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A Novel Power Efficient Routing Scheme for Wireless Sensor Networks

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Abstract— The nodes in a sensor network are severely constrained by energy. Reducing the energy consumption of the nodes to prolong the network lifetime is considered a critical challenge while designing a new routing protocol. In this paper we propose a new power-aware, adaptive, hierarchical and chain based protocol - CCPAR (Clustered Chain based Power Aware Routing) that utilizes the periodic assignments of the cluster head role to different nodes based on the highest residual battery capacity for ensuring the even dissipation of power by all the nodes. Transmission from a single cluster head to the base station in each round and the distribution of the data aggregation workload among all the nodes, save the cluster heads from early exhaustion. The use of data aggregation also reduces the amount of information to be transmitted to the base station. By chaining the nodes in each cluster and using a separate chain for the cluster heads, CCPAR offers the advantage of small transmit distances for most of the nodes and thus helps them to be operational for a longer period of time by conserving their limited energy. The simultaneous construction of multiple chains in different clusters reduces the time for chain construction as well as the length of each of the chains. These shorter length chains solve the problem of excessive delay in transmission for the distant nodes. Use of a fresh set of parameter values in each round provides the users the flexibility to change these values in a way to control the power consumption. The introduction of MAX threshold enables CCPAR to be quickly responsive and thus highly suitable for time critical applications. From the performance evaluation we observe that CCPAR outperforms other protocols in terms of energy saving and longevity of the network.

Index Terms-- Wireless sensor networks, power aware routing protocol, energy consumption, network lifetime, clustering, chaining, data aggregation

I. INTRODUCTION

The recent technological advancements in the field of micro electrical mechanical systems (MEMS) have made the manufacturing and use of small, low powered and moderate cost micro-sensors[1-5] both technically and economically feasible. A Wireless Sensor Network (WSN) [6-12] consists of hundreds to thousands of low-power multi-functioning sensor nodes, operating in an unattended environment, having capabilities of sensing, computation and communications. Basically, a sensor node is a micro-electro-mechanical system [MEMS] and it can sense the environment periodically, fuse data if required and broadcast data to some other node. Wireless Sensor Networks are used for monitoring and collecting information from an unattended environment and for reporting events to the user. They monitor physical or environmental conditions such as temperature, humidity, pressure, sound, vibration etc.

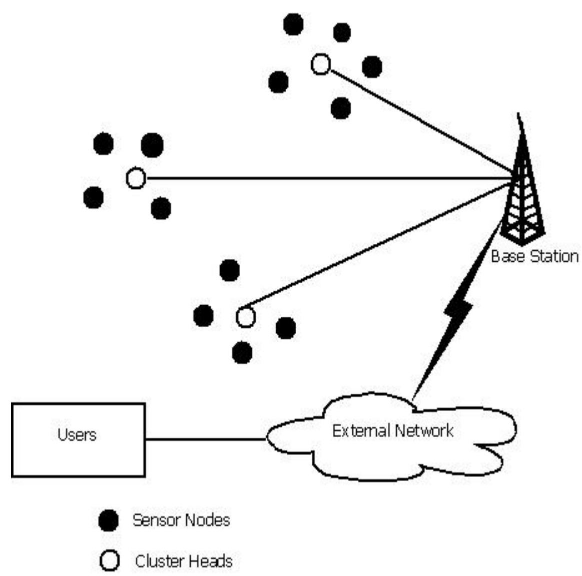

Figure 1 Wireless sensor network

Since a sensor node is limited in terms of sensing and computation capacities, communication performance and power - a large number of sensor nodes can be distributed over an area of interest for collecting information. The decrease in size and cost of the sensor nodes has made it possible to have a network of large number of sensor nodes, thereby increasing the reliability and accuracy of data as well as the area of coverage. Due to the low-cost deployment, the nodes are generally deployed with greater degree of connectivity. Such redundancy also increases the network fault tolerance as the failure of a single node has negligible impact on the entire network operation. These sensor nodes can communicate with each other either directly or through other nodes and thus form an autonomous intelligent network. The sensed information by the sensor nodes must be transmitted to a control center called the Base Station (BS) either directly or through other sensor nodes. The base station is fixed and located far away from the sensors. The base station can communicate with the end users either directly or through the existing wired network. In recent years wireless sensor networks have found widespread applications due the easy availability, ease of deployment, low cost and unattended nature of management. They are especially useful in sensing scenarios which are difficult to monitor directly by the human beings such as nuclear accident sites, disaster management, military surveillances in inhospitable terrain etc. Another potential area of use is security applications.

In wireless sensor networks the nodes are severely constrained by the amount of battery power available. Usually sensor networks are deployed in harsh physical environments where it is very difficult to replace the individual nodes or their batteries. Therefore, the preservation of the consumed energy plays an important role in the design of a new routing protocol in order to increase the longevity of the network. In this paper we propose a new power aware routing protocol - Clustered Chain based Power Aware Routing (CCPAR), which provides further reduction in power consumption and thereby increasing the lifespan of the network.

In our model of sensor network we have made the following assumptions

- The position of the base station is fixed and it is located far away form the sensors.
- All nodes in the network are homogeneous and energy constrained.
- No mobility of sensor nodes.

The rest of this paper is organized as follows. We discuss our proposed work in section 2. Section 3 presents the simulation and results. Finally in section 4 we conclude the paper.

II. PROPOSED SCHEME - CLUSTERED CHAIN BASED POWER AWARE ROUTING (CCPAR)

We propose a self-organizing, adaptive, hierarchical and chain based routing protocol - Clustered Chain based Power Aware Routing (CCPAR) that offers greater minimization of energy dissipation in sensor networks. Our wireless sensor network scenario consists of a base station which is located at a fixed position far away from the other nodes. It is the base station through which the external users interact and collect data about the environment sensed by the sensor nodes. The base station has constant source of power supply. It is, therefore, not constrained in terms of energy and can transmit with high power to all the nodes. We also assume that the base station has global knowledge about the entire network. All the nodes are homogeneous in terms of hardwire complexity and posses the same amount of initial energy.

Since sensor nodes can use their limited supply of energy for computations and data transmissions, energy-conserving forms of communication and computation are essential for Wireless Sensor Networks. Moreover, as WSNs consist of hundreds to thousands of sensor nodes, there is a possibility of huge number of transmissions within the network. Therefore, the routing protocol should be aware of these points. The proposed protocol can solve these problems. The key idea of CCPAR is to divide the whole network area into several clusters and select a cluster head for each cluster. Within each cluster a chain of sensor nodes is formed so that each node receives from and transmits to a close neighbour. This results in small transmit distances for most of the nodes and reduced power consumption for transmission. The chain is connected to the cluster head in each cluster. The gathered data move from node to node, get fused and eventually reach the cluster head. Each cluster head is also connected in a chain of cluster heads. Thus every cluster head needs to transmit data only to the next cluster head in the chain instead of transmitting to the far away base station. This reduces the transmit distances for the cluster heads and saves them from high energy transmission. The data gets aggregated and propagated along the chain of cluster heads. Ultimately in each round, instead of multiple cluster heads transmitting to the base station, only a single cluster head from the chain sends the aggregated data to the base station thus reducing both the number of transmissions as well as the amount of data to be transmitted. As computation is much cheaper than communication, this saves the cluster heads from quickly dying out and increases the overall network lifetime.

A. Radio Model [13][14]

In this protocol, we use the first order radio model of LEACH [13]. According to this model, a radio dissipates E_{elec} =50 nJ/bit to run the transmitter or receiver circuitry and for transmitter amplifier it dissipates ε_{amp}= 100 pJ/bit/m^2 .We consider an r^2 energy loss due to channel transmission [15, 16]. The following equations are used for calculating transmission costs and receiving costs for a k-bit message and a distance d.

For transmitting:-

$$E_{Tx}(k, d) = E_{Tx\text{-}elec}(k) + E_{Tx\text{-}amp}(k, d)$$
$$E_{Tx}(k, d) = E_{elec} * k + \varepsilon_{amp} * k * d^2$$

For receiving:-

$$E_{Rx}(k) = E_{Rx\text{-}elec}(k)$$
$$E_{Rx}(k) = E_{elec} * k$$

For these parameters receiving is also a high cost operation. Therefore, the focus should not only be on reducing the transmit distances but also be on minimizing the number of transmissions and receives. CCPAR achieves its energy efficiency by reducing the distance d, the number of transmit and receive operations as well as the amount of data to be transmitted and received. We also assume that the radio channel is symmetric in the sense that for a given signal to noise ratio, the required energy for transmitting a message from node x to node y is the same as the energy needed for transmitting a message from node y to x.

B. CCPAR – Algorithm Details

The total process for this protocol consists of a number of rounds. At the end of each round, data is sent to the base station. And then the base station transmits the required data to the users through external networks. Each round of this algorithm consists of the following phases.

1) *Cluster Formation, Cluster Head Selection and Chain of Cluster Heads Construction:* In our scheme the base station has global knowledge about the location of all the nodes in the network and, therefore, at the very first round it divides the whole area into a number of clusters in an attempt to uniformly distribute the nodes across all the clusters and to ensure the coverage of the whole of the deployed region. The base station then selects one node from each cluster as the cluster head. This initial selection is done depending on the proximity to the base station based on the assumption that at startup every node has the same energy level. After the selection of the cluster heads, the base station computes the chain of cluster heads and broadcasts this chain to the cluster head nodes.

2) *Chain Formation within Clusters and Schedule Set Up:* After the chain of cluster heads is formed, each cluster head node broadcasts the "cluster-head-declaration" message to other nodes in its corresponding cluster. In order to prevent any possible collision, CSMA MAC protocol is used by the cluster heads. Each non-cluster head node then selects its own cluster head on the basis of the signal strength of the received declaration message. This approach is followed because, assuming the propagation channel to be symmetric, a non-cluster head node will require minimum transmission power for communicating with that particular cluster head node, from which it receives the declaration message with the highest signal strength. In case of a tie, a random tie-break is applied. Once the non-cluster head node has selected its cluster head, it must inform its decision by transmitting back to the cluster head. This transmission is done using CSMA MAC protocol in order to avoid collision from other nodes.

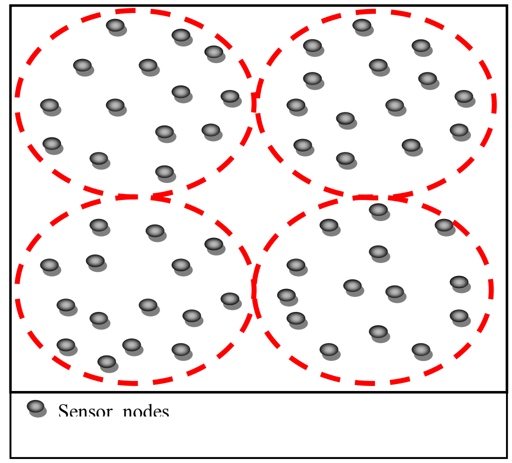

Figure 2 Clusters in CCPAR

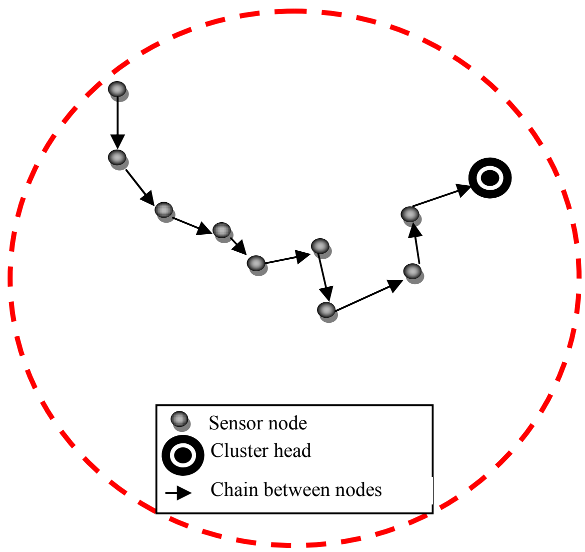

Figure 3 Chain of sensor nodes in a cluster

The cluster head node, after having received the responses from all the other nodes belonging to its corresponding cluster, computes the chain of non-cluster head nodes and broadcasts it to all the sensor nodes in its cluster. Once this chain construction within the cluster is complete, the cluster head node creates a TDMA schedule according to the number of nodes in its cluster. It then broadcasts the schedule to all the nodes in the chain thus instructing them to start the data transmission from one end of the chain and telling each node the time at which it can transmit.

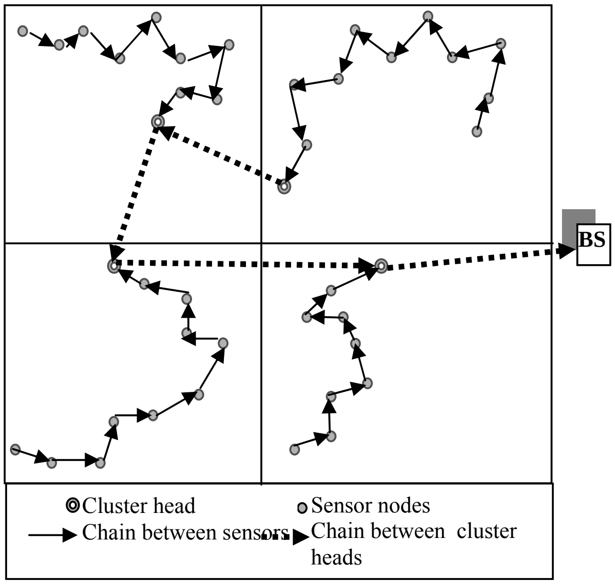

Figure 4 Network structure of CCPAR

3) *Data Transfer:* After the chain construction within the cluster is complete, each cluster head broadcasts the sensor nodes belonging to its cluster the following three parameters – MIN Threshold, MAX Threshold and Change Factor (CF). Each sensor node senses the environment continuously. If the sensed value is less than the MIN threshold in that case the node does not aggregate its sensed value with the one that it receives from its previous node in the chain. It directly transmits the received data from its previous node to the next node in the chain. MIN threshold thus saves the local sensor nodes from performing data aggregation function and in this way saves their precious battery power when the value of the sensed attribute does not fall in the range of interest of the user. The node behaves similarly if the sensed attribute value is equal to or greater than the MIN threshold and less than the MAX threshold but it changes by an amount that is less than the Change Factor (CF). The Change Factor (CF) thus also plays its role in reducing the amount of data to be aggregated and transmitted and thereby increasing the energy efficiency. In any of the previous two cases if a node does not receive any data from its previous node in the chain, then the node does not need to perform both data aggregation and data transmission. Thus in case of less frequent changes in the sensed attribute values, CCPAR is able to achieve a significant reduction in data aggregation and data transmission. This reduces a lot of energy consumption for the nodes. When the sensed value is equal to or greater than the MIN threshold but less than the MAX threshold and the change in the value of the attribute is equal to or greater than the Change Factor (CF), in that case the node aggregates its own data with the one received from its closest neighbour in the chain. Then it transmits the aggregated data to its next neighbour in the chain during its allocated transmission time according to the previously received TDMA schedule. The gathered data thus move from node to node along the chain of sensor nodes within the cluster, get fused and eventually reach the cluster head.

Each cluster head is also connected in another chain of cluster heads. Thus every cluster head does not need to transmit directly to the base station, which is at a greater distance. It fuses its data with the one received from its previous cluster head in the chain before forwarding it to next neighbour. Ultimately only a single cluster head, which is selected as the leader by the base station for the current round, transmits the data to the base station.

Thus in normal cases the sensed data has to wait for the scheduled transmission time of a node to get transmitted. But this delay in transmission is intolerable in case of time critical data which needs to be sent urgently to the base station. Hence, for time critical applications an alternate approach is taken. Here we introduce the concept of MAX threshold. When the sensed data value is less than the MAX threshold the normal approach is taken. But when it is equal to or greater than the Max threshold – the sensor node immediately sends the data directly to the corresponding cluster head. This then sends it directly to the base station. Thus the use of MAX threshold enables us to reduce the transmission delay in case of critical data.

At the end of each round, every node sends the information about its remaining energy level to the next node in the chain, and ultimately this information reaches the cluster head of each cluster. Every cluster head then forwards the information aggregated with the information regarding its own remaining energy level, along the chain of cluster heads to the base station. Having this information the base station can select the cluster heads for the next round based on the maximum remaining energy level of the nodes in each cluster and based on their proximity to the base station. The base station then informs its decision to the cluster heads. Once the cluster heads are selected, the base station can compute the chain of cluster heads and select the leader in that chain for the next round depending on the remaining energy level so that the cluster head with the duty of transmission to the base station is the one with the highest remaining energy level. After this the base station broadcasts this chain to the cluster heads and then the further steps are repeated for the next round.

III. Simulation and Results

We have carried out our simulations using OMNeT++ v3.2 [17] simulation tool with the mobility framework. OMNeT++ is an object-oriented modular discrete event network simulator. In order to evaluate the protocols, we have set up a simulation environment consisting of 100 sensor nodes deployed randomly over a 100mX100m square area. The base station is fixed at (50,150) position and its distance to the closest node is 50 meters. It is also assumed that all the nodes begin with the same initial energy of .5 Joules. The transmission and receiving costs are calculated according to the transmission and receiving formulas of the radio model. The nodes dissipate their energy during the course of the simulation for transmission and reception. As the nodes have limited energy, they will exhaust their energy source after a certain time. A node is considered dead and therefore, becomes unable to transmit or receive for the rest of the simulation, once it runs out of energy.

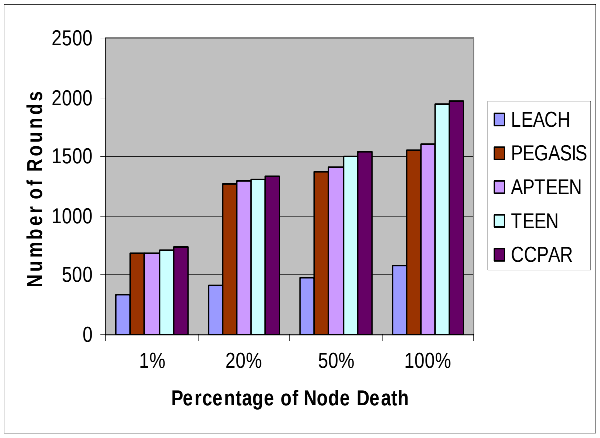

Figure 5 Performance results for percentage of node death Vs. number of rounds

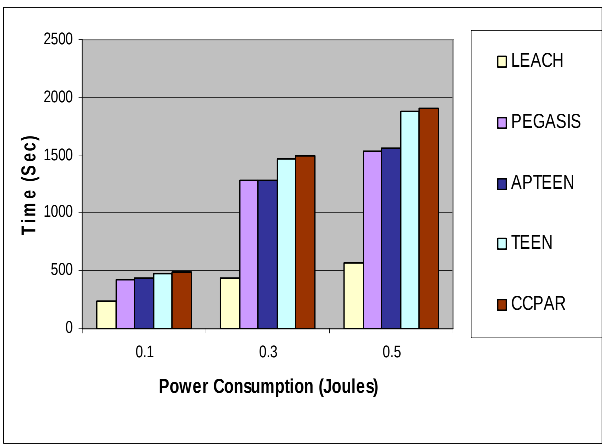

Figure 6 Performance results for power consumption Vs. time

In our simulation scenario the sensor nodes sense the varying temperatures in different regions. We have divided the entire simulation area into four quadrants. During each simulation run, each quadrant is assigned a random temperature between 0 degree Fahrenheit and 100 degree Fahrenheit every 5 seconds. For our experiment the MIN threshold is chosen to be 30 degree Fahrenheit and the MAX threshold is set at 70 degree Fahrenheit. The Change Factor (CF) is assigned the value of 3 degree Fahrenheit.

We have compared the performance of the protocols on the basis of two parameters – percentage of node death and power consumption. The first parameter gives an idea of the overall lifetime of the network whereas the second parameter indicates the average energy dissipation per node over time as it performs various activities such as transmitting, receiving, sensing the environment, data aggregation etc.

From Fig. 5 and Fig. 6 we see that CCPAR outperforms other protocols in terms of both the longevity of the network and energy saving. The reduced power consumption of CCPAR is mainly due to the small transmit distances of most of the nodes as they need to transmit only to their closest neighbours in the chain instead of transmitting directly to the far away base station or cluster head, which was the case with LEACH [13], TEEN [18] and APTEEN [19]. Moreover, the concept of the chain of cluster heads relieves the cluster heads from the high power transmission to the base station as they need to transmit only to their next neighbour in the chain. And in each round, instead of multiple cluster heads transmitting directly to the distant base station, only one cluster head chosen according to the highest residual energy, takes the responsibility of this high power transmission. This helps the nodes in saving their energy which ultimately enhances the system lifetime.

CCPAR also relieves the sensor nodes from the workload related to cluster head selection as it is now the responsibility of the base station. The significant decrease in the number of data packets to be received by the cluster head and the even distribution of the data aggregation workload among all the sensor nodes in the cluster, help the cluster head in conserving its power and thereby increasing its lifetime. Instead of a single node acting as the cluster head for the entire duration and thus ending up its energy source quickly, in CCPAR the role of cluster head is assigned periodically to the different nodes based on the highest residual energy contained by a node. This ensures the even dissipation of power by all the nodes and therefore, increases their lifetime. In addition to that, the periodic assignment of the cluster head role also saves the nodes closest to the cluster head from early dying out due to the heavy burden of data aggregation and data transmission, as all the nodes now share this responsibility periodically. Our scheme also offers superior performance than PEGASIS [14]. This is attributed to the fact that multiple chains are constructed parallely in CCPAR which causes the chains to have smaller length than the single chain in PEGASIS. This reduces the amount of data to be aggregated and propagated along the chain which results in more savings in the power consumption of the nodes. The introduction of the concept of MIN threshold and Change Factor (CF) in CCPAR also helps in reducing the amount of data to be aggregated and transmitted when the sensed attribute value is not in the range of interest of the user or if there is little or no change in the sensed value. This further helps the nodes in retaining their power for a longer duration which ultimately increases the overall network lifetime.

From Fig. 6 we also note that the power consumption increases with time. This is due to the fact that as time passes, nodes in the chain die. Consequently, the distance between two successive nodes in the chain also increases. This requires the nodes to spend higher energy to transmit the data packets along this greater transmission distance to the next node in the chain.

IV. CONCLUSIONS

In this paper we have proposed a new power aware routing scheme – Clustered Chain based Power Aware Routing (CCPAR) which is a hierarchical clustered chain based scheme that provides greater reduction in power consumption and therefore, increased lifespan of the entire network. The basic idea of our scheme is that the nodes within a cluster are connected in a chain and each node receives from and transmits to the closest neighbours in the chain. The data thus move from node to node, get aggregated and ultimately reach the cluster head. A separate chain is also constructed which connects the cluster heads. Each cluster head thus transmits the data only to its next neighbour in this chain and in each round, instead of every cluster head transmitting to the base station only a single cluster head is selected on the basis of the highest residual energy to send the data to the base station.

CCPAR outperforms other protocols by providing advantages over them in several stages. The use of multi-tier architecture enables this scheme to cover a wider network area thus making it suitable for sensor networks deployed over larger region. The assignment of the cluster head selection function solely on the base station coupled with the small transmit distances for most of the nodes, help the local sensors in saving their constrained energy resources. The use of the chain between the cluster heads and the transmission from a single cluster head to the base station in each round save the cluster heads from the high energy transmissions to the distant base stations. This, together with the even distribution of the data aggregation workload between all the local sensor nodes and the significant decrease in the number of data packets to be received by the cluster heads, protect the cluster heads from quickly dying out. In addition to that, the periodic assignment of the cluster head role to different nodes based on the highest residual energy also ensures the even dissipation of power by all the nodes. This effectively increases the longevity of the network. CCPAR offers superior performance over PEGASIS by constructing several short chains in different clusters and thus solving the problem of excessive delay in transmission experienced by the distant nodes in the chain due to the greater length of the single chain. Simultaneous formation of the multiple chains in different clusters also reduces the time for chain construction phase. The use of MIN threshold and Change Factor (CF) increases the energy efficiency of the nodes by reducing the amount of data to be aggregated and transmitted when the sensed attribute value is not in the range of interest of the user or if there is little or no change in the sensed value. The introduction of MAX threshold makes this scheme highly responsive and therefore well suited for time critical applications. By allowing the users to set a fresh set of values for the parameters in each round, CCPAR provides the users the flexibility to change these values in a way to control the power consumption. Based on the simulation results it is evident that CCPAR outperforms other protocols by providing greater energy conservation and increased system lifetime, which makes it more suitable for wireless sensor networks.

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