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Energy Efficient APTEEN Routing Algorithm for increasing the Network Lifespan of MANETs

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Abstract: A Wireless sensor networks is a specialized wireless network made up of large number of tiny sensor nodes and at least one base station. The primary difference between WSN and the traditional wireless networks is that sensors are extremely sensitive to energy consumption. Energy saving in the crucial issue in designing the wireless sensor networks. Since the radio transmission and response consumes more energy, one of the most or the main significant issue in wireless sensor network is the inherent limited battery power within network sensor nodes. The energy constraint of WSNs make energy saving become the most important objective of various routing algorithms. Routing algorithms for WSNs are responsible for selecting and maintaining the routes in the network and ensure reliable and effective communication in limited periods. In this paper, we propose a hybrid routing protocol (APTEEN) which allows for comprehensive information retrieval. The nodes in such a network not only react to time-critical situations, but also give an overall picture of the network at periodic intervals in a very energy efficient manner. Such a network enables the user to request past, present and future data from the network in the form of historical, one-time and persistent queries respectively. We evaluated the performance of these protocols and observe that these protocols are observed to outperform existing protocols in terms of energy consumption and longevity of the network.

Keywords: Energy consumption, Wireless Sensor Networks, Routing Protocols, energy efficiency, Network life time, sensor.

I. INTRODUCTION

Mobile Ad Hoc Networks (MANETs) are wireless networks that offer multi-hop connectivity between self-configuring and self-organizing mobile hosts. A MANET environment is characterized by energy-limited nodes (mobile hosts), band width – constrained, variable-capacity wireless links and dynamic topology, leading to frequent and unpredictable connectivity changes. The advancement in sensor technology has made it possible to have tremendously small, low powered sensing devices equipped with programmable computing, multiple parameter sensing and wireless communication capability. Also, the low cost makes it possible to have a network of hundreds or thousands of these sensors, thereby enhancing the reliability and accuracy of data and the area coverage. Wireless sensor networks offer information about remote structures, wide-spread environmental changes, etc. in unknown and inhospitable environments. There are a number of advantages of wireless sensor networks over wired ones such as ease of deployment (reducing installation cost), extended range (network of tiny sensors can be distributed over a wider region), fault-tolerance(failure of one node does not affect the network operation),self-organization (the nodes can have the capability to reconfigure themselves) But there are a few inherent limitations of wireless media such as low bandwidth, error prone transmissions, collision free channel access requirements etc. Also, since the wireless nodes are mostly mobile and are not connected in any way to a constant power supply, they derive energy from a personal battery. These limits the amount of energy available to the nodes. In addition, since these sensor nodes are deployed in places where it is difficult to either replace

individual nodes or their batteries, it is desirable to increase the longevity of the network and preferable that all the nodes die together so that the whole area could be replaced by a new set of sensor nodes. Finding individual dead nodes and then replacing those nodes selectively would require pre-planned deployment and eliminate some advantages of these networks. sensor nodes that may sense the environment or surroundings and gather the knowledge from the observance field and communicate through wireless links; the information collected is forwarded, via multiple hops relaying to a sink (also referred to as controller or monitor) that may use it internally, or is connected to alternative networks. Every of those distributed sensor nodes has the capabilities to gather information and route information back to the sink and also the end users. A model of such a sensor network, is shown in Figure1.
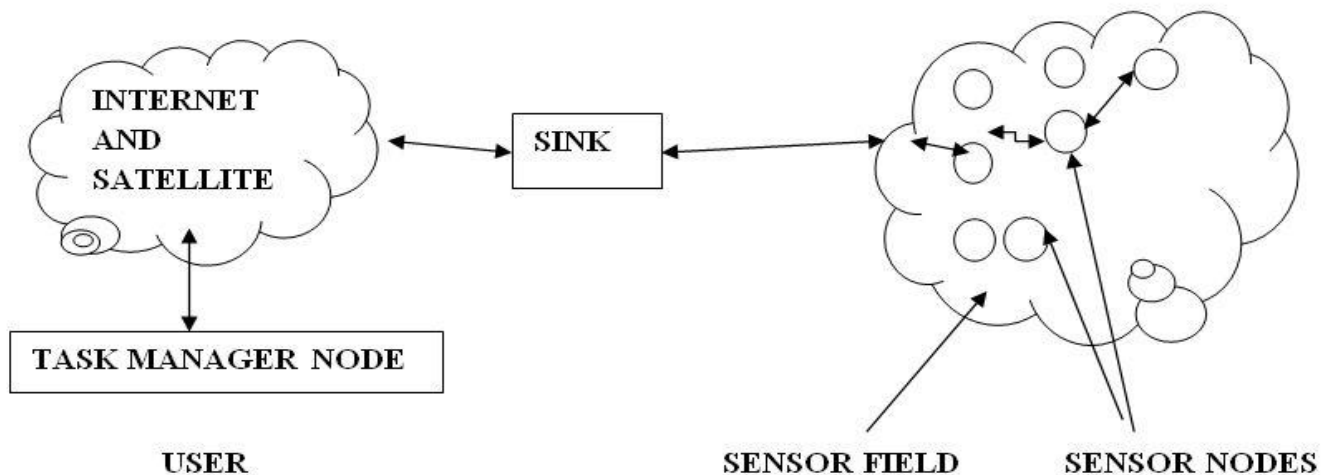

Figure 1:A Model of A Sensor Netwotk System

Each tiny sensor has a sensing module, a computing module, memory and a wireless communication module with a limited radio range and hence constituting a multi-hop MANET. The only difference here is the presence of powerful Base Station (BS), which can directly access any or all sensors in the region as well as has adequate storage capacity to hold the data from the sensors. The user would expect to be able to query the network through the BS. Elements of sensor node are shown as below:
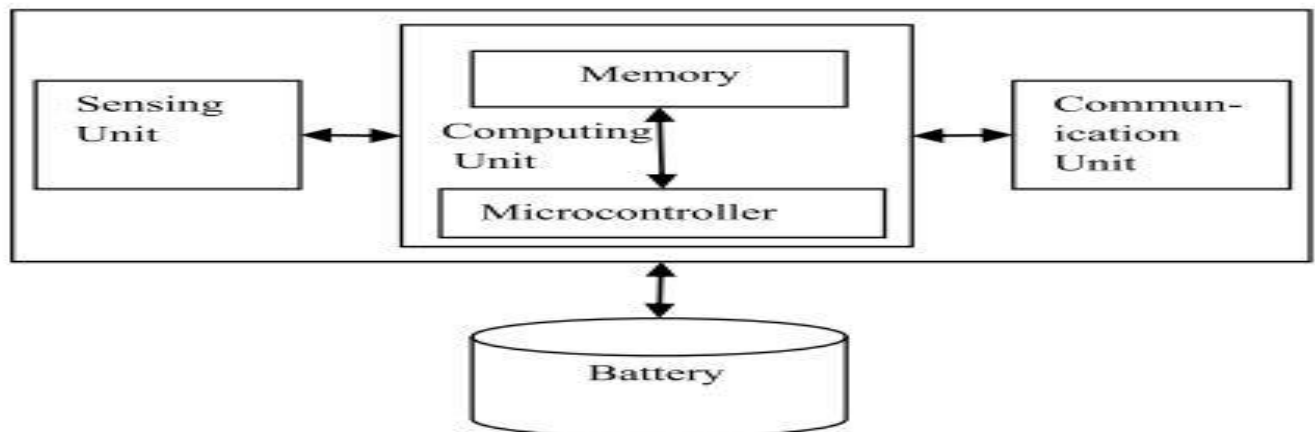
Consider the following scenario:

For example, the body of the human being is equipped with sensors that is they are able to capture optical data from the surroundings (eyes), acoustic information or data like sounds (ears), and smells (nose). These are the examples of remote sensors, which do not need to touch the monitored object to collect data. From a technical perspective, a sensor may be a device that translates parameters or events within the physical world into signals that may be measured and analyzed. Another unremarkably used term is transducer, which is usually used to describe a tool or device that converts energy from one kind into another . When several sensors hand and glove monitor giant physical environments, then they usually outline a wireless sensor

networks. Networks of many sensor nodes are usually wont to monitor giant geographic areas and statement environmental pollution and flooding, grouping structural health data on bridges using vibration sensors etc.

In general, user queries can be broadly categorized into three types:

1. ***Historical queries***: This type of query is mainly used for analysis of historical data stored at the BS (base station). For example, "What was the temperature of the room 2 hours back in the particular building?"

2. ***One-time queries***: This type of query gives a snapshot view of the network. For example, "What is the temperature in the Room?"

3. ***Persistent***: This type of query is mainly used to monitor a network over a time interval with respect to some parameters. For example, "Report the temperature in the room for the next 2 hours".

The protocol should enable strategic distribution of energy degeneracy, which in turn increases the overall lifetime of the system. In addition, slightly longer latency for non-critical data is acceptable if that helps increasing node's life. However, queries for time critical data should not be delayed and should be handled immediately. Traditional routing protocols defined for MANETs are not well suited for wireless sensor networks Routing in WSNs is very challenging due to the essential characteristics that distinguish these networks from other wireless networks like mobile ad hoc networks or cellular networks.

First, due to the relatively large number of sensor nodes, it is not possible to build a global addressing scheme for the deployment of a large number of sensor nodes as the overhead of ID maintenance is high. Thus, traditional IP-based protocols may not be applied to WSNs. In WSNs, sometimes getting the data is more important than knowing the IDs of which nodes sent the data.

Second, in contrast to typical communication networks, almost all applications of sensor networks require the flow of sensed data from multiple sources to a particular BS. This, however, does not prevent the flow of data to be in other forms (e.g., multicast or peer to peer).

Third, sensor nodes are tightly constrained in terms of energy, processing, and storage capacities. Thus, they require careful resource management.

Fourth, in most application scenarios, nodes in WSNs are generally stationary after deployment except for, may be a few mobile nodes. Nodes in other traditional wireless networks are free to move, which results in unpredictable and frequent topological changes. However, in some applications, some sensor nodes may be allowed to move and change their location (although with very low mobility).

Fifth, position awareness of sensor nodes is important since data collection is normally based on the location. Currently, it is not feasible to use Global Positioning System (GPS) hardware for this purpose. Methods based on triangulation, for example, allow sensor nodes to approximate their position using radio strength from a few known points. It is found in that algorithms based on triangulation or multilateration can work quite well under conditions where only very few nodes know their positions apriority, e.g., using GPS hardware.

Due to such differences, many new algorithms have been proposed for the routing problem in WSNs. These routing mechanisms have taken into consideration the inherent features of WSNs along with the application and architecture requirements. The task of finding and maintaining routes in WSNs is nontrivial since energy restrictions and sudden changes in node status (e.g., failure) cause frequent and unpredictable topological changes. To minimize energy consumption, routing techniques proposed in the literature for WSNs employ some well-known routing policies as well as procedures special to WSNs, e.g., data aggregation and in-network processing, clustering, different node role assignment, and data-centric methods were employed.

Almost all of the routing protocols can be classified according to the network structure as flat, hierarchical, or location-based. Furthermore, these protocols can be classified into multipath-based, query-based, negotiation-based, QoS-based, and coherent-based depending on the protocol operation. In flat networks, all nodes play the same role while hierarchical protocols aim at clustering the nodes so that cluster heads can do some aggregation and reduction of data in order to save energy. Location-based protocols utilize the position information to relay the data to the desired regions rather than the whole network. The last category includes routing approaches that are based on the protocol operation, which vary according to the approach used in the protocol.

II. RELATED WORK

An energy-efficient communication protocol LEACH, has been introduced recently which employs a hierarchical clustering done based on information received by the BS. The BS periodically changes both the cluster membership and the cluster-head (CH) to support energy. The CH collects and aggregates information from sensors in its own cluster and passes on information to the BS. By rotating the cluster-head randomly, energy consumption is expected to be uniformly distributed. Otherwise, the CHs closest to the BS, end up transmitting majority of data and drain age of power could force them to die much earlier than other nodes. If a CH, for some reason, cannot communicate With its cluster members or the BS, then periodic re clustering by BS, would enable selection of another active node as the CH. Details of how to form a cluster and how to select a CH for each cluster have been covered in and we assume a similar scheme. The main problem we see is how to process user's query and how to route needed information. Most current protocols, assume a sensor network collecting data periodically from its environment and then respond to a query when it arrives.

In LEACH, sensed data is sent to CHs periodically, and after aggregation, data is passed on to the BS for storing the information. No particular attention has been given to the time criticality of the target application in sensor networks. Sensor networks should also provide the end user with the Ability to control the trade-off between energy efficiency, accuracy and response times dynamically. In our research, we have focused on developing an efficient routing protocol and a comprehensive query handling mechanism which can best full fill these needs.

III. QUERY HANDLING

The two ways of handling queries are:

- The sensor nodes send a pre-defined set of data regularly to a centralized site (BS) and are stored in a database. The user queries this centralized system, known as the *warehousing* approach. An obvious drawback of this method is that data is sent always, the critical data has to be extracted from the database.

- When a user sends any query, the data satisfying the query is collected on demand. The main drawback of such a method is the unacceptable delay for the queries concerning time critical data. We need a mechanism where the BS always possess time critical data so that the queries about such data are not delayed. When a user wants an answer to a non-critical query and BS does not has the BS can send the query to the sensor nodes directly. Therefore we need protocol where nodes not only react to time-critical situations but also send periodic information.

IV. HYBRID NETWORK

In this paper we have described a classification methodology for sensor networks based on their mode of functioning and type of target applications as:

- **Proactive Networks**: The nodes in this network periodically switch on their sensors and transmitters, sense the environment and transmit the data of interest and are employed in LEACH.
- **Reactive Networks**: In this scheme the nodes react immediately to sudden changes in the value of a sensed attribute beyond a pre-determined threshold value and are well suited for time critical applications as used in TEEN.

However, both methods have their limitations. In reactive networks, if the thresholds are not reached, the nodes will not communicate and the user will never get any data from the network at all, or will not come to know even if all the nodes die. We propose to combine the best features of proactive and reactive networks by creating a Hybrid Network with that sends data periodically, as well as responds to sudden changes in attribute values. In section 6, we introduce a protocol for hybrid networks, called APTEEN.

V. SENSOR NETWORK MODEL

These tiny sensor nodes have limited energy and memory constraints, and routing protocols that could possibly reduce the routing complexity are desirable. One way of doing this is to use a topology different from a conventional flat topology and assign the routing responsibilities to just a few nodes and rotate this periodically. In this section, we give a brief introduction to the sensor network model on which we have based our protocols. We assume that all the nodes in the network are homogeneous and begin with the same initial energy. The BS has adequate power to transmit directly to the sensor nodes, providing a direct path for the down-link. However, the sensor nodes cannot always do this because of their limited power supply, leading to an asymmetric communication. This stringent energy constraints, makes hierarchical clustering to be the most suitable model for Wireless Sensor networks. The nodes of Figure 3 are grouped into clusters (for example, nodes 1.1.1, 1.1.2, 1.1.3,1.1.4,1.1.5 and 1.1) with each cluster having a cluster head (node 1.1 for the example cluster). This cluster head aggregates all the data sent to it by all its members and forwards it to its upper level cluster head (node 1) and so on till the data reaches the BS. Since the CHs perform functions that consume more energy, and to evenly distribute energy consumption, clusters exist for an interval called the cluster period T, and then BS regroups clusters. This happens at a time called the cluster change time.

The main features of such an architecture are:

- All the nodes need to transmit only to their immediate cluster-head, thus saving energy.

- Only the cluster head needs to perform additional computations on the data such as aggregation, etc. So, energy is conserved.

- The cluster members of a cluster are mostly adjacent to each other and sense similar data and are aggregated by the CH.

- CHs at increasing levels in the hierarchy need to transmit data over relatively larger distances. To distribute this consumption evenly, all nodes take turns becoming the CH.

- Since only the CHs need to know how to route the data towards its higher level CH or the BS, it reduces its routing complexity.
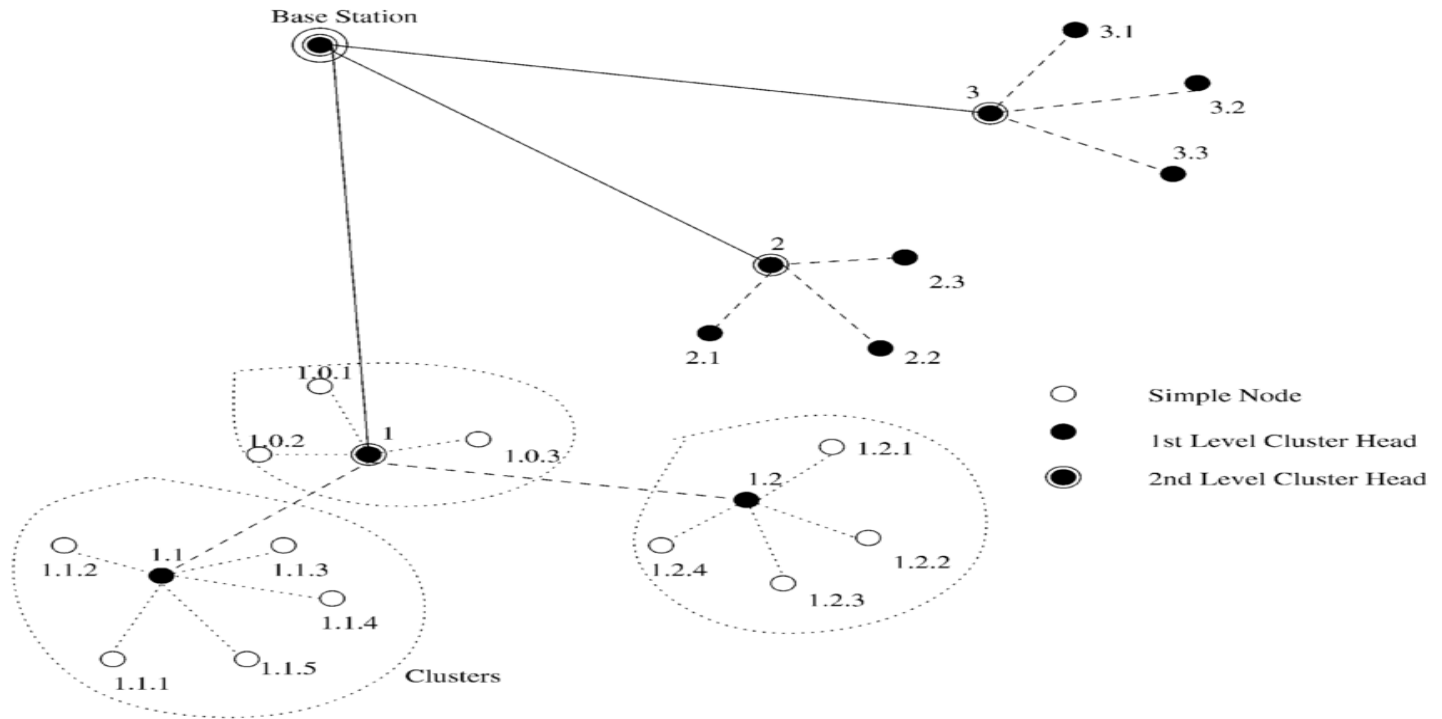
Figure 2.*Hierarchical Clustering*

Many protocols have been proposed in literature which use such a hierarchical clustering scheme such as CBPR, Scalable Coordination in Wireless Networks, LEACH and any of these clustering techniques is appropriate.

We have used the second version of LEACH, *leach-c* wherein clusters are formed by the BS based on the information received about sensor's energy and location by the sensors at the end of the cluster change period.

In *leach*, the clustering is done by sensor nodes themselves. Even though the performance depends on how far the BS is from the CHs, we found this most suitable for our protocol due to the following reasons:

- Since BS decides the cluster heads, it can appoint a fixed number of nodes as cluster heads,(viz. 5% nodes used as CH in *leach* and *leach-c*.

- Since BS has global information of the network, it can optimally form clusters and evenly distribute the number of nodes in each cluster.

VI. APTEEN – THE NEW HYBRID PROTOCOL

In this section, we introduce a new protocol developed for hybrid networks, called APTEEN *(Adaptive *Periodic* Threshold-sensitive Energy Efficient Sensor Network Protocol)*. In APTEEN once the CHs are decided, in each cluster period, the cluster head first broadcasts the following parameters:

Attributes (A): This is a set of physical parameters which the user is interested in obtaining data about.

Thresholds: This parameter consists of a hard threshold (HT) and a soft threshold (ST). HT is a particular value of an attribute beyond which a node can be triggered to transmit data. ST is a small change in the value of an attribute which can trigger a node to transmit data again.

Schedule: This is a TDMA schedule similar to the one used in, assigning a slot to each node.

Count Time (TC): It is the maximum time period between two successive reports sent by a node. It can be a multiple of the TDMA schedule length and it accounts for the proactive component.

In a sensor network, close-by nodes fall in the same cluster, sense similar data and try to send their data simultaneously, affecting possible collisions.

We introduce a TDMA schedule such that each node in the cluster is assigned a transmission slot, as shown in Fig. 3.
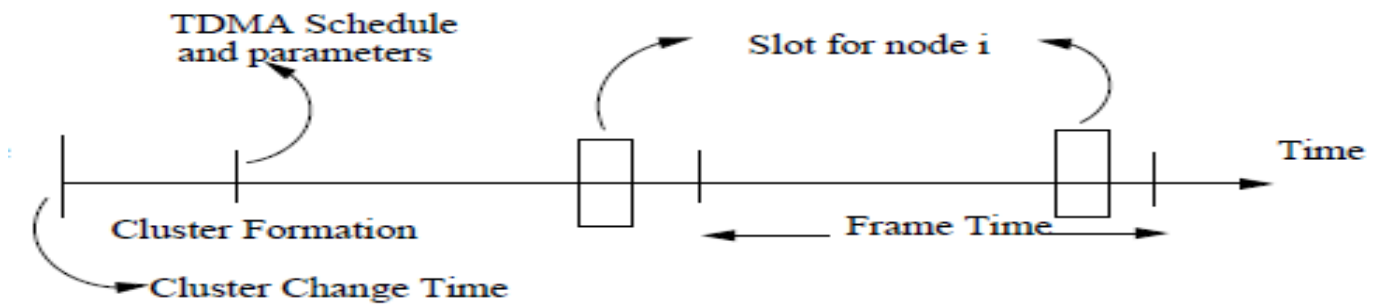

Figure 3.Time Line for APTEEN

In the following section, we refer to data values exceeding the threshold value as critical data.

6.1. Important Features

The main features of our scheme are:

1. By sending periodic data, it gives the user a complete picture of the network. It also responds immediately to drastic changes, thus making it responsive to time critical situations. Thus, it combines both proactive and reactive policies.

2. It offers a flexibility of allowing the user to set the time interval (TC) and the threshold values for the attributes.

3. Energy consumption can be controlled by the count time and the threshold values.

4. The hybrid network can emulate a proactive network or a reactive network, by suitably setting the count time and the threshold values.

The main drawback of this scheme is the additional complexity required to implement the threshold functions and the count time. However, this is a reasonable trade-off and provides additional flexibility and versatility.

6.2. Query Modelling

To handle queries efficiently in a network, with hundreds and thousands of sensors, we could consider two possible alternatives of a flat topology and a cluster-based approach.

- In a flat topology, each node satisfying the query conditions has to individually send the data to the requesting node. At best, some intermediate nodes may do some aggregation, as shown in Fig 4.

- In a hierarchical cluster, only the CH needs to aggregate and so it seems more efficient. This is the scheme used here. If we assume that adjacent nodes can sense similar data, we can form pairs of two nodes and make only one node from each pair respond to a query. The other node can go to a "sleep" mode and need not receive the query. Thus, two nodes can alternately take the role of handling queries if there are nodes close enough to form pairs.
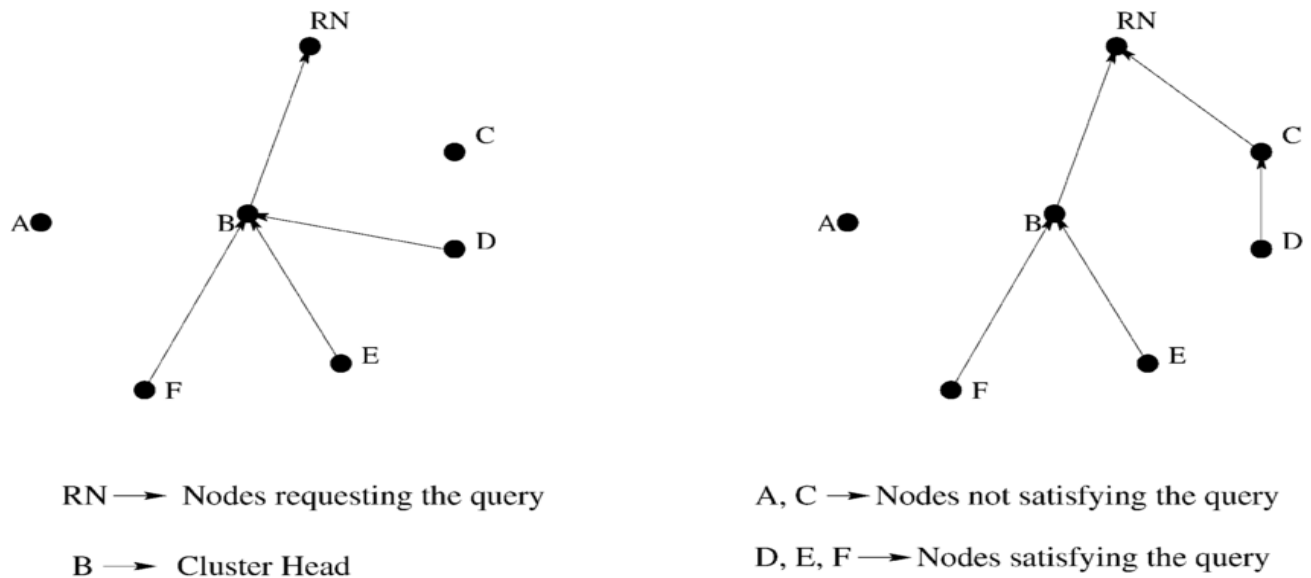
RN ⟶ Nodes requesting the query

B ⟶ Cluster Head

A, C ⟶ Nodes not satisfying the query

D, E, F ⟶ Nodes satisfying the query

Figure 4.Comparison of query routing topologies

6.3. Modified TDMA Schedule

A best possible pairing of sleeping and idle nodes can be found by the BS using simulated annealing. The nodes which listen for the queries have to be always awake (i.e., in idle state ready to receive any query). Also, these idle nodes will have more data to send if they receive queries, since they might have to send data as well as the queries.

Hence, the slots for these idle nodes have to be larger than the slots for the sleeping nodes. By modifying the TDMA schedule, we can have the sleeping nodes send their data first and then the idle nodes. For example, if adjacent node *a* and node *b* constitute sleep/idle pair, they will have their slots at an average distance of half the frame time. So, even though the interval between two successive slots of node *a* is larger because of larger slots for idle nodes, the critical data can still be sensed and transmitted by node *b* without having to wait for node *a*'s next slot. The nodes can change their roles midway between cluster change times, so that sleeping nodes now go into idle mode to handle queries and the idle nodes now go into sleep mode. The CH aggregates all the data and sends it to its higher level CH (or the BS). Once the BS receives the data from all the CHs, it extracts the queries and the answers from the data and transmits them in down-link mode, directly to the sensor nodes or the user rather than going through the CHs. Different CDMA code is used in each cluster to avoid inter-cluster collision. However, a common CDMA code is employed for the uplink from the cluster heads to the BS and the down-link from the BS to all sensor nodes. This implies that the BS should not transmit to the nodes when the nodes are transmitting data to their CHs in their slots. So, we need to assign a separate slot for the BS and include it in the TDMA schedule. However, each cluster might have different number of members, leading to different TDMA frame lengths. So, the BS has to calculate the length of the longest TDMA schedule among the clusters and make allowance for the transmitted data from the CHs to reach it, after which it can transmit its own data. Finally, incorporating all these factors, a TDMA schedule can be defined as shown in Fig. 5.
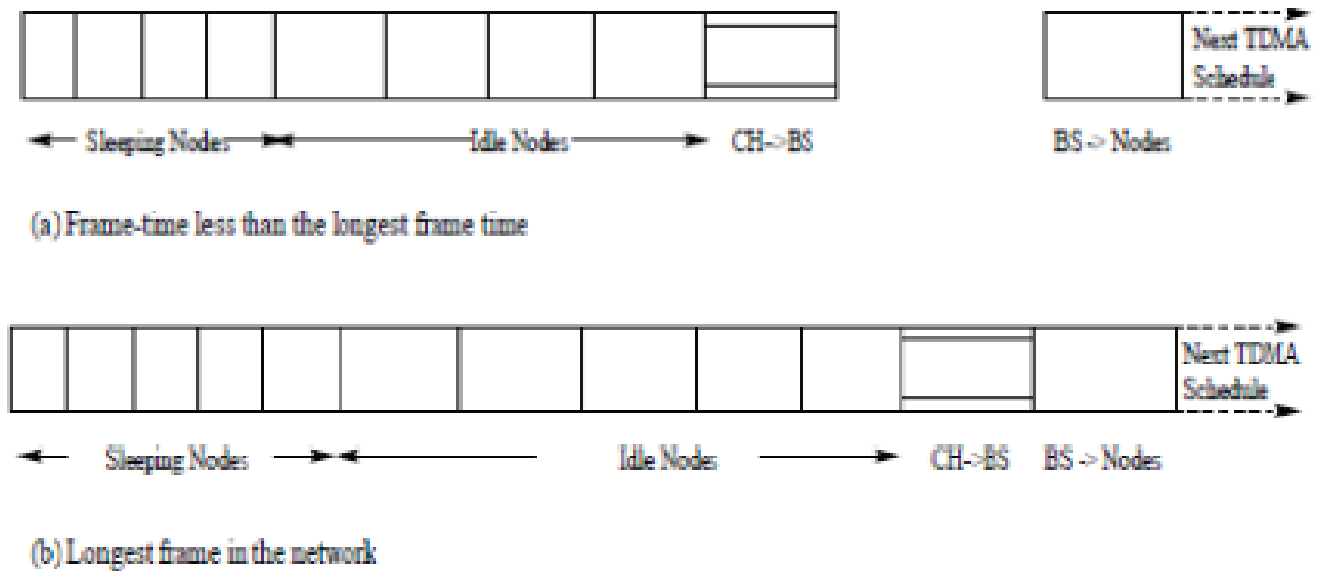
(a) Frame-time less than the longest frame time

(b) Longest frame in the network

Figure 5.Different Frame lengths in a network

VII. PERFORMANCE EVALUATION

7.1. Simulation Environment

We have based the implementation of the queries on the *ns-2* simulator with the *LEACH e*xtension. The simulation has been performed on a network of 100 nodes and a fixed base station. The nodes are placed randomly in the network. All the nodes start with an initial energy of 2J.

Cluster formation is done as in the *leach-c* protocol. However, their radio model is modified to include idle time power dissipation (set equal to 10% of the radio electronics energy) and sensing power dissipation (set equal to 10% of the idle energy). For our experiments, we simulated an Environment with varying temperature in different regions.

The sensor network nodes are first placed randomly in a bounding area of 100x100 units. The actual area covered by the network is then divided into four quadrants. Each quadrant is later assigned a random temperature between 00F and 2000F every 5 seconds during the simulations. It is observed that most of the clusters have been well distributed over the four quadrants.

7.2. Query Generation

For our experiments we assume a *Poisson arrival* process for the arrival of queries at each node, with a mean rate of λ. The type of query (0, 1, 2) is picked randomly and the duration (for types 0, 2) of the query and the location of interest are also decided randomly.
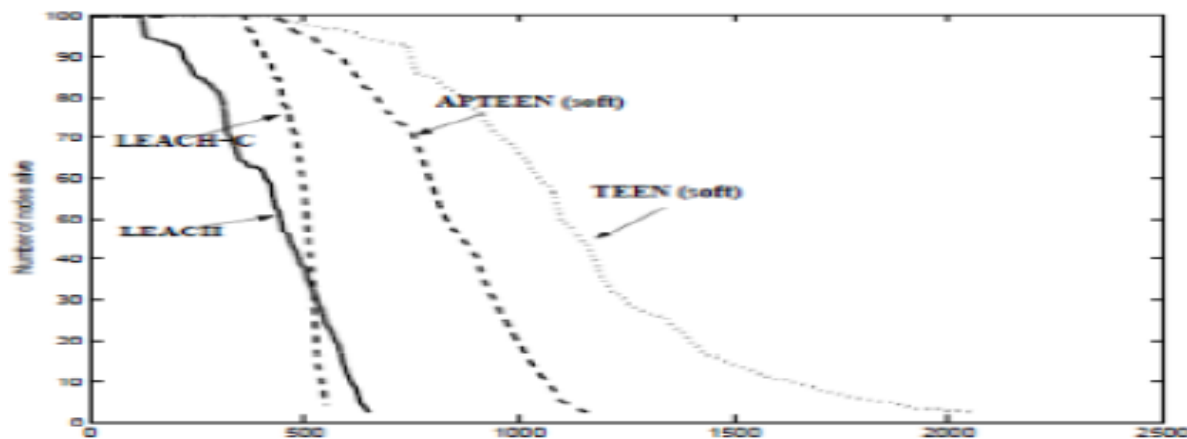

Figure 6.Comparison of the no. of nodes alive for LEACH, APTEEN and TEEN
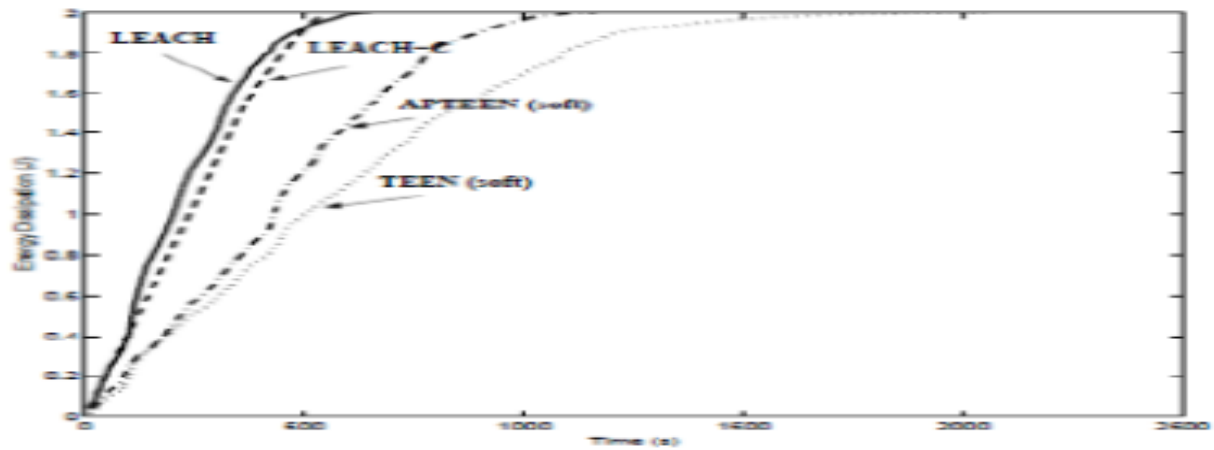
Figure 7: Comparison of average energy dissipation for LEACH, APTEEN and TEEN

To analyse and compare the effect of queries on our protocol, we use the following metrics:

- *Average energy dissipated:* This metric shows the average dissipation of energy per node in the network

- *Total number of nodes alive*: This metric indicates the overall lifetime of the network. More importantly, it gives an idea of the area coverage of the network overtime.

- *Total number of data signals received at BS:* This metric explains how our protocol is saving energy by not transmitting data continuously, which is not required (neither time-critical nor satisfying any query).

- *Average Delay*: This metric gives the average response time in answering different types of queries.

For all our experiments, the attribute to be sensed is the temperature. The performance of APTEEN is studied in the Soft mode using both the thresholds.

In this mode, as discussed in section 6, once a node senses a value beyond HT , it next transmits data only when the current sensed value differs from the previous transmitted value by an amount equal to or greater than the soft threshold ST . The hard threshold is set at 1000F, the average of the highest and the lowest possible temperatures. The soft threshold was arbitrarily assigned a value of 20F for our experiments.

The count time is set equal to 5 times the frame-time. In experiments involving queries, mean arrival rate of the queries at each node, λ, is set at 0.01 and increased gradually to 1.0

VIII. RESULTS

We have simulated different protocols and we observe that our protocol provides lower dissipation value of energy and a higher number of alive nodes at any given time.
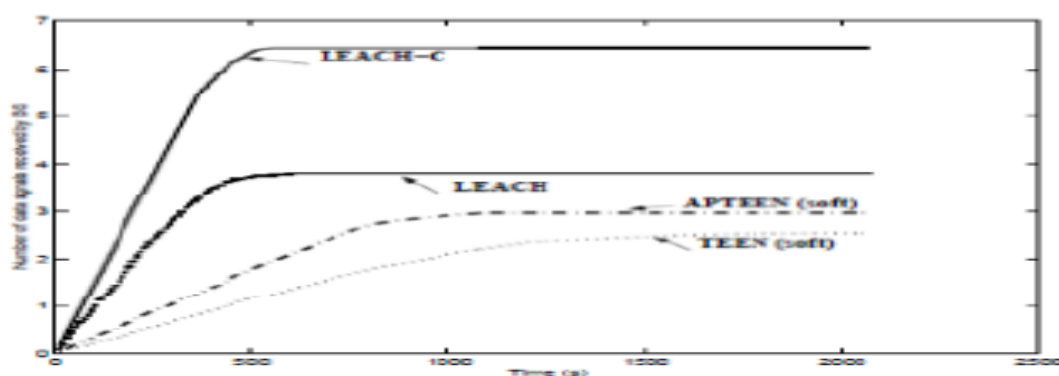

Figure 8.Total data received at the BS over time

Figures 6,7 and 8 compare APTEEN with TEEN and LEACH (*leach* and *leach-c*) with respect to energy consumption, number of nodes alive and total data signals received at the BS over time, respectively. The performance of APTEEN lies between TEEN and LEACH with respect to energy consumption and longevity of the network. This is expected as *TEEN* only transmits time critical data while sensing the environment continuously. To overcome the drawbacks of *TEEN* we incorporated the periodic data transmission to form *APTEEN*. APTEEN performs better than LEACH since APTEEN transmits data based on the threshold values unlike LEACH which transmits data at all times. So, based on the application and the energy constraints, we can decide how to select the parameters in our APTEEN protocol. But this energy saving does increase the response time for the queries. In *leach-c* the queries can be directly asked from the BS and answers are also received directly. Virtually no routing of query is required. For *APTEEN* with query, the delay depends on the frame time. Fig.9 gives the average delay over λ. As λ increases, the load increases and as expected.
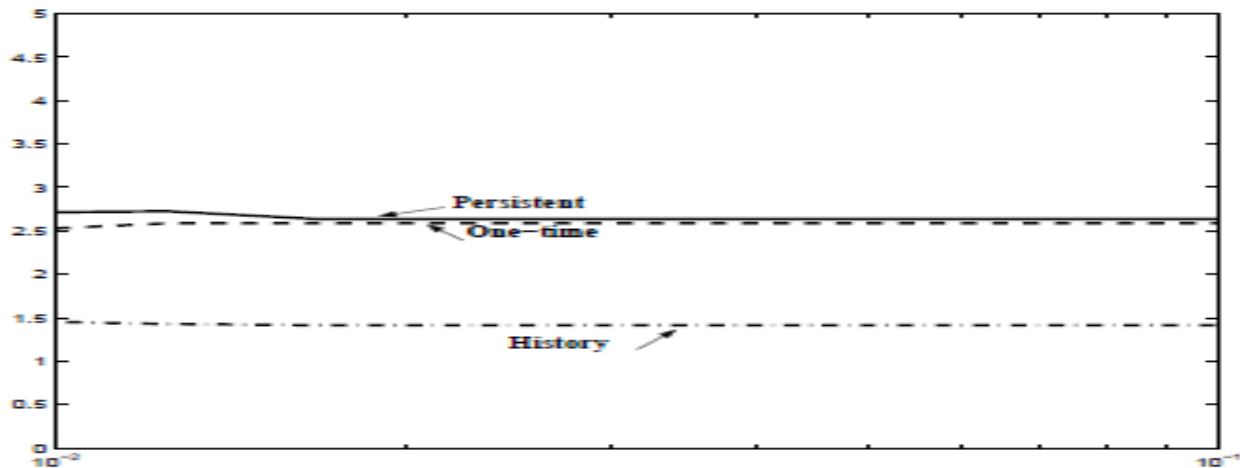

Figure 9. Variation in response time

IX. CONCLUSION

In this paper we have introduced Hybrid protocol APTEEN which combines the best features of both proactive and reactive networks and to provide periodic data collection as well as near real-time notices about critical events. We have also validated implementation of a query which is useful enough to respond to a variety of queries. Even though, our query model is suitable for a network with evenly distributed nodes, it can be extended further to sensor networks with uneven node distributions. We believe we have taken first step in defining an appropriate protocol for upcoming field of wireless sensor networks.

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