by the nodes, cumulatively leading to minimization of network lifetime. In this paper, we put forth a Sink administered Load balanced Dynamic Hierarchical Protocol (SLDHP) to balance the load on the principal nodes. Hierarchical layout of the sensors endows the network with considerable minimization of energy consumption of nodes leading to an increased lifespan. Simulation results indicate significant improvement of performance over Base station Controlled Dynamic Clustering Protocol (BCDCP).

Keywords: Wireless Sensor Network, Sink, Principal Node, Superior Node, Network Lifetime

1. Introduction

A Wireless Sensor Network (WSN) is an ad-hoc wireless telecommunication network which embodies a number of tiny, low-powered sensor nodes densely deployed either inside a phenomenon or close to it [1]. The multi-functioning sensor nodes operate in an unattended environment with limited sensing and computational capabilities. The advent of wireless sensor networks has marked a remarkable change in the field of information sensing and detection. It is a conjunction of sensor, distributed information processing, embedded and communication techniques. WSNs may in the near future be equally prominent by providing information of the physical phenomena of interest and ultimately being able to detect and control them or enable us to construct more meticulous models of the physical world.

WSNs are easier, faster and cheaper to deploy than other forms of wireless networks as there are no predetermined positions for the sensors. They have higher degree of faulttolerance than other wireless networks and are self-configuring or self-organizing [2]. Sensors are deployed randomly and are expected to perform their mission properly and efficiently. Another unique feature of sensor networks is the co-operative effort of sensor nodes to achieve a particular task.

A WSN is envisioned to consist of a large number of sensors and many base stations. The sensors are equipped with transceivers to gather information from the environment and pass it on to one of the base stations. A typical sensor node consists of four major components: a data processor unit; a sensor; a radio communication subsystem that consists of transmitter/receiver electronics, antennas, an amplifier; and a power supply unit [3]. The sensors are compact in size which make them extremely energy restrained. Further more, replacing batteries in large scales in possibly harsh terrain becomes infeasible. Hence, it is well accepted that the key challenge in unlocking the potential of such networks is maximizing their post-deployment active lifetime. The lifetime of the wireless sensors may be prolonged by ensuring that all aspects of the system achieve energy efficiency. Since communications in wireless sensor networks consume significant amount of energy, the designed algorithms must ensure that nodes expend minimum amount of energy for transmitting and receiving data.

A web of sensor nodes can be deployed to gather productive information from the sensor field. Some of the benefits of using WSNs are extended range of sensing, fault-tolerance, improved accuracy and lower cost. As a consequence, the sensor networks are expected to find extensive use in a variety of applications including remote climate monitoring, seismic, acoustic, medical and intelligence data-gathering [4,5]. Hence, they are suitable for a wide range of applications like military, health, education, commerce and so on. Military applications may range from tracking enemy movement in the battlefield to guiding targeting system. Bio-sensors are used for monitoring patients blood sugar level. Commercial applications may range from tracking postal packages or office equipment to monitoring product quality on an assembly line. Environmental applications include forest-fire detection, flood detection, tracking movements of birds etc. Sensors are also used to simulate home automation and to build smart environments.

Efficient utilization of energy is crucial to the WSNs. Wireless microsensor network protocols should therefore be selfconfiguring to enable ease of deployment of nodes, latency aware, qualitative, robust and to extend system lifetime. The sensors are extremely energy bounded, hence the network formed by these sensors are also energy constrained. The communication devices on these sensors are small and have limited power and sensing ranges. A routing protocol coordinates the activities of individual nodes in the network to achieve global goals and does it in an efficient manner. The simplest is the Direct Communication Routing Protocol, where each node transmits the sensed information directly to the base station. The nodes consume considerable amount of energy if the communication path is long. This results in the early death of distant nodes. To overcome this drawback, the technique of Minimum Transmission Energy utilizes a multhop routing scheme. In this scheme, the nodes that are close to the base station drain their energy rapidly as they are involved in transmission of messages on behalf of others.

Hierarchical routing groups sensors in the entire network into clusters. It aims at reduction of energy consumption by localizing data communication within a cluster and aggregating data to decrease transmissions to the base station. The first attempt in this regard, was made by Low Energy Adaptive Cluster Hierarchy (LEACH). The operation is framed in iterations and each iteration comprises of a setup and a data transmission phase. During the setup phase, nodes organize themselves into clusters with predetermined number of nodes serving as cluster heads. In the data transmission phase, the self-elected cluster heads aggregate data received from the nodes in their cluster before forwarding to the base station. The role of cluster heads is randomly rotated among all the nodes in the network. This technique serves as a basic model for other hierarchical routing protocols. A centralized version of the adaptive approach comprises a hierarchical structure in which the base station has control over the cluster formation. The base station uses the location and energy information sent by the nodes to select the predetermined number of cluster heads. Efficient clustering is achieved as the base station possess the global knowledge of the network. This technique exhibits improvement over the adaptive approach.

In Power Efficient Gathering in Sensor Information Systems (PEGASIS), the nodes function co-operatively to optimize network lifetime. A greedy algorithm is used to configure the network into chains. In each iteration, a randomly chosen leader node directs the aggregated data to the base station. A centralized energy efficient routing protocol called Base Station Controlled Dynamic Clustering Protocol (BCDCP), was proposed which widened the area for research in hierarchical routing. Here, much of the functionalities like formation of clusters and routing paths are performed by the high energy base station which lightens the load of sensor nodes. This protocol configures the network into balanced clusters where each cluster head serves an approximately equal number of member nodes. Cluster head-to-cluster head multihop routing is employed in this protocol to transfer the data to the base station.

Motivation: Efficient management of energy deserves much of the attention in the WSNs. Routing protocols designed for WSNs must therefore effectively tackle this issue in order to enhance the lifetime of the network. Hierarchical routing techniques are preferable in this direction. The arrangement of the nodes in the form of a load balanced hierarchy proves to be beneficial.

Contribution: In our paper, we propose a energy efficient hierarchical routing protocol, SLDHP to increase the lifetime of homogeneous as well as heterogeneous WSNs. SLDHP achieves a load balanced hierarchical arrangement of nodes in the network which performs better than the other hierarchical routing protocols.

Organization: The rest of the paper is organized as follows. In section II, we discuss the related work. In section III, the underlying model is described and the problem is defined in section IV. Our proposed algorithm, SLDHP is presented in section V. Performance analysis is presented in section VI and section VII contains the conclusion.

2. Related Work

Hierarchical routing aims to efficiently maintain the energy consumption of sensor nodes by involving them in multihop communication within a particular cluster and

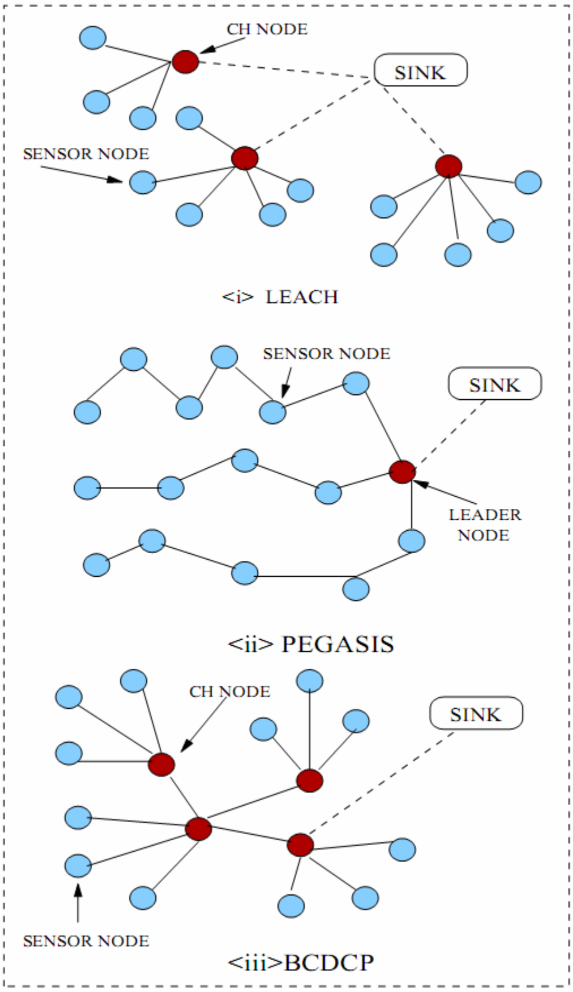

Figure 1. Three main topologies of hierarchical routing protocols.

by performing data aggregation and fusion to decrease the number of transmitted messages to the base station.

Heinzelman *et al*. [6] proposed an adaptive clustering protocol. This approach employs the technique of randomly changing the role of cluster head among all nodes in the sensor network. The operation of this protocol is organized into different iterations where each iteration consists of a setup phase and a transmission phase. During setup phase, nodes organize themselves into clusters in which cluster head is elected locally within each cluster. During transmission phase, the self elected cluster heads aggregate data received from all the nodes within its cluster, applies a data fusion technique before sending it directly to the base station. In this method, the decision is made per iteration and it is assumed that we have a knowledge of the total residual energy of the network.

In [7], a centralized algorithm for routing is described. This protocol uses the base station for centralized computation of cluster heads. The base station upon receiving the location and energy level information from the sensor nodes during the setup phase, locates a predetermined number of cluster heads and configures the entire network into clusters. The cluster heads are chosen in such a way that nodes consume minimum energy for transmitting their data. The shortcoming may be that they drain their energy rapidly as they have to communicate directly with the base station irrespective of their positions. The results in [7] show improvement over [6].

A chain based protocol is presented in [8]. In this protocol, each node communicates only with a close neighbour and takes turns to transmit to the base station, thus reducing the amount of energy spent per iteration. For constructing a chain, it is assumed that all nodes have global knowledge of network. A greedy algorithm is employed to ensure that nodes already on the chain need not be revisited. Here, even though the forwarding node has capability of taking more load, it is not assigned if it is already on the chain.

A centralized clustering based routing protocol is discussed in [9]. According to this protocol, energy intensive tasks such as cluster setup, cluster head selection, routing path formation and TDMA schedule creation are performed by the base station which is assumed to have unlimited power supply. This protocol configures the network into balanced clusters, i.e., the number of nodes in each cluster are same. Such equal clustering results in an unequal load on the cluster head.

Guangyan *et al*. [10] have reviewed the energy efficiency of cluster based routing protocols with extended conditions of general complexity of data fusion algorithm, general data compressing ratio and long distances. They present three discoveries, first of which is that data fusion algorithm is computed based on applications. Secondly, multihop scheme not used by earlier works could sometimes prove beneficial. Thirdly, when network area is larger than 200mx200m, the number of high energy dissipating nodes are more which accelerates the death of nodes. These findings guide in improving the routing protocols and hence to extend their application ranges.

Geographic and energy aware routing algorithm developed by Yan Yu *et al*. [11], propagates a query to the appropriate geographical region without flooding. The protocol uses energy aware and geographically informed neighbor selection to route a packet towards the target region. To disseminate the packet inside the destination region, a recursive geographic forwarding or restricted flooding algorithm is used. The protocol exhibits noticeably longer network lifetime as compared to non-energy aware geographic routing algorithms.

A novel algorithm proposed by Andrea in [12], performs three main functions of configuring the network into optimum number of clusters, decentralized cluster head selection and cluster formation. The value of optimum number of clusters depends on total number of sensors in the network, on the path-loss exponent (α), on dimensions of the network and distance of the broadcast packets. They use an adaptive strategy for cluster head selection. The algorithm for cluster formation uses total path energy dissipation instead of energy lost in path from the node to its cluster head. The algorithm optimizes system lifetime in a large range of applications and situations.

A cost based comparison of homogeneous and heterogeneous clustered sensor networks has been presented. It first considers single hop clustered sensor networks and use adaptive clustering protocol. It also takes into account sensor-network with two types of nodes as representative single hop heterogeneous networks. For multihop homogeneous network Vivek *et al*. [13] propose and analyze a multihop variant of the adaptive approach. They consider communication radius for in-cluster communication and size of clusters. This algorithm exhibits better energy efficiency in many cases, but does not give expected performance if the heterogeneity is due to the operation of the network.

An energy efficient distributed clustering approach for adhoc sensor network is developed in paper [14]. In this approach, cluster heads are chosen randomly based on their residual energy and nodes participate in cluster operation such that the communication cost is minimized. The protocol does not make any assumptions regarding the distribution density of nodes. The clustering process takes a fixed number of iterations and does not depend on network topology. This protocol acheives only a two-level hierarchy.

Alan *et al*. [15] have derived a load balancing heuristic for wireless adhoc networks in order to extend the lifespan of a cluster head to as large an extent as possible before another node becomes the cluster head. Two cluster head load balancing heuristics are described. The first approach is for cluster election heuristics that favour the election of cluster head based on *node-id*, and the second approach is based on the degree of connectivity.

In [16], a cluster based query protocol is illustrated for wireless sensor networks using self-organized sensor clusters to register queries, process queries and disseminate data within the network. This protocol uses cluster heads as data storage and aggregation points. Instead of sending large amounts of raw data over a network to reply to a query, each cluster head collects and filters data from its member sensors. This is achieved using the information about the cluster location. With this protocol, energy efficiency is achieved by reducing the number of data transmissions over the network during the course of the data collection and query processing.

A stable election protocol is described in [17] which is a heterogeneous-energy-aware protocol. It is based on weighted election probabilities of each node to become cluster head based on the remaining energy of each node. In this approach every sensor node in a heterogeneous two-level hierarchical network independently elects itself as a cluster head based on its initial energy relative to that of other nodes. The protocol does not demand any global knowledge of energy at every election iteration and also does not consider as to how nodes could be assigned optimally to cluster heads.

In [18], a balanced *k*-clustering algorithm, for clustering sensor nodes into *k* number of clusters is described. Each cluster is balanced and the total distance between sensor nodes and the head nodes is minimized. Minimizing the total distance helps in reducing the communication overhead and hence energy dissipation. The algorithm demonstrates that the balanced *k*-clustering problem can be solved optimally using network flow, but assumes the number of nodes as a multiple of *k* at all times, which may not be practical.

A cluster based routing algorithm is depicted in [19] to extend the lifetime of the sensor networks and hence to maintain a uniform consumption of the energy by the nodes. This is obtained by the addition of a slot in a frame, which enables the exchange of residual energy messages between the base station, cluster heads and nodes. The algorithm takes into account the residual energy of the nodes during cluster head selection, resulting in balanced energy consumption of the sensor nodes. The protocol performs better than the adaptive approach.

In [2], the authors focus on the design criteria for routing protocols and issues and challenges of cluster-based routing in WSNs. The characteristics and the general routing models for protocols in sensor networks are studied here. Yunfeng et al. [20] have devised a protocol called energy balancing multipath routing, the basic idea being that instead of source-initiated or destination-initiated route discovery, it is the base station that finds multiple paths to the source of the data and selects one of them to be used during communication. It is based on the assumption that the base stations are typically many orders of magnitude more powerful than common sensor nodes. It adopts a scheme similar to the well known software architecture client server model.

Energy aware routing that uses sub-optimal paths occasionally to provide substantial gains is designed by Rahul et al. [22]. It emphasizes that using lowest energy paths may not be always optimal from the point of view of network lifetime and long-term connectivity. The protocol is suitable for low energy and low bitrate networks. The key concept is to send traffic through different routes which helps in using the node resources more evenly. It sends the traffic on multiple paths without adding much complexity by using a probabilistic forwarding technique. According to this method, the nodes burn their energy uniformly across the network ensuring a more graceful degradation of service with time.

The problem of energy-aware routing in networks with renewable energy sources is adressed by Longbi *et a*l. [21]. They present a simple, static multi-path routing approach that is optimal in the large system limit. The proposed static routing scheme utilizes the knowledge on the traffic patterns and energy consumption, and does not demand the instantaneous information about the node energy. For the distributed computation of the optimal policy, they outline the possible approaches and propose heuristics to build the set of pre-computed paths. This scheme outperforms leading dynamic routing algorithms, and is close to an optimal solution when the energy claimed by each packet is relatively small compared to the battery capacity.

3. Model

3.1. The Nomenclature

The terminology used in our study are,

HmNt Homogeneous Network consists of sensors possessing a uniform initial energy.

HtNt Heterogeneous Network comprises of sensors with different initial energies.

$\mathbb{N}$ Set of all the sensor nodes deployed in the sensor field of the network.

E_{avg} This is defined as the average energy of the wireless sensor network.

$$E_{avg} = \frac{1}{n}\sum_{k=1}^{n} E_k \tag{1}$$

where n is the number of the sensors and E_k is theenergy of the k^{th} sensor.

$\mathbb{P}$ Set consisting of sensor nodes with energy equal to or greater than E_{avg}, and is a subset of set $\mathbb{N}$, which is a set of all the sensor nodes deployed in the network.

PrNd Principal Node is a node which receives the sensed data from other nodes in its hierarchy, aggregates it to forward either to another principal node or to the *Superior Node*. This functions as the root of the hierarchy and sends the aggregated message to the sink.

n_{min} Minimum energy node.

3.2. Radio Power Model

A typical sensor node is depicted in Figure 2 and consists of four major components: a data processor unit; a micro-sensor; a radio communication subsystem that consists of transmitter/receiver electronics, antennas and an amplifier; and a power supply unit. [23]. Although energy is dissipated in all of the first three components of a sensor node, energy dissipations associated with the radio component is considered since the core objective of this study is to develop an energy-efficient network layer protocol to improve the network lifetime. In addition to this, energy dissipated during data aggregation in the cluster heads is also accounted.

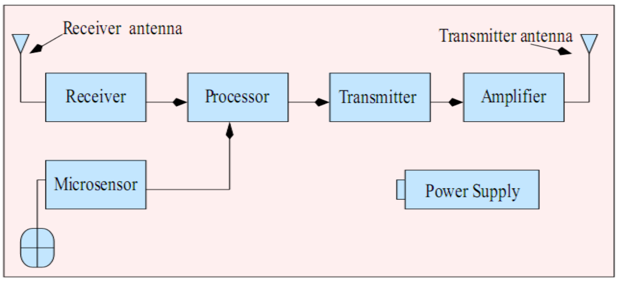

Figure 2. A typical sensor node.

The radio energy model [9] employed in our study is described in terms of the energy dissipated in transmitting k-bits of data between two nodes separated by a distancer meters and also the energy spent for receiving at the destination sensor node and is given by,

$$E_T(k,r) = E_{Tx} * k + E_{amp}(r) * k \tag{2}$$

$$E_{amp}(r) = \varepsilon_{FS} * r^2 \tag{3}$$

The energy cost incurred in the receiver is given by,

$$E_R(k) = E_{Rx} * k \tag{4}$$

where E_{amp} denote energy dissipated in the transmitter of the source node is required to maintain an acceptable signal-to-noise ratio for reliable transfer of data messages. We use free space propagation model and hence the energy dissipation of the amplifier is given by:

$$E_{amp}(r) = \varepsilon_{FS} * r^2 \tag{5}$$

where ε_{FS} denotes the transmit amplifier parameter corresponding to free space.

The assumed values for the various parameters is as given below.

$$E_{Tx} = E_{Rx} = 50\text{n}J / bit$$

$$\varepsilon_{FS} = 10\,pJ / bit / m^2$$

The energy spent for data aggregation is,

$$E_{DA} = 5\text{nJ / bit / message.}$$

4. Problem Definition

A sensor network is described by means of an edge-weighted graph, $G_{WSN}(\mathbb{N}, \mathbb{D}, \text{Sink})$, $\mathbb{N} = \{n_1, n_2 .... n_n\}$ is a set of sensor nodes and $\mathbb{D} = \{d_1, d_2 .... d_n\}$ contains the inter-node distances.

The objectives of our work are:

1) To develop an energy-efficient hierarchical routing algorithm which minimizes the energy consumption of the network.

2) To maximize the network lifetime.

4.1. Assumptions

- WSN consisting of a fixed sink with unlimited supply of energy and *n* wireless sensor nodes having limited power resources.
- The wireless sensor network can be either homogeneous or heterogeneous in nature.
- The nodes are equipped with power control capabilities to vary their transmitted power.
- Each node senses the environment at a fixed rate and always has data to send to the sink.
- The sensor nodes are aware of their geographic position as each of them are equipped with a Global Positioning System (GPS).

5. Sink Administered Load Balanced Dynamic Hierarchical Protocol (SLDHP)

This section focuses on design details of our proposed protocol SLDHP, which is a hierarchical wireless sensor network routing protocol. Here the sink with unrestrained energy plays a vital role by performing energy intensive tasks thereby bringing out the energy efficiency of the sensors and rendering the network endurable. The pattern of the hierarchy varies dynamically as it is based on energy levels of the sensors in each iteration.

SLDHP functions in two phases namely:
1) Network Configuring Phase
2) Communication Phase.
The algorithm steps are described in Table 1.

5.1. Network Configuring Phase

The goal of this phase is to establish optimal routing paths for all the sensors in the network. The key factors considered are balancing the load on the principal nodes and minimization of energy consumption for data communication. In this phase, the sink probes the sensors to send the status message that encapsulates information regarding their geographical position and current energy level. The sink upon receiving this, stores the information in its data structures to facilitate further computations. To construct the routing path, first the sink traces the node with minimum energy, n_{min} from the set N. The minimum energy node n_{min} will be alloted to the principal node, which will be selected based on the following criteria:

- The sink reckons the set $\mathbb{P}$, that contains nodes with energy above E_{avg}, which is a subset of set $\mathbb{N}$.
- It then computes the distance between n_{min} and each of the nodes in $\mathbb{P}$. Consider any two nodes with respective *x* and *y* positions given by (x_1, y_1) and (x_2, y_2). The Euclidean Distance between these two nodes is given by:

$$\sqrt{(|x_1 - x_2|)^2 + (|y_1 - y_2|)^2} \quad (6)$$

- The node in the set P which has minimum distance to n_{min} is selected as the principal node.

To aid further calculations, the amount of energy spent by the principal node on receiving and aggregating message sent from n_{min} is reduced virtually. The minimum energy node is then removed from the set $\mathbb{N}$. This phase repeats until all the nodes in the network are assigned to principal nodes. The last node that remains in set $\mathbb{N}$ is the node with maximum energy which serves as a superior node and has the job of sending the aggregated message to the sink.

The protocol gives prime importance to balance the load on the principal nodes. The minimum energy nodes will be assigned to a principal node as long as it has the capability to handle them. Once the energy of the principal node falls below E_{avg}, it will be treated as a normal node and hence will be assigned to another principal node. In this way, multihop minimal spanning tree is constructed without a need for running a separate *minimal spanning tree algorithm*. Figure 3 depicts the hierarchical setup of our protocol.

SLDHP eliminates the necessity of knowing the optimum number of clusters in the network. The load is evenly balanced depending upon the capacity of the principal nodes. The protocol starts with a chaining setup and ends in a hierarchical model. In this way, multihop, load balanced network is achieved. The concluding task of this phase is to determine the Time Division Multiple Access (TDMA) slots for all the nodes within the hierarchy. Once all the computations are over, the sink sends messages to all the sensors indicating their principal nodes and the TDMA slots.

5.2. Communication Phase

The sensors send their sensed data to their respective principal nodes. Each of the principal nodes gather data from the nodes down in their hierarchy, fuses and then forwards either to another principal node or to the sink. This phase inturn comprises of three activities.

- *Data gathering*: utilizes a time-division multiple access scheduling scheme to minimize collisions between sensor nodes trying to transmit data to the principal node.
- *Data fusion or aggregation*: Once data from all sensor nodes have been received, the principal node combines them into a target entity to greatly reduce the amount of redundant data sent to the sink.
- *Data routing*: Transfers the data along the principal node-to-principal node routing to the superior node, which transmits the fused data to the sink.

Table 1. SLDHP algorithm.

I *Network Configuring Phase*

(i) Initialize

- The $Sink$ queries all nodes regarding their status.
- Nodes reply by sending the status message.

(ii) Main Processing

- Sink computes the average energy of the network.
- begin
  - In addition to computing the average energy, the sink also does the following operations.
    - It traces n_{min}, which is the node with minimum energy. It then computes the set $\mathbb{P}$ which contains the node-ids of all the nodes with energy above E_{avg}.
    - Finds distance between n_{min} and elements of $\mathbb{P}$.
    - An element of $\mathbb{P}$, p_i having minimum distance to n_{min} is assigned as the principal node.
    - Checks whether p_i is still eligible to be in set $\mathbb{P}$. If not, it is eliminated from the set.
    - n_{min} is discarded from $\mathbb{N}$.
  - Repeat this until all the nodes have been assigned to principal nodes.
  - Schedules $TDMA$ slots for all the nodes.

(iii) Finalize

- Sink sends messages to all the nodes indicating their principal nodes and the $TDMA$ slots.

II *Communication Phase*

- Data Gathering
- Data fusion or aggregation
- Data routing

6. Performance Analysis

6.1. The Simulation Test-Bed

A homogeneous sensor network was set up with the simulation environment comprising 100 nodes, with all nodes possesing the same initial energy of 2*J*. The simulations were carried out using the Objective Modular Network Testbed in $C++$ (OMNeT++) simulator [24]. The sensor nodes were deployed randomly in a sensor field of a grid size of 500mx500m. The simulations were carried out several times, for different network configurations in order to obtain consistent results. The performance metrics considered are Average Energy Consumption by the nodes and Network Lifetime. The proposed protocol was compared with BCDCP and it was found that SLDHP performed significantly better in all simulation runs.

6.2. Average Energy Consumption of the Sensor Network

Figure 4 shows the Average Energy Consumption of the sensor network, as a variation with reference to number of iterations of the network. The simulation environment is setup with the initial battery energy of all nodes being 2J and a message length of 4 kbits/packet. We observe that the protocol greatly reduces the energy consumed and hence outperforms others in terms of battery efficiency. This is due to the minimum-spanning tree hierarchical structure formed by SLDHP as compared to the cluster-based structure which consists of equal number of member nodes with unequal distribution of energy. BCDCP achieves balancing by assigning equal number of nodes to each of the clusters which results in overloading the already overloaded cluster-heads to drain out much of their energy on receiving, aggregating and transmitting the data at a much faster rate. In comparison, our proposed algorithm comprises of unequal member nodes within the hierarchy, but load balanced in terms of energy resources, which contributes significantly to the increased energy efficiency of the algorithm. Hence the packet transmission time in our algorithm is predominantly short as compared to others. From the plot, it is observed that initially when the number of iterations is less, energy consumption in both the schemes is found to be almost the same, with no conspicuous results. This is due to the fact that the hierarchical structure at this point of time seems almost the same. The real advantage comes to light when the number of iterations increases, with the hierarchical structure adapting itself dynamically to the changing scenario. The superior performance offered by SLDHP enables to achieve a reduction of energy consumption by about 21% as compared to the earlier algorithms.

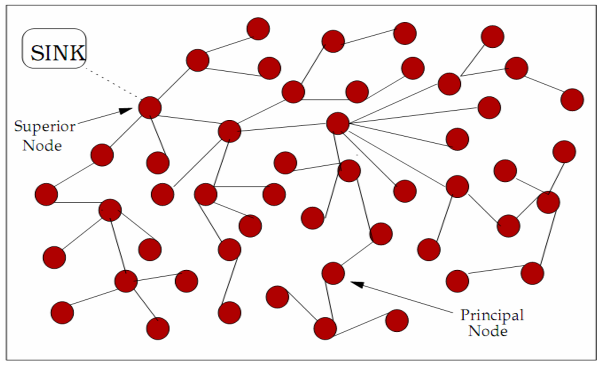

Figure 3. Hierarchical setup of SLDHP.

6.3. Sensor Network Lifespan

The energy consumption rate can directly influence the lifes-pan of the sensor nodes as the depletion of battery resources will eventually cause failure of the nodes. Hence the wireless engineer is always entrusted with the task of prolonging the lifespan of the network by improving the longevity of the sensor nodes. The simulation results of number of nodes alive over a period of time are presented in Figure 6. The simulation environment is the same, i.e., initial energy of nodes being 2J, message length being 4 kbits/packet and the initial node density being 100. Both the protocols are based on a hierarchical structure in which all the nodes rotate to take responsibility for being the cluster-head and hence no particular sensor is unfairly exploited in battery consumption. Due to the hierarchical structure, it is found that till the 806th iteration, the number of nodes that are alive is almost the same in both schemes and equals 100.

This implies that the time duration between the first exhausted node and the last one is quite short or the difference in energy levels from node to node does not vary greatly for lower number of iterations. After this critical point, both the curves in the Figure drop indicating the fall in the number of alive nodes. It is evident from the plot that the number of alive nodes is significantly more in our protocol as compared to other and which agrees with the results obtained in the previous simulation. This algorithm can extend the lifespan of the network by about 34% as compared to the earlier algorithm. It is observed that the number of alive nodes in earlier algorithm is a maximum of 100, dropping at a steady rate till none of the nodes are found to be alive at the 1800th iteration. In comparison, the nodes of SLDHP are very much live and active even for a little beyond the 2000th iteration, once again indicating the superior performance of the algorithm. The reason for this is again the same, the difference in hierarchical structure, plus the added advantage of dynamically having a load balancing scheme.

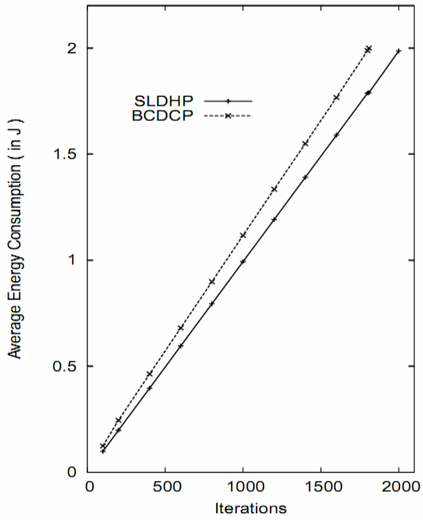

Figure 4. Comparison of average energy consumption.

6.4. Average Energy Consumption for Varying Message Lengths

Figure 5 shows the average energy consumption of the network when SLDHP is run with the data communication phase transmitting data at varying message lengths of 4kbits/packet and 8kbits/packet respectively. From the plot, it is observed that when the message length is 4 kbits/packet, the behaviour is exactly similar to the one depicted in Figure 4 for SLDHP due to the similarities of the simulation environment set up. When the message length is doubled, the average energy consumption of the sensor network is much more as observed from the simulation results. This is quite obvious because of greater overhead involved in aggregating and transmitting a larger sized message. From the plot, it is seen that at the end of the 2000th iteration, the energy consumed for transmitting a smaller message is close to 2J while the same energy level is reached in the 1620th iteration itself, for a larger message transmission. A message length of 4 kbits/pkt seems ideal as lesser length message may not be in a position to carry out the desired task and a larger length may unnecessarily contribute to additional overhead which can degrade the performance of the network.

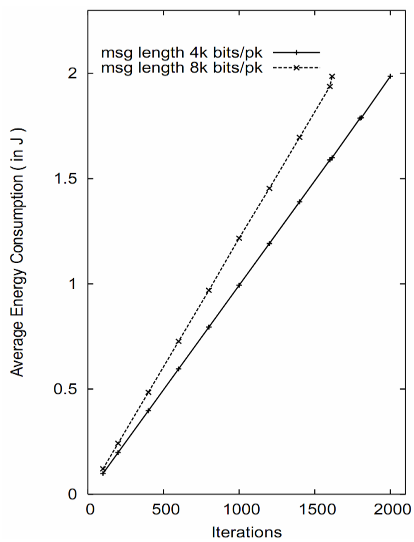

Figure 5. Average energy consumption (SLDHP) with variable size of the packet.

The plots in Figure 7 show the average energy consumption of the network with proposed algorithm run for two different message lengths. The simulation environment is set up with all the nodes equipped with a uniform initial energy of 2J. The node density is varied to account for scalability of the WSN and at the same time will aid in understanding the behaviour of the network especially in terms of energy management of the network for varying node densities. For comparatively lower value of node density, the average energy consumption of the network is smaller being a little less than 0.06J for a smaller message length, increasing steadily to about 0.09J for a node density of 100. In comparison, it is found that the energy consumption is relatively more for a larger sized message, varying from 0.078J for 40 nodes reaching a value of 0.12J for 100 nodes. This behavior is much the same as for a smaller message, the difference being that obviously more energy is consumed for a larger message size. As the number of nodes increase, the complexity of the network configuring phase also increases proportionately leading to an increased overhead on the sink to dynamically form load balanced hierarchical structures. The complexity of the data communication phase is no less, with more number of nodes being involved in data communications and with the complexity increasing with increasing nodes. The energy consumption of the network increases in proportion to the number of nodes and the same analogy holds good for

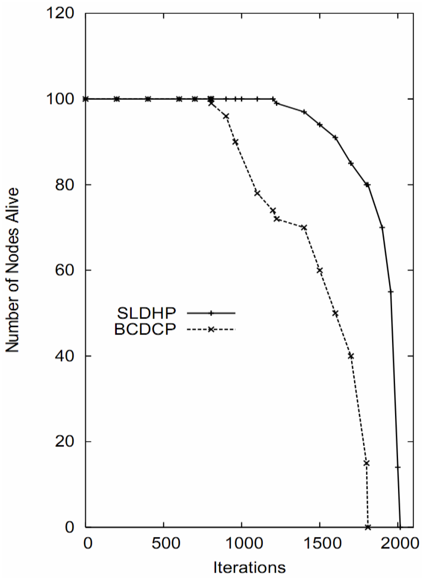

Figure 6. Comparison of lifespan of the wireless sensor network.

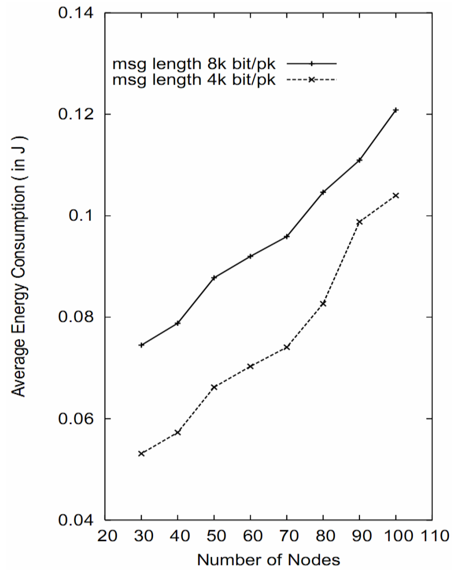

Figure 7. Average energy consumption (SLDHP) for different packet lengths.

different message lengths, the consumption being much more for larger sized messages.

6.5. Network Lifespan for Varying Size of Packet

Figure 8 shows another performance run when communications in SLDHP, take place by transmitting varying length messages of 4 kbits/packet and 8 kbits/packet. The simulations are carried out under similar conditions. As seen from the plot, when the message length is 4 kbits/packet, larger number of nodes are alive and the same is confirmed by the results obtained in Figure 6. When the message length is doubled, the saturation of the network takes place at a faster rate due to increased overhead on the sensor nodes and the principal nodes in particular. This manifests in nodes consuming larger energy, resulting in a larger transmission cost, leading to a shorter lifespan of the network. The smaller the message length, greater is the lifespan of the network with the number of live nodes prolonging the network lifespan to as long as the 2000th iteration. Till the 1400th iteration, the number of alive nodes in both cases seems exactly the same, but drops abruptly to zero at the 1635th iteration, for a larger message length. The reason for this is the same as described for Figure 6 and hence the same inference can be drawn here as well. Hence it is inferred that 4kbits/packet is apt for the present scenario.

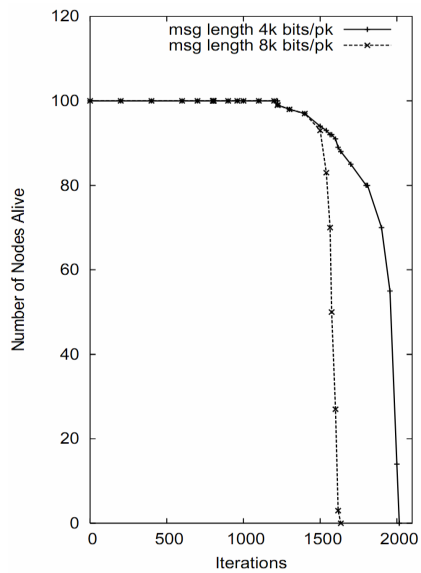

Figure 8. Lifespan of the wireless sensor network (SLDHP) with variable size of packet.

7. Conclusions

A WSN is composed of tens to thousands of sensor nodes which communicate through a wireless channel for information sharing and processing. The sensors can be deployed on a large scale for environmental monitoring and habitat study, for military surveillance, in emergent environments for search and rescue, in buildings for infrastructure health monitoring, in homes to realize a smart environment. SLDHP manages to balance the load on the principal nodes and hence the sensor nodes are relieved from the energy intensive tasks such as formation of hierarchy and scheduling of slots to send their sensed data. This job is effectively accomplished by the high powered sink. The simulation results indicate that the network lifetime is elevated to a large extent when compared to other hierarchical routing protocols. The future work includes applying our protocol to a distributed wireless sensor network and hence to improve the network performance as in present scenario.

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