Clustered Chain based Power Aware Routing (CCPAR) Scheme for Wireless Sensor Networks

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***Abstract*—Wireless sensor networks with thousands of tiny sensor nodes are becoming immensely popular due to their wide applicability in multitude of applications such as monitoring and collecting data from unattended hazardous environments, emergency rescue operations, military surveillances in inhospitable terrains etc. But 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.** *(Abstract)*

Keywords- Wireless sensor networks, power aware routing protocol, energy consumption, network lifetime, clustering, chaining, data aggregation (key words)

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. The basic components [13] of a node are the sensor unit, ADC (Analog to Digital Converter), CPU (Central Processing Unit), a communication unit and an energy source, usually a battery. The sensor unit is responsible for collecting the required data from the area of interest. ADC converts the data collected by the sensor to digital form and CPU processes data according to requirement. The last unit i.e. communication unit transmits data to another node.

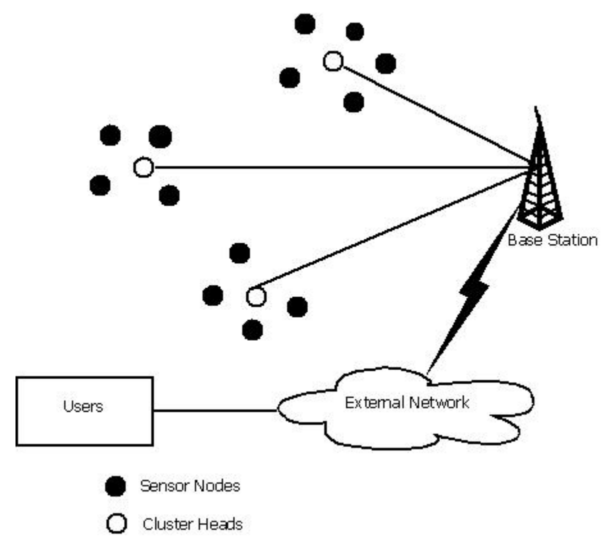

Figure 1. Wireless sensor network

Basically, a sensor node is a micro-electro-mechanical system [MEMS] [14] 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.

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.

There are different routing techniques for sending the data between the sensor nodes and the base stations. A very critical constraint related to the sensor nodes is their limited energy resources. Therefore, these routing schemes must be aware of this limited energy resource and should reduce the data transmissions among the nodes in order to reduce the energy dissipation and to increase the lifetime of the whole network. Different routing protocols [14] have been proposed for the wireless sensor networks and these protocols can be classified depending on several parameters. The protocols can be categorized as *proactive*, *reactive* and *hybrid* based on their mode of functioning. In proactive protocols the nodes switch on their sensors and transmitters, sense the environment and transmit the data to BS according to the predefined schedule. LEACH[15] (Low Energy Adaptive Clustering hierarchy) belongs to this type of protocols. In case of reactive protocols if there are sudden changes in the sensed attribute value beyond a pre-determined threshold, the nodes immediately react. This type of protocol is expended in time critical applications. TEEN [16] (Threshold sensitive Energy Efficient sensor Network) is an example of a reactive protocol. Hybrid protocols combine both the proactive and the reactive approaches. They are both periodic and event driven. APTEEN [17] (Adaptive Periodic TEEN) protocol employs hybrid approach.

Further, depending on the network structure, protocols can be classified as *flat*, *hierarchical*, *data centric* and *location based*. In flat routing all the nodes share the same functionality. They work together in order to perform the sensing and routing activities. Directed Diffusion [18-21] is an example of this category of protocols. Hierarchical routing is used to perform energy efficient routing i.e. higher energy nodes can be used to process and send the information; low energy nodes are used to perform the sensing of the area of interest. LEACH, TEEN, APTEEN fall in this category. Data centric protocols are query based and they depend on the naming of the desired data, thus eliminating much redundant transmissions. The BS sends queries to a certain area for information and waits for reply from the nodes of that particular region. Since data are requested through queries, attribute based naming is required to specify the properties of the data. Depending on the query, sensors collect a particular data from the area of interest and only this particular information is required to be transmitted to the BS, thus reducing the number of transmissions. SPIN [10, 22] is the first data centric protocol. Location based routing protocols [14, 23-27] need location information of the sensor nodes. Location information can be obtained from the GPS (Global Positioning System) signals, received radio signal strength etc. Using location information, an optimal path can be formed without using flooding technique. GEAR [28], GPSR [29] are examples of location based routing protocols.

Transmission protocols can also be categorized according to the transmission mechanism as direct transmission, multi-hop transmission and clustering. In case of direct transmission protocols, in each round every sensor node collects the data and sends it directly to the base station which may be located far away from the sensor nodes. This is the easiest approach. But as the transmission power attenuation of a wireless link is proportional to the square or even higher order of the distance between the source and the destination, direct transmission consumes a significant amount of transmission power form each node. With limited amount of battery power, the nodes are drained out of their energy resources and die quickly. This reduces the system lifetime. This approach provides the best result when the sensor nodes are very close to the base station or when the cost of receiving data is very high compared to the cost of transmitting data. In case of multi-hop transmission protocols [30-34] the sensor nodes send their data to the base station through intermediate nodes. Thus the nodes perform the activity of both sensing and routing data for other nodes. Here the transmission distance is reduced in comparison to the direct approach, as the nodes need to transmit only to their nearest neighbours. The decrease in the transmission distance also reduces the consumption of the transmission power from the nodes. This is a huge improvement as it saves the nodes from quickly dying out and increases the system lifetime. The multi-hop transmission consumes less energy than the direct transmission when the nodes are scattered randomly over the area of interest. However, multi-hop communication introduces significant overhead for the nodes that are closest to the base station as they need to route a large number of data packets from other nodes to the base station. Thus these nodes will die soon causing increase in the energy requirement to send the future data to the base station and more nodes to die. This cascading effect will ultimately shorten the network lifetime. Moreover, the area in which the nodes die can no longer be monitored.

In sensor networks the sensed data need to flow from multiple regions to a particular base station. Sometimes multiple sensor nodes which are in the vicinity of a particular event may generate the same data. This results in significant data redundancy. Using data aggregation [35, 36] similar packets from multiple nodes can be aggregated thus reducing the amount of data traffic to be transmitted. Recognizing the fact that computation is less energy consuming than communication, this results in reduction of the latency and power dissipation of the network.

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. Section 2 briefly investigates the related research work. We discuss our proposed work in section 3. Section 4 presents the simulation and results. Finally in section 5 we conclude the paper.

II. Related Work

In this section we provide a brief overview of some of the related research works.

A. *LEACH [15]: Low-Energy Adaptive Clustering Hierarchy*

LEACH [15] is a self-organizing, adaptive, cluster-based protocol and includes distributed cluster formation. LEACH uses periodic randomized rotation of cluster heads in order to evenly distribute the energy load among all the sensors in the network. The cluster head nodes compress the data arriving from the nodes belonging to the corresponding subordinate clusters and send the aggregated packet to the base station in an attempt to reduce the amount of information to be transmitted. This further reduces energy dissipation and enhances system lifetime. A TDMA/CDMA MAC is used for avoiding the inter-cluster and intra-cluster collisions. In LEACH data collection is centralized and performed periodically. Hence, this protocol is most appropriate when there is a need to constantly monitor the environment. The total operation of LEACH consists of a number of rounds. Each round again has two phases: setup phase followed by the steady-state phase. In the setup phase, the clusters are formed and the cluster-heads are selected. In the steady-state phase the actual data transmission to the base station occurs. The steady-state phase is longer than the setup phase for minimizing the overhead.

1) Setup Phase: Initially after the formation of the clusters, each node decides independent of others whether or not to become a cluster-head for the current round. This decision is based on the suggested percentage of cluster heads for the network (previously determined) and the number of times the node has already been a cluster head. A sensor node chooses a random number r, between 0 and 1. If the random number is less than a threshold value T(n) , the node becomes a cluster head for the current round. The threshold value T(n) is determined by the following expression:

$$T(n) = \begin{cases} \dfrac{P}{1 - p\left(rMOD\ \dfrac{1}{P}\right)} & \text{if } n \in G \\ = 0 & \text{otherwise,} \end{cases}$$

where P = the desired percentage of cluster heads, r = the current round and G is the set of nodes that have not been cluster heads in the last 1/P rounds.

Each elected cluster head then broadcasts an advertisement message to the whole network using CSMA MAC protocol. The non-cluster head nodes receive the broadcast message and take decisions on the cluster to which they want to belong to in the current round on the basis of the signal strength of the received advertisement. Each non-cluster head node then transmits this decision back to their corresponding cluster heads by using CSMA MAC protocol. After receiving all the replies from the nodes that would like to be included in the cluster and depending on the number of nodes in the cluster, the cluster-head node creates a TDMA schedule and allocates each node a time slot when it can transmit. This schedule is then broadcast back to all the nodes in the corresponding cluster.

2) Steady-state Phase: During the steady-state phase, the non-cluster head nodes sense the environment and transmit the sensed data to their cluster head according to their allotted schedule. After getting data from the sensor nodes in its own cluster, the cluster head aggregates it before transmitting to the base station. Since the base station is located far way, this is a high energy transmission. After a certain time (predetermined) interval, the next round begins to select a new set of cluster heads so as to rotate the role of the cluster head among the nodes for even distribution of power dissipation. Each cluster uses different CDMA spreading codes for communication to avoid interference from nodes of other clusters.

LEACH assumes that depending on the need all nodes can transmit with enough power to reach the base station and relies on this direct reachability to function correctly. As a consequence, it can not be applied to networks deployed in large regions.

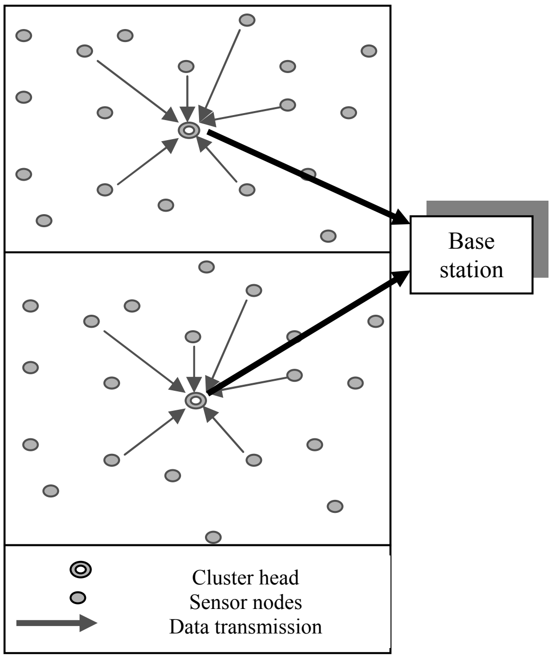

Figure 2. LEACH protocol

B. PEGASIS [37]: Power Efficient GAthering in Sensor Information Systems

PEGASIS [37] is a near optimal chain based power efficient protocol based on LEACH. The idea of cluster formation and cluster head selection is not used in PEGASIS. The key idea here is to construct a chain among the sensor nodes so that each node receives from and transmits only to the closest neighbors. Each node determines the distance to its neighbors using the signal strength and then adjusts the signal strength to communicate only with the closest neighbor. Collected data moves across the nodes, gets aggregated at each node, and eventually, a single designated node transmits to the base station. Nodes take turns in transmitting to the base station so that the power dissipation for communicating with the base station is distributed uniformly over all the nodes. Further improvement in power saving and as a result greater increase in network lifetime is achieved as only one node transmits to the base station per round instead of multiple nodes and as each node in the chain needs to transmit only to the local neighbor. In PEGASIS the chain construction is done in greedy fashion with the assumption that all the nodes have global knowledge of the network. The leader in each round of communication is selected from a random location in the chain. This causes nodes to die at random positions in the chain which is important to make the sensor network robust to failure. In each round, a simple control token passing is initiated by the leader to start the data transmission form the ends of the chain. The cost is very small due to the small token size. In PEGASIS data fusion is performed at each node except the terminal nodes in the chain. In Figure 3, node n2 is the leader and it passes the token along the chain to node n0. Node n0 passes its data to node n1. Node n1 fuses its data with that of node n0 and then transmits it to the leader n2. Node n2 now passes the token to the other end of the chain to node n4. Now in a similar way data of node n4 and n3 comes to the leader n2. n2 waits to receive data from its two neighbors, fuses its own data with that of the neighbors and finally transmits one message to the base station.

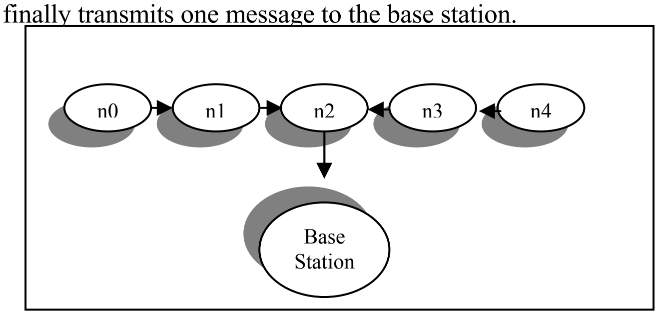

Figure 3. Chaining and token passing in PEGASIS

PEGASIS outperforms LEACH in energy saving in several ways. First, as most of the nodes need to transmit only to their local neighbors, the transmission distance is reduced in comparison to transmitting to the cluster head in LEACH. Second, the number of messages for the leader to receive is at most two in comparison to the cluster head receiving a large number of messages from the non-cluster head nodes of its cluster in LEACH. Finally, unlike multiple cluster heads transmitting to the base station, in PEGASIS only one node needs to transmit to the base station in each round.

In dense scenarios the chain may be long enough and in that case PEGASIS introduces excessive delay in data transmission for the distant nodes in the chain. The single leader in the chain can also become a bottleneck.

C. SPIN [10, 22] : Sensor Protocols for Information via Negotiation

Sensor Protocols for Information via Negotiation (SPIN) [10, 22] is a family of adaptive protocols and these protocols use data negotiation and resource-adaptive algorithms. SPIN is a data centric routing protocol. The key idea behind SPIN is to name the data using high-level descriptors or meta-data. The focus is on efficient dissemination of information among sensor nodes in an energy-constrained manner assuming all the sensor nodes as potential sinks. Before transmission, meta-data are exchanged between sensor nodes (meta-data negotiation) via a data advertisement procedure and thus avoiding transmission of redundant data in the network. After receiving the data each node advertises it to its neighbors and interested neighbors get this data by sending a request message. The format of this meta-data is not specified in SPIN and is assumed to be application specific as each application's meta-data format may be different. The storage, retrieval and general management of the meta-data incurs a certain cost. But the advantage of having succinct representation for the large data messages far outweighs these costs. SPIN uses three types of messages: ADV, REQ and DATA for communication with each other.

ADV is used for advertising new data, REQ is used for requesting the specific data and DATA is the actual message.

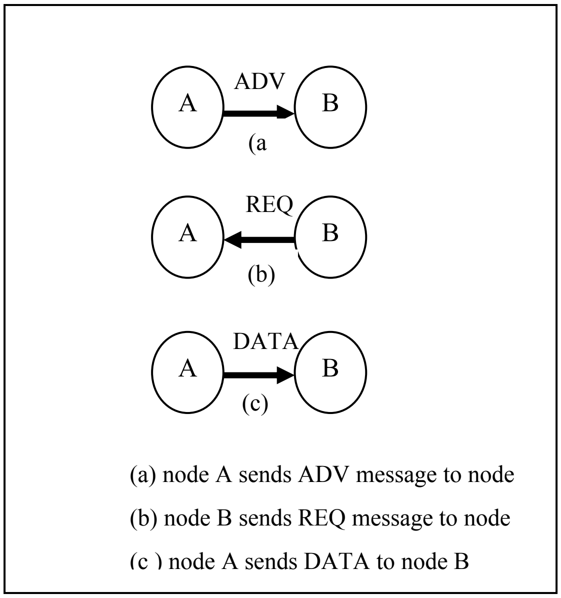

Figure 4. Data transmission in SPIN

SPIN protocol works in three stages (ADV-REQ-DATA). According to this protocol first a node gets a new data and if the node wants to distribute that data, it broadcasts an ADV message containing meta-data to its neighbors. The interested neighbors request for that data by sending a REQ message and then the DATA is sent to the requested nodes. DATA messages contain actual data with a meta-data header. The neighbor node repeats this process with its neighbors and the process continues until the entire network gets the new data.

In SPIN one of the main advantages is that topological changes are localized as each node needs to know only its one-hop neighbors. SPIN is more energy efficient than flooding and meta-data negotiation almost halves the redundant data. However, SPIN's data advertisement procedure cannot guarantee the delivery of data. For instance, if the interested nodes are located far away from the source node, and the nodes residing in the area between the source and destination are not interested in the data, in that case such data can not be delivered to the destination at all. Therefore, SPIN is not an appropriate choice for applications like intrusion detection, where the reliable delivery of data over periodic interval is a major concern.

III. Proposed Work - 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 possess 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 neighbor. 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 [15][37]

In this protocol, we use the first order radio model of LEACH [15]. 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 [38, 39]. The following equations are used for calculating transmission costs and receiving costs for a k-bit message and a distance d.

For transmitting:-

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

$E_{Tx}(k, d) = E_{elec} * k + \varepsilon_{amp} * k * d2$

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*

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.

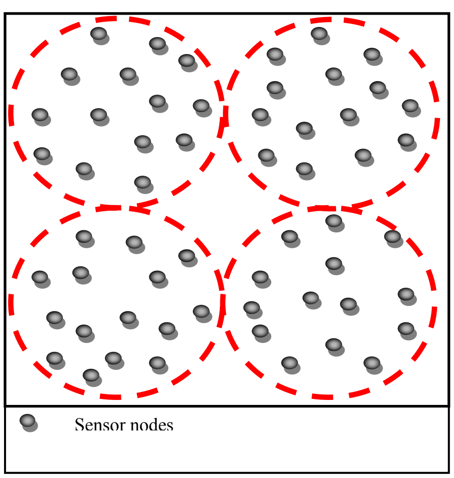

Figure 5. Clusters in CCPAR

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.

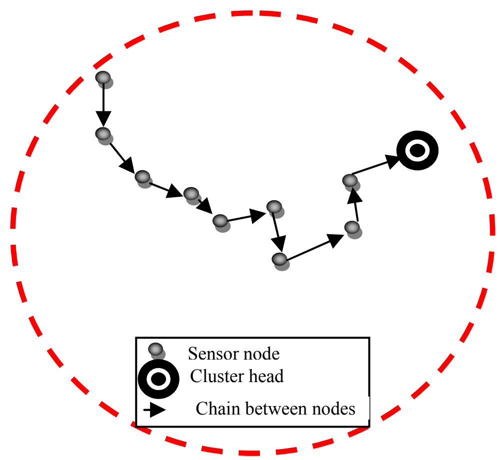

Figure 6. Chain of sensor nodes in a Cluster

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.

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 neighbor in the chain. Then it transmits the aggregated data to its next neighbor 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.

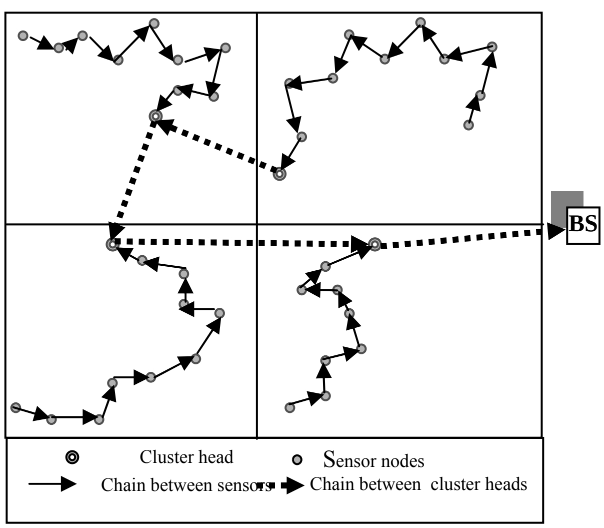

Figure 7. Network structure of CCPAR

Each cluster head is also connected in another chain of cluster heads. So, 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 neighbor. 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. Hence, the use of MAX threshold enables us to reduce the transmission delay in case of critical data.

At the end of each round i.e. at the end of a certain periodic interval, 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.

This scheme is advantageous over LEACH in terms of cluster head selection. This is due to the fact that in LEACH, during every round each node needs to take part in the cluster head selection process. Thus every node has to bear the overhead of computing a random number and threshold value. In our scheme the sensor nodes are relieved from this workload of computation related to the cluster head selection. It is now the responsibility of the base station to select the cluster heads based on the highest remaining energy level of the nodes. This approach thus saves the battery power of the sensor nodes and increases their lifetime. In LEACH, during each round every node needs to send its data to its corresponding cluster head which may be at a significant distance, thus causing the nodes to loose a considerable amount of battery power. Also, every cluster head node needs to transmit to the far away base station in each round. As the transmission power attenuation of a wireless link is proportional to the square or even higher order of the distance between the source and the destination, this causes the cluster heads a significant amount of energy loss and results in their quick death. In CCPAR on the contrary, the sensor nodes need not transmit either to the base station or to the cluster head directly. Each of them needs to communicate only to its closest next neighbor in the chain. This advantage of small transmit distances for most of the nodes helps them to conserve their limited energy and thus increases the network lifetime. This is especially true in case of a dense network. Moreover, in each round every cluster head node does not need to transmit directly to the base station which may be at a greater distance. It only transmits to the next cluster head in the chain. Ultimately only a single cluster head node in each round needs to transmit to the base station. This saves most of the cluster heads from the high power transmissions to the distant base station and protects them from early exhaustion. In LEACH each cluster head node has to collect a large number of data packets from all the nodes residing within the cluster. The number of data packets for the cluster head to receive is reduced significantly in CCPAR, as it receives only one data packet from its closest neighbor in the chain of local sensor nodes. Moreover, in this scheme as the data propagates along the chain of non-cluster head nodes, data aggregation function takes place at the individual nodes. This even distribution of the data aggregation workload among all the nodes from the cluster helps the cluster head in preserving its power and protects it from dying out fast. This also saves the local sensors. This is due to the fact that the death of the cluster head makes the other nodes from that particular cluster essentially ineffective as they have no other way to send their data to the base station. In case of static clustering once the nodes are selected as cluster heads, they will remain so for the rest of their life time. But as cluster heads they need to handle the extra load of transmission to the remote base station. These high power transmissions exhaust the cluster heads before other nodes. Once a cluster head in a particular cluster dies, it also makes other nodes from that cluster non-functional, as they have no other way to send their data to the base station. Consequently a portion of the network dies premature death. For longer network lifetime, it is, however, desirable that all the nodes exhaust their energy at the same rate. One way to ensure this is to distribute the load of power dissipation evenly among all the nodes. In our scheme we have been able to achieve this by periodically assigning the role of the cluster head to the different nodes based on the highest residual energy of a node. This strategy is based on the assumption that all the nodes are identical in terms of initial energy level and hardwire capability. As all the nodes are capable of serving as cluster heads, hence, even if a few nodes die, it will not bring down the functionality of the entire network. In this way our scheme makes the entire network more reliable and robust to node failures. The node which is closest to the cluster head in the chain within each cluster has the highest burden of data aggregation and relaying data to the cluster head. The periodic assignment of the responsibility of the cluster head to different nodes based on the highest residual energy level also saves the nodes in the chain from early die-out, as all the nodes in a cluster are equally likely to share this responsibility.

This scheme also offers certain advantages over PEGASIS. In PEGASIS only one chain is created for all the nodes in the entire network area. As a result the chain becomes longer and the nodes which are near the end of the chain experience excessive delay in transmitting their data to the base station. Unlike PEGASIS, in CCPAR the entire workload is distributed among the different clusters and a separate chain is constructed in each cluster. Consequently, each chain will be of much smaller length than the single chain constructed in PEGASIS. The smaller length of each chain in CCPAR solves the problem of excessive delay experienced by the distant nodes in the chain. Also due to the greater length of the chain, the chain construction process takes a significant amount of time in PEGASIS. In contrast, multiple chain construction processes proceed simultaneously within different clusters in CCPAR. Hence the length of chain construction and consequently the time required for each round will be reduced too.

The introduction of the concept of MAX threshold makes this scheme quickly responsive and thus extremely suitable for time critical applications. For non-critical data the concept of MIN threshold and Change Factor (CF) plays an important role in enhancing the energy efficiency of the nodes and thereby increasing the system lifetime. The use of MIN threshold helps the nodes in saving their limited energy resources by relieving them from performing data aggregation function when the sensed attribute value is not in the range of interest of the user. The Change Factor (CF) further enhances the energy efficiency of the nodes by reducing the amount of data to be aggregated and transmitted when there is little or no change in the value of the sensed attribute. The value of the Change Factor (CF) can be varied depending upon the user choice. A smaller value of the Change Factor (CF) gives the user a more complete and accurate picture of the scenario at the expense of increased energy dissipation. Thus CCPAR enables the user to control the trade off between energy efficiency and data accuracy. In CCPAR after the completion of the chain construction phase within each cluster in every round, a fresh set of parameters including MIN threshold, MAX threshold and Change Factor (CF) are broadcast to every sensor node by the cluster head. Therefore, this scheme provides the users the flexibility to change these values as required and thus gives them the power to control the energy consumption.

IV. SIMULATION AND RESULTS

We have carried out our simulations using OMNeT++ v3.2 [40] 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.

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.

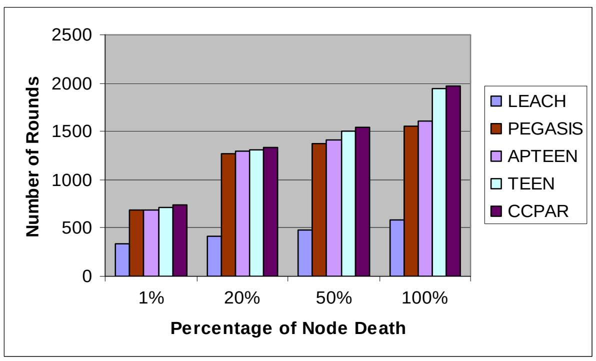

Figure 8. Performance results for percentage of node death Vs. number of rounds

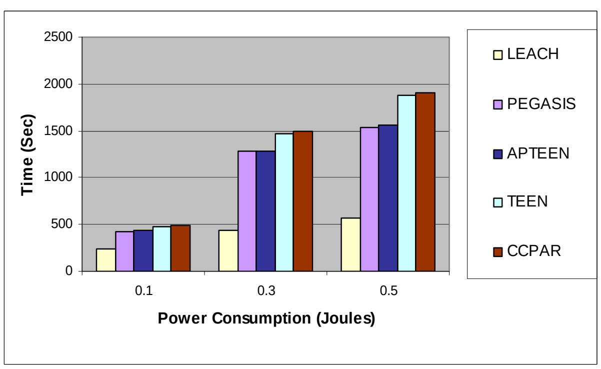

Figure 9. Performance results for power consumption Vs. time

From Figure 8 and Figure 9 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 neighbors in the chain instead of transmitting directly to the far away base station or cluster head, which was the case with LEACH, TEEN and APTEEN. 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 neighbor 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 dying out early 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. 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 Figure 9 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.

V. CONCLUSIONS

In this paper first we have discussed some of the existing routing protocols for the wireless sensor networks and then 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 neighbors 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 neighbor 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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