# A Review of APTEEN in Wireless Sensor Networks

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*Abstract*——**Wireless sensor networks with thousands of tiny sensornodes, are expected to find wide applicability and increasing deployment in coming years, as they enable reliable monitoring and analysis of the environment. 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.**

## I. INTRODUCTION

The advancement in sensor technology has made it possibleto have extremely small, low powered sensing devicesequipped with programmable computing, multiple parametersensing and wireless communication capability. Also,the low cost makes it possible to have a network of hundredsor thousands of these sensors, thereby enhancing the reliabilityand accuracy of data and the area coverage. Wirelesssensor networks offer information about remote structures,wide-spread environmental changes, etc. in unknown andinhospitable terrains.There are a number of advantages of wireless sensor networksover wired ones such as ease of deployment (reducinginstallation cost), extended range (network of tiny sensorscan 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 reconfigurethemselves) But there are a few inherent limitations of wireless media such as low bandwidth, error pronetransmissions, collision free channel access requirementsetc. Also, since the wireless nodes are mostly mobile andare not connected in any way to a constant power supply,they derive energy from a personal battery. These limitsthe amount of energy available to the nodes. In addition,since these sensor nodes are deployed in places where itis difficult to either replace individual nodes or their batteries,it is desirable to increase the longevity of the networkand preferable that all the nodes die together so thatthe whole area could be replenished by a new set of tinynodes. Finding individual dead nodes and then replacingthose nodes selectively would require pre-planned deploymentand eliminate some advantages of these networks.A model of such a sensor network, is shown in

Figure1. Each tiny sensorhas a sensing module, a computingmodule, memory and awireless communication modulewith a limited radio range and hence constituting a multi-hopMANET. The only difference here is the presence of apowerful Base Station (BS), which can directly access anyor all sensors in the region as well as has adequate storagecapacity to hold the data from the sensors. The userwould expect to be able to query the network through the BS.

Consider the following scenario: Temperature sensorsare placed around a factory (such as chemical, automotive,etc.) Typical queries posed by the user include:

- Report immediately if the temperature in north-east Quadrant goes below $40^0$F
- Retrieve the average temperature in southern quadrantover the last 5 hours
- For the next two hours report if the temperature goesbeyond $200^0$F.
- Which areas had a temperature between $40^0$F and $200^0$F in the past two hours.
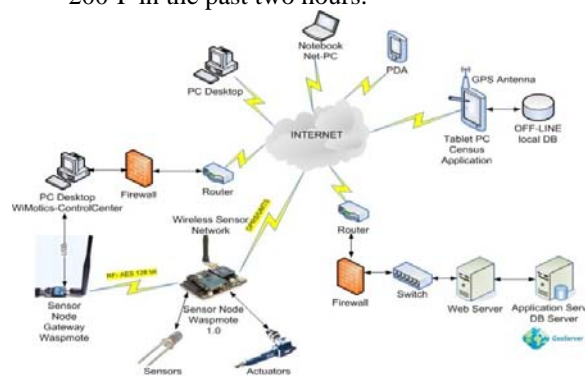


**Figure 1.***A model of a Sensor Network System.*

In general, user queries can be broadly categorized intothree types:

1. *Historical queries*: This type of query is mainly usedfor analysis of historical data stored at the BS (basestation). For example, "What was the temperature 2hours back in the northwest quadrant?"

2. *One-time query*: This type of query gives a snapshotview of the network. For example, "What is the temperaturein the northwest quadrant?"

3. *Persistent*: This type of query is mainly used to monitora network over a time interval with respect to someparameters. For example, "Report the temperature inthe northwest quadrant for the next 2 hours".The protocol should enable strategic distribution of energydissipation,

which in turn increases the overall lifetimeof the system. In addition, slightly longer latency for noncriticaldata is acceptable if that helps increasing node's life.However, queries for time critical data should not be delayedand should be handled immediately.Traditional routing protocols defined for MANETs arenot well suited for wireless sensor networks as mentionedin our earlier paper [12]An ideal sensor network should have *Attribute based addressing*,and *location awareness*. Another important requirementin some cases is that the sensors should react immediatelyto drastic changes in their environment, for example,in *time-critical applications*. The end user shouldbe made aware of the ground situation with minimum delaywhile making efficient use of the limited wireless channelbandwidth. Thus, wireless sensor network needs protocolswhich are data centric, capable of effective data aggregationdistribute energy dissipation evenly, efficiently usetheir limited energy to increase the longevity of the networkand avoid any single point bottleneck (except the BS).

## II. RELATED WORK

An energy-efficient communication protocol LEACH,has been introduced [7] recently which employs a hierarchicalclustering done based on information received by theBS. The BS periodically changes both the cluster membershipand the cluster-head (CH) to conserve energy. The CHcollects and aggregates information from sensors in its owncluster and passes on information to the BS. By rotatingthe cluster-head randomly, energy consumption is expectedto be uniformly distributed. Otherwise, the CHs closest tothe BS, end up transmitting majority of data and drainageof power could force them to die much earlier than othernodes. If a CH, for some reason, cannot communicate withits cluster members or the BS, then periodic re-clusteringby BS, would enable selection of another active node as theCH. Details of how to form a cluster and how to select a CHfor each cluster have been covered in [9] and we assume asimilar scheme.The main problem we see is how to process user's queryand how to route needed information. Most current protocols[7] assume a sensor network collecting data periodicallyfrom its environment and then respond to a querywhen it arrives. In LEACH [9], sensed data is sent to CHsperiodically, and after aggregation, data is passed on to theBS for storing the information. No particular attention hasbeen given to the time criticality of the target application insensor networks. Sensor networks should also provide theend user with the ability to control the trade-off between energyefficiency, accuracy and response times dynamically.In our research, we have focused on developing an efficientrouting protocol and a comprehensive query handlingmechanism which can best fulfill these needs.

## III. QUERY HANDLING

The two ways of handling queries are:

- The sensor nodes send a pre-defined set of data regularlyto a centralized site (BS) and are stored in a database. The user queries this centralized system, known as the *warehousing* approach [1]. An obvious

drawback of this method is that data is sent always, thecritical 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 ofsuch 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 NETWORKS

In an earlier paper [12], 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 areemployed in *LEACH* [8].
- *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* [12].

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

## V. SENSOR NETWORK MODEL

These tiny sensor nodes have limited energy and memoryconstraints, and routing protocols that could possibly reducethe routing complexity are desirable. One way of achievingthis is to use a topology different from a conventional flattopology and assign the routing responsibilities to just a fewnodes and rotate this periodically.In this section, we give abrief introduction to the sensor network model on which wehave based our protocols.We assume that all the nodes in the network are homogeneousand begin with the same initial energy. The BShas adequate power to transmit directly to the sensor nodes,providing a direct path for the down-link. However, thesensor nodes cannot always do this because of their limitedpower supply, leading to an asymmetric communication. This stringent energy constraints, makes hierarchicalclustering to be the most suitable model forWireless Sensornetworks.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) witheach cluster having a cluster head (node 1.1 for the examplecluster). 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, energyis conserved.
- The cluster members of a cluster are mostly adjacentto each other and sense similar data and are aggregatedby 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 becomingthe 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.
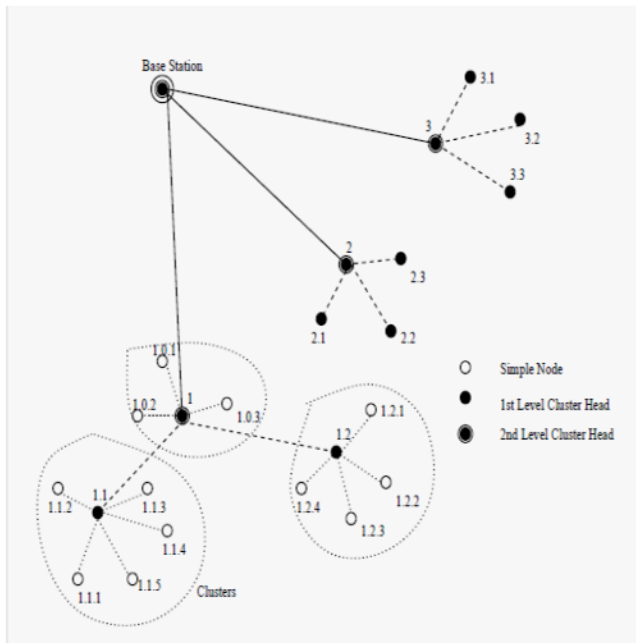


**Figure 2.***Hierarchical Clustering*

Many protocols have been proposed in literature which use such a hierarchical clustering scheme such as CBPR [11], Scalable Coordination in Wireless Networks [5], LEACH [8] 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% nodesused as CH in *leach* and *leach-c*.

- Since BS has global information of the network, it can optimally form clusters and evenly distribute the numberof 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 ($H_T$ )and a soft threshold ($S_T$ ). $H_T$ is a particular value of an attribute beyond which a node can be triggered to transmit data. $S_T$ 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 [8], assigning a slot to each node.

*Count Time (*$T_C$*):* 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, causing possible collisions. We introduce a TDMA schedule such that each node in the cluster is assigned a transmission slot, as shown in Fig. 3. 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 immediatelyto drastic changes, thus making it responsive to time critical situations. Thus, It combines both proactive and reactive policies.
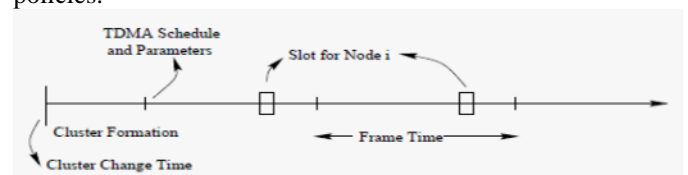


**Figure 3.***Time Line for APTEEN*

2. It offers a flexibility of allowing the user to set the time interval ($T_C$) 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 Modeling

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.
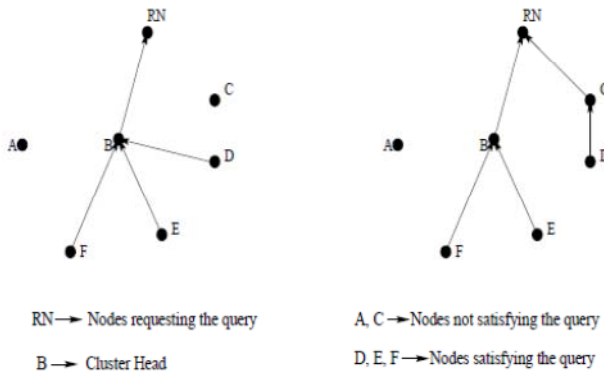


**Figure 4.***Comparison of query routing topologies*

*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 up-link 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.
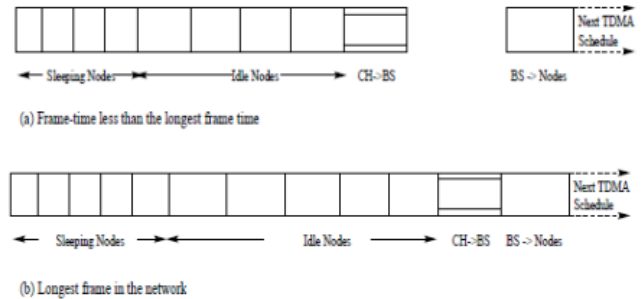


**Figure 5.***Different Frame lengths in a network*

## VII. PERFORMANCE EVALUATION

*7.1. Simulation Environment*
We have based the implementation of the queries on the *ns-2* [13] simulator with the *LEACH* extension. 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 [8] [9]. 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 $0^{o}F$ and $200^{o}F$ 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.
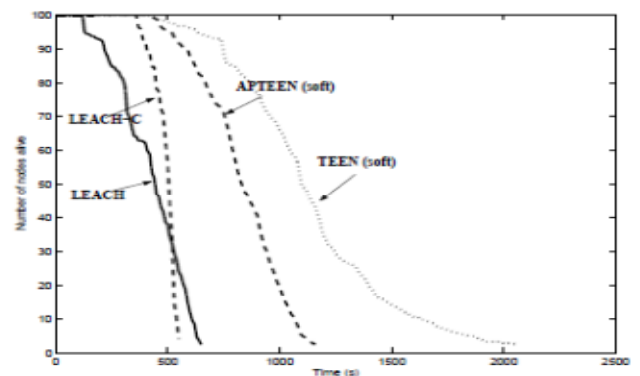


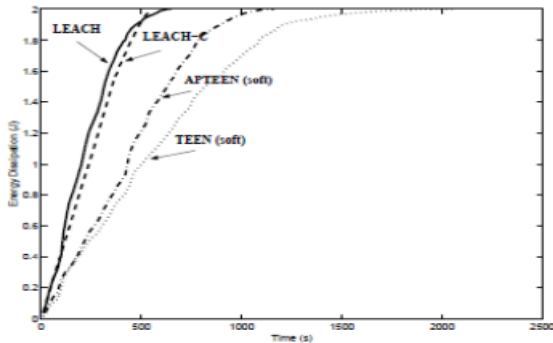**Figure 8.***Comparison of the no. of nodes alive for LEACH, APTEEN and TEEN*

**Figure 9.***Comparison of average energy dissipation for LEACH, APTEEN and TEEN*
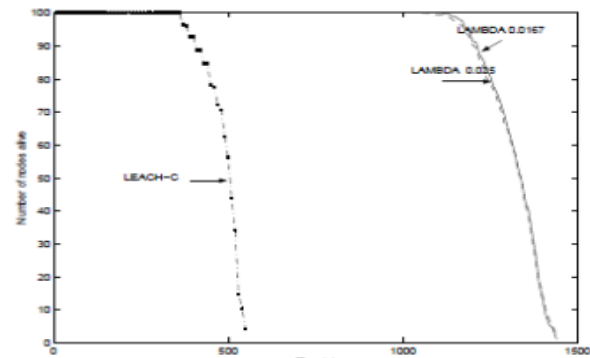


**Figure 11.***Effect of queries on APTEEN*

### 7.3. Experiments

To analyze 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, itgives 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 $H_T$, 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 $S_T$. The hard threshold is set at $100^{o}F$, the average of the highest and the lowest possible temperatures. The soft threshold was arbitrarily assigned a value of $2^{o}F$ 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, $\lambda$, is set at 0.01 and increased gradually to 1.0

### 8.4. 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.
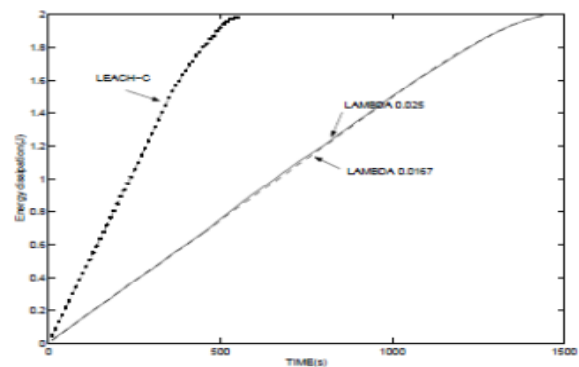


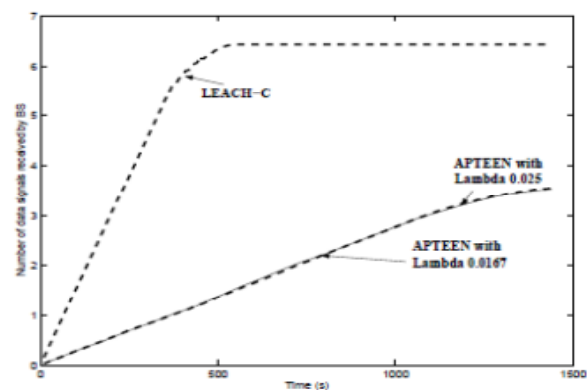**Figure 12.***Effect of queries on energy consumption in APTEEN*



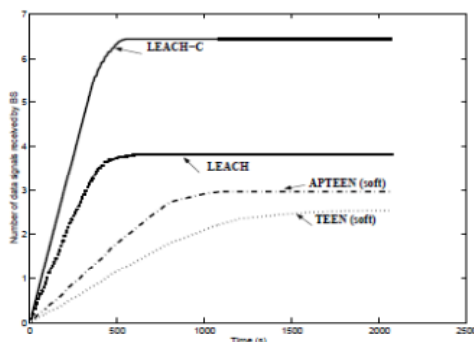**Figure 13.***Effect of queries on the total data received*

Figures 8, 9 and 10 compare APTEEN with TEEN andLEACH (*leach* and *leach-c*) with respect to energy consumption,number of nodes alive and total data signalsreceived at the BS over time, respectively. The performanceof APTEEN lies between TEEN and LEACH withrespect to energy consumption and longevity of the network.This is expected as *TEEN* only transmits time-criticaldata while sensing the environment continuously. To overcomethe drawbacks of *TEEN* we incorporated the periodicdata transmission to form *APTEEN*. APTEEN performs betterthan LEACH since APTEEN transmits data based on thethreshold values unlike LEACH which transmits data at alltimes. So, based on the application and the energy constraints,we can decide how to select the parameters in ourAPTEEN protocol. But this energy saving does increasethe response time for the queries.In *leach-c* the queries can be directly asked from the BSand answers



**Figure 10.***Total data received at the BS over time*

are also received directly. Virtually no routingof query is required. For *APTEEN* with query, the delay depends on the frame time. Fig. 14 gives the average delay over$\lambda$. As $\lambda$ increases, the load increases and as expected
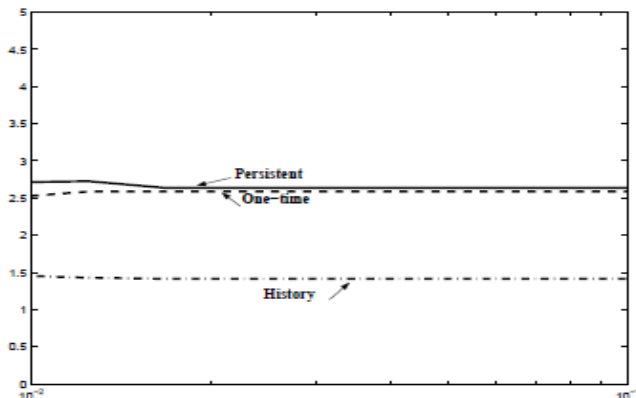


**Figure 14.***Variation in response time with*

## CONCLUSIONS

In this paper we have introduced *Hybrid* protocol*APTEEN* which combines the best features of both proactiveand reactive networks and to provide periodic data collectionas well as near real-time warnings about criticalevents. We have also demonstrated implementation of aquery which is versatile enough to respond to a variety ofqueries. Even though, our query model is suitable for a networkwith evenly distributed nodes, it can be extended furtherto sensor networks with uneven node distributions. Webelieve we have taken first step in defining an appropriateprotocol for upcoming field of wireless sensor networks.

## REFERENCES

[1] P. Bonnet, J. Gehrke, and P. Seshadri. Querying the PhysicalWorld. In *IEEE Personal Communications. Special Issue onSmart Spaces and Environments*, October 2000.

[2] P. Bonnet, J. Gehrke, and P. Seshadri. Towards SensorDatabase Systems. In *2nd International Conference on Mobile Data Management*, January 2001.

[3] S. Das, C. Perkins, and E. Royer. Performance Comparisonof two On-demand Routing Protocols for Ad-Hoc Networks.In *Proceedings of the INFOCOM*, pages 3–12, March 2000.

[4] J. Elson and D. Estrin. An Address-Free Architecture forDynamic Sensor Networks. Technical Report 00-724, ComputerScience Department, USC, January 2000.

[5] D. Estrin, R. Govindan, J. Heidemann, and S. Kumar. Next Century Challenges: Scalable Coordination inWireless Networks.In *Proceedings of the 5th Annual ACM/IEEE InternationalConference on Mobile Computing and Networking (MOBICOM)*, pages 263–270, 1999.

[6] D. Estrin, Y. Xu, and J. Heidemann. Geography-informed Energy Conservation for Ad-Hoc Routing. In *Proceedingsof the 7th Annual ACM/IEEE International Conferenceon Mobile Computing and Networking (MOBICOM), Rome,Italy*, pages 70–84, July 2001.

[7] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan.*"uAMPS ns Code Extensions"*. http://wwwmtl.mit.edu/research/icsystems/uamps/ leach.

[8] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan.Energy-Efficient Communication Protocols forWireless MicrosensorNetworks. In *Proceedings of Hawaiian InternationalConference on Systems Science*, January 2000.

[9] W. B. Heinzelman. *"Application-Specific Protocol Architecturesfor Wireless Networks"*. PhD thesis, MassachusettsInstitute of Technology, June 2000.

[10] C. Intanagonwiwat, R. Govindan, and D. Estrin. Directed Diffusion: A Scalable and Robust CommunicationParadigm for Sensor Networks.

[11] M. Jiang, J. Li, and Y. C. Tay. Cluster Based Routing Protocol.Internet Draft, 1999.

[12] A. Manjeshwar and D. P. Agrawal. TEEN: A Routing Protocolfor Enhanced Efficiency in Wireless Sensor Networks.In *1st International Workshop on Parallel and DistributedComputing Issues in Wireless Networks and Mobile Computing*,April 2001.

[13] UCB/LBNL/VINT. *"Network Simulator-ns"*. http://wwwmash.cs.berkeley.edu/ns.