APTEEN:

A Hybrid Protocol for Efficient Routing and Comprehensive Information Retrieval in Wireless Sensor Networks

OUTLINE

Introduction(1)

- There are a number of advantages of wireless sensor networks over wired ones such as
  - ease of deployment
  - extended range
  - fault-tolerance
 - self-organization

Introduction(2)

- But there are a few inherent limitations of wireless media such as
  - low bandwidth
  - error prone transmissions
  - collision free channel access requirements

Introduction(3)

- derive energy from a personal battery , This limits the amount of energy available to the nodes

- It is difficult to either replace individual nodes or their batteries

- It is desirable to increase the longevity of the net-work and preferable that all the nodes die together so that the whole area could be replenished by a new set of tiny nodes

- Finding individual dead nodes and then replacing those nodes selectively would require preplanned deployment and eliminate some advantages of these networks

A model of a Sensor Network System

MSN

MSN

MSN

Base Station

PDA
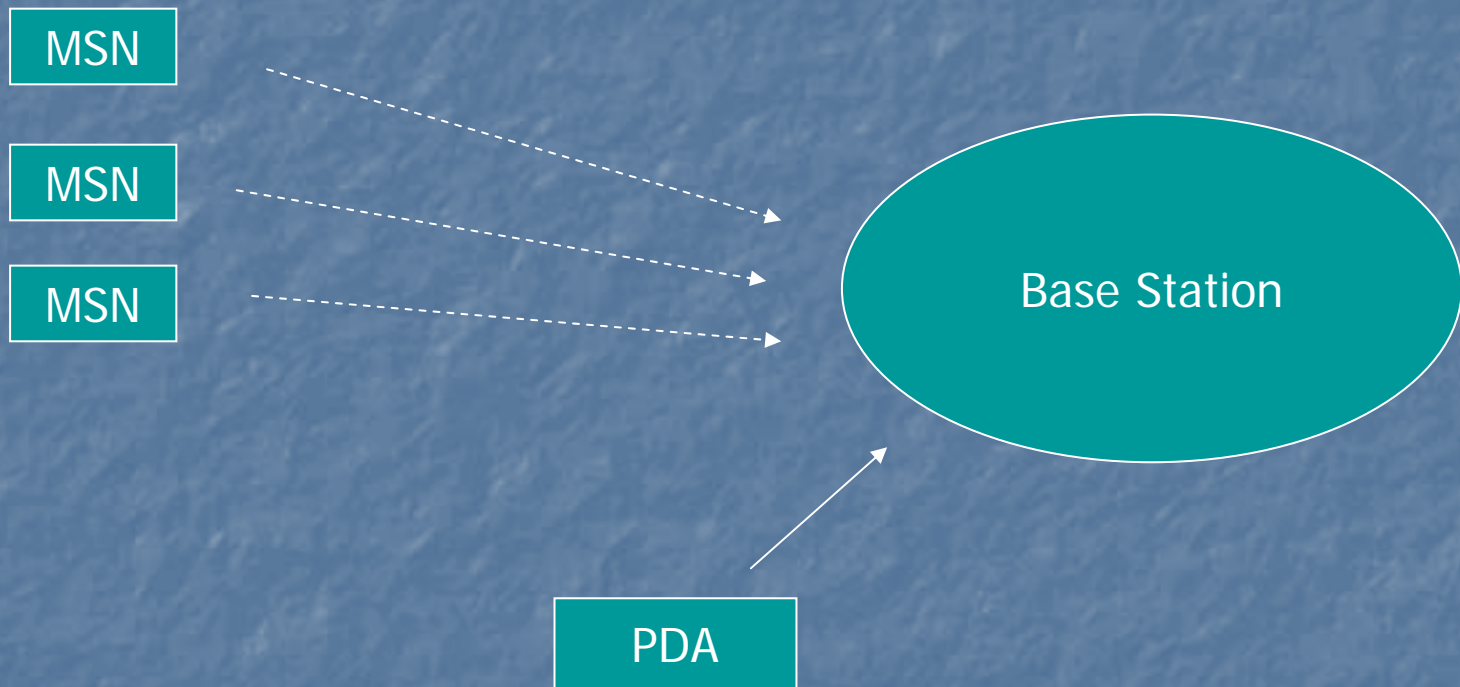
EXAMPLE

- The user would expect to be able to query the network through the BS
- Temperature sensors are placed around a factory
- Typical queries posed by the user include:
  - Report immediately if the temperature in north-east quadrant goes below 40 F
  - Retrieve the average temperature in southern quadrant over the last 5 hours
  - For the next two hours report if the temperature goes beyond 200 F.
  - Which areas had a temperature between 40 F and 200F in the past two hours.

User queries three types:

- 1. Historical queries
- 2. One-time query
- 3. Persistent

non-critical and time critical data

- slightly longer latency for non-critical data is acceptable if that helps increasing node's life

- queries for time critical data should not be delayed and should be handled immediately

Motivation

- LEACH
  - An energy-efficient communication protocol
  - employs a hierarchical clustering done based on information received by the BS
- The BS periodically changes both the cluster member-ship and the cluster-head (CH)
- The CH collects and aggregates information from sensors
- By rotating the cluster-head randomly

Main problem

- how to process user's query
- how to route needed information

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 is stored in a database
  - When a user sends any query, the data satisfying the query is collected on demand

Hybrid Networks

- Proactive Networks
- Reactive Networks

- We propose to combine the best features of proactive and reactive networks by creating a Hybrid net-work :
  - sends data periodically, as well as responds to sudden changes in attribute values
  - called APTEEN

Sensor Network Model (1)

- 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

- these sensor nodes cannot always do this because of their limited power

- This stringent energy constraints, makes hierarchical clustering to be the most suitable model

Sensor Network Model (2)
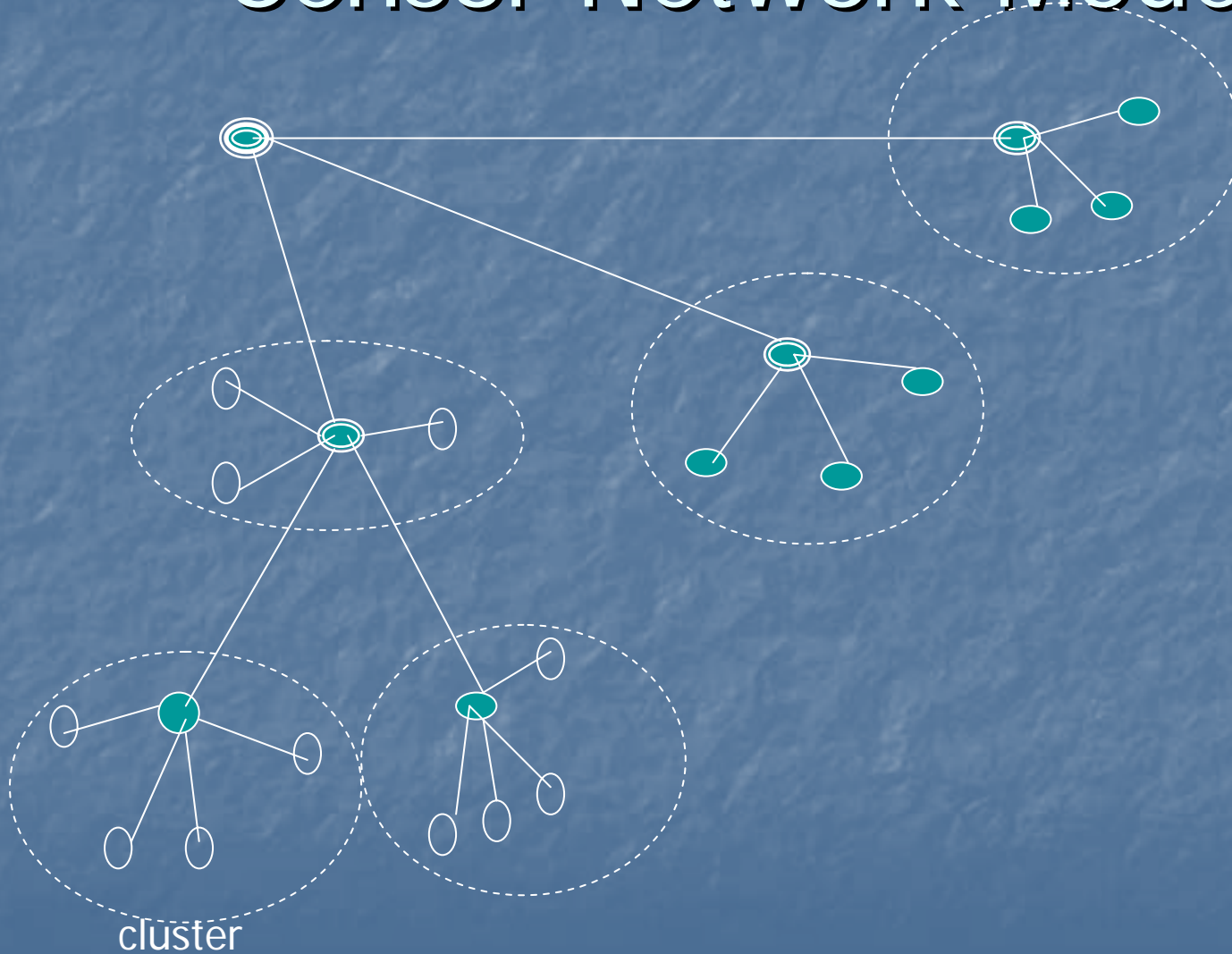
cluster

Sensor Network Model (3)

- This cluster head aggregates all the data sent to it by all its members

- forwards it to its upper level cluster head (node 1) and so on till the data reaches the BS

- CHs perform functions that consume more energy, and to evenly distribute energy consumption

The main features of such an architecture

- All the nodes need to transmit only to their immediate cluster-head
- Only the cluster head needs to perform additional computations on the data such as aggregation, etc.
- 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

LEACH

- 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

- Since BS decides the cluster heads, it can appoint a fixed number of nodes as cluster heads

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

Hybrid Network Protocol: APTEEN

- In APTEEN once the CHs are decided, in each cluster period, the cluster head first broadcasts the following parameters
    - **Attributes(A)**
    - **Thresholds**
    - **Schedule**
    - **Count Time(TC)**

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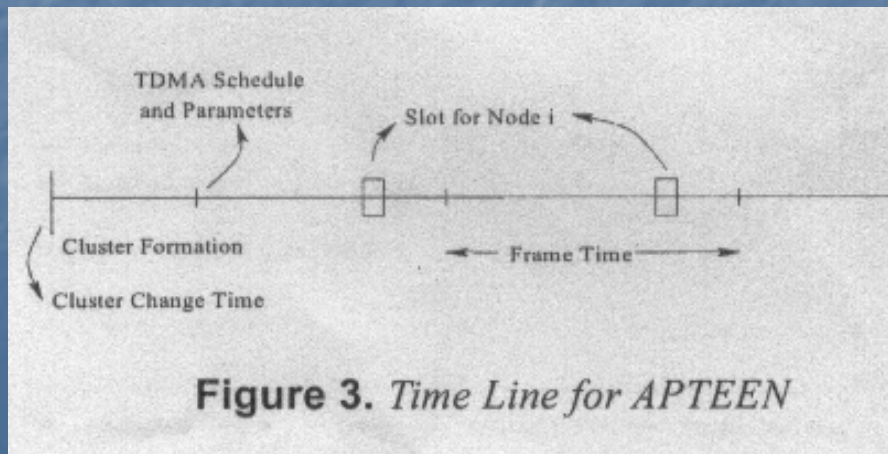
Important Features

- sending periodic data

- responds immediately to drastic changes

- offers a flexibility to set the time interval (TC) and the threshold values

- Energy consumption can be controlled

- can emulate a proactive network or a reactive network

Query Modeling

- flat topology and cluster-based approach
- In a hierarchical cluster, only the CH needs to aggregate and so it seems more efficient
- we can form pairs of two nodes and make only one node from each pair respond to a query
- two nodes can alternately take the role of handling queries

RN → Nodes requesting the query   A, C → Nodes not satisfying the query
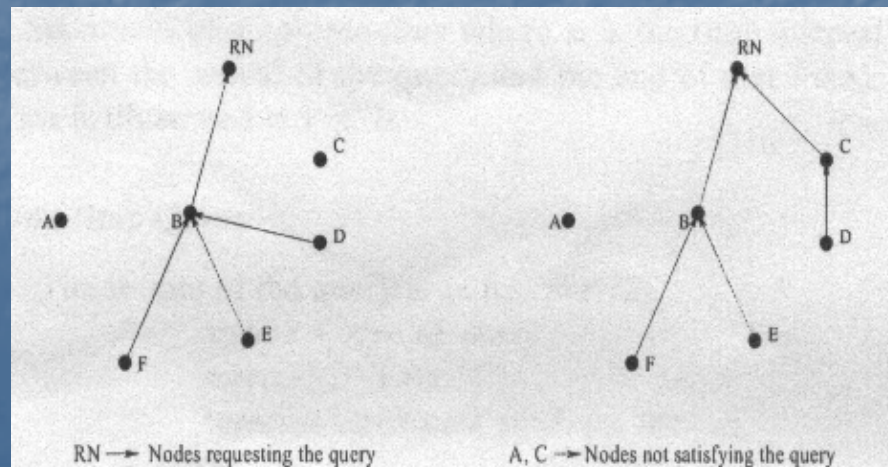
Modified TDMA Schedule (1)

- The nodes which listen for the queries have to be always awake

- idle nodes will have more data to send if they receive queries

- slots for these idle nodes have to be larger than the slots for the sleeping nodes.

Modified TDMA Schedule (2)

- 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
- 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

Modified TDMA Schedule (3)

- The CH aggregates all the data and sends it to its higher level CH

- 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

Modified TDMA Schedule (4)

- Different CDMA code is used in each cluster to avoid inter-cluster collision
- BS should not transmit to the nodes when the nodes are transmitting data to their CHs in their slots
- assign a separate slot for the BS and include it in the TDMA schedule
- each cluster might have different number of members, leading to different TDMA frame lengths

Query Routing(1)

- **Historical Query**
  - The node that receives this query transmits it to its CH in its slot
  - CH aggregates all the data and transmits it to the BS at the end of the schedule
  - BS checks the query type and retrieves the answer
  - node gets the answer in a minimum of x and a maximum of x + frame-time

Figure 6. *Handling of History queries*
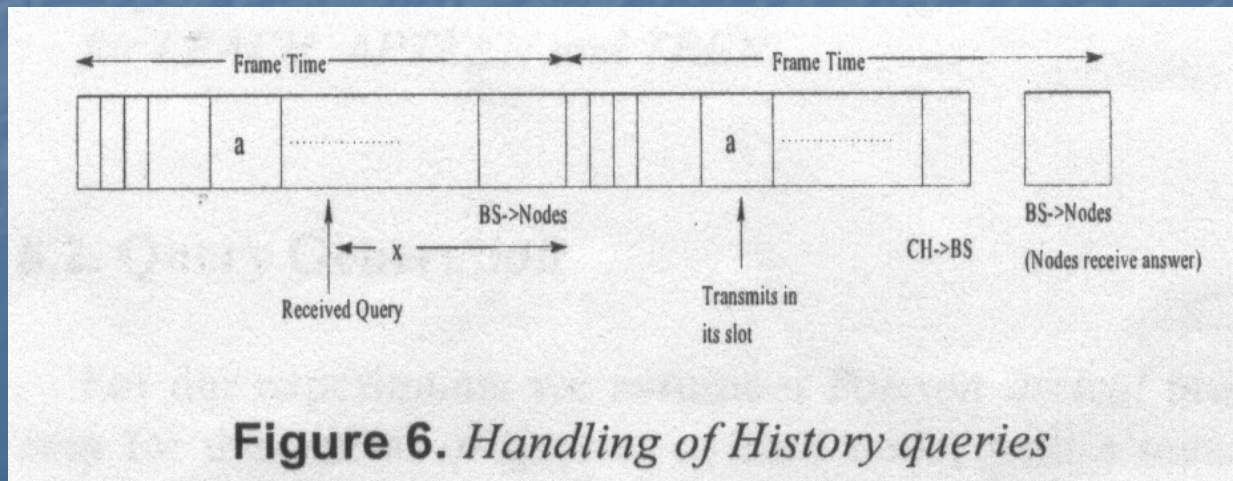
Query Routing(2)

- One-time Query
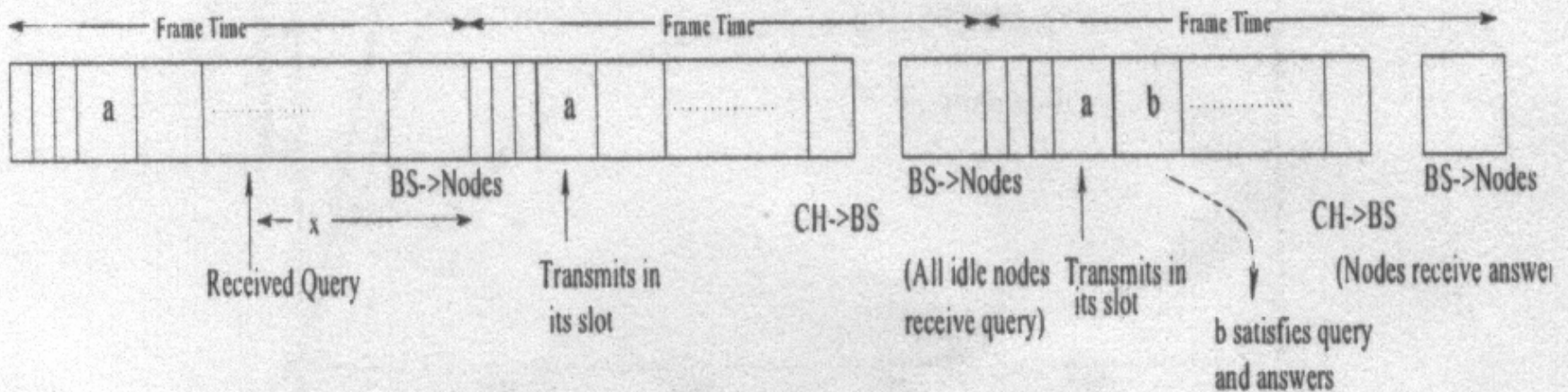
Figure 7. *Handling of One-time queries*

Query Routing(3)

- Persistent Query
  - This type of query is handled almost exactly as the one-time query
  - The initial delay is the same as that of the one-time query
  - the delay is one frame-time for the duration of the query

Performance Evaluation

- 100 nodes and a fixed base station
- placed randomly in the network
- All the nodes start with an initial energy of 2J

Experiments

- analyze and compare the effect of queries on our protocol
  - Average energy dissipated
  - Total number of nodes alive
  - Total number of data signals received at BS
  - Average Delay

Results(1)
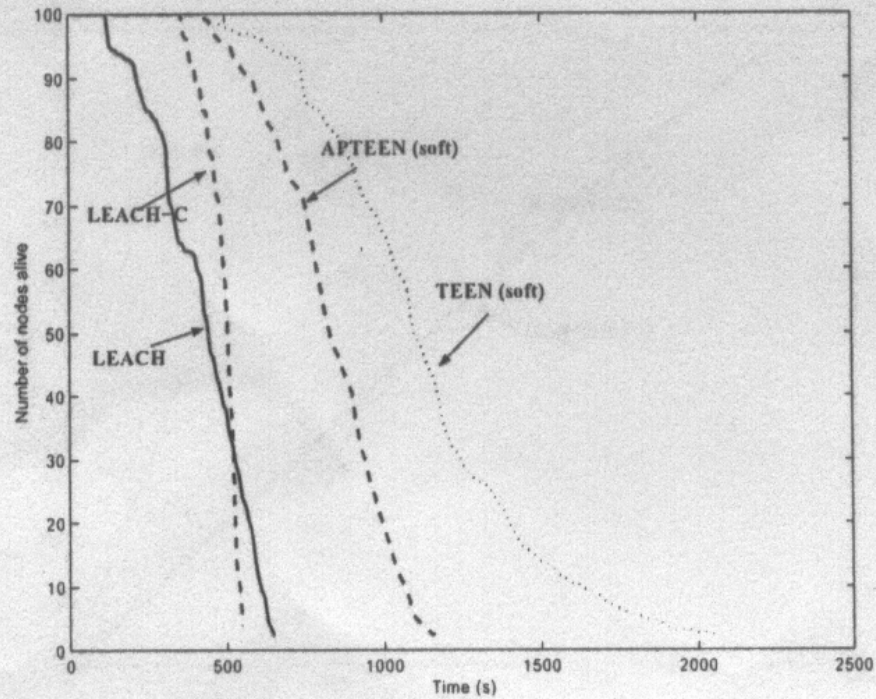
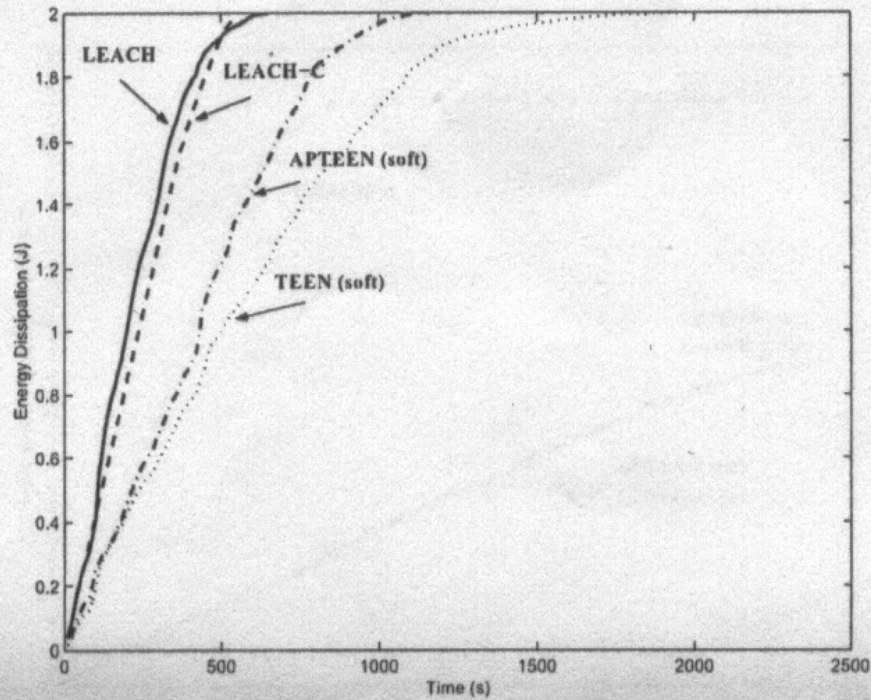**Figure 8.** *Comparison of the no. of nodes alive for LEACH, APTEEN and TEEN*

Results(2)

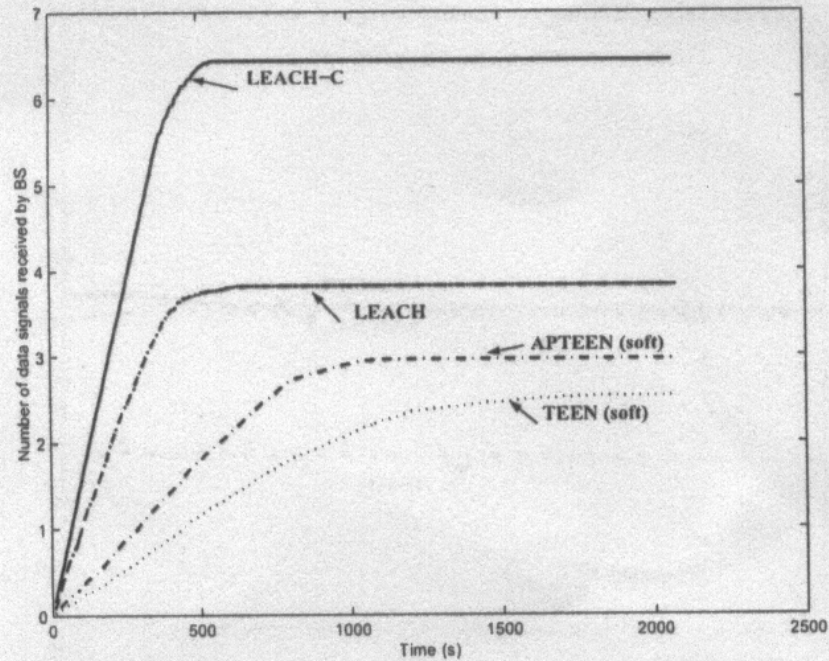**Figure 9.** *Comparison of average energy dissipation for LEACH, APTEEN and TEEN*

Results(3)

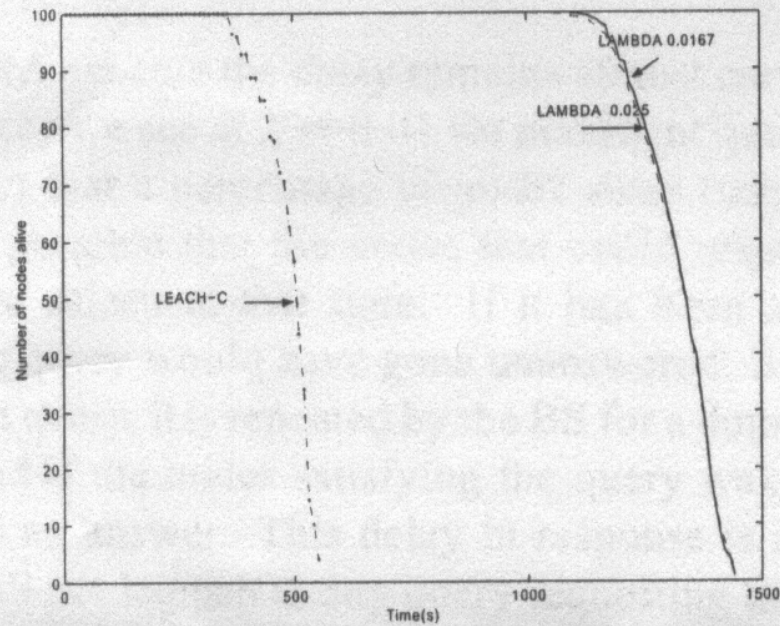**Figure 10.** *Total data received at the BS over time*

Results(4)

Figure 11. *Effect of queries on APTEEN*
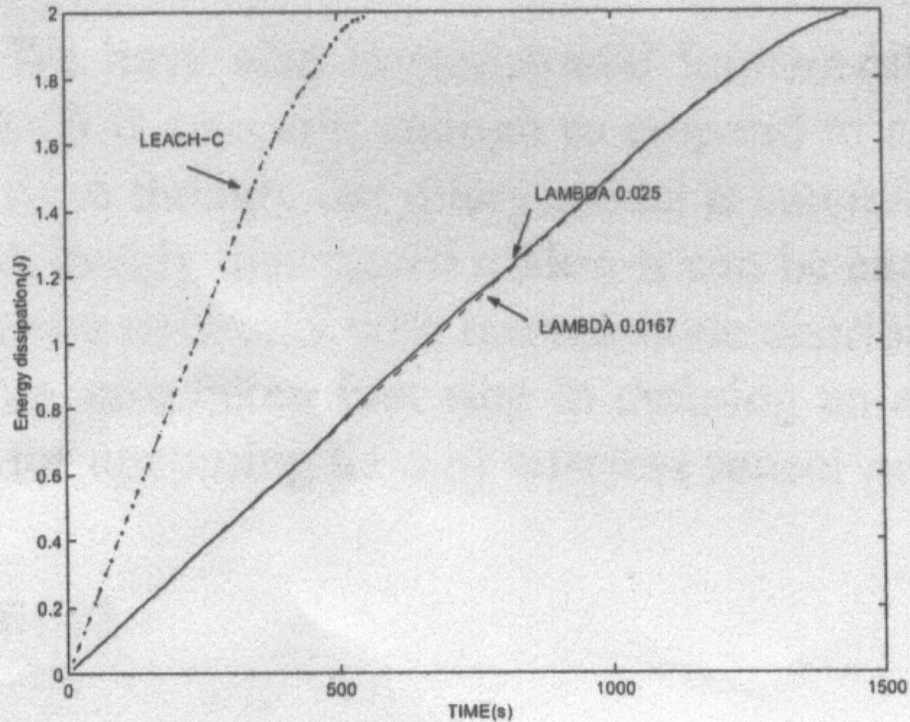
Results(5)

Figure 12. *Effect of queries on energy consumption in APTEEN*
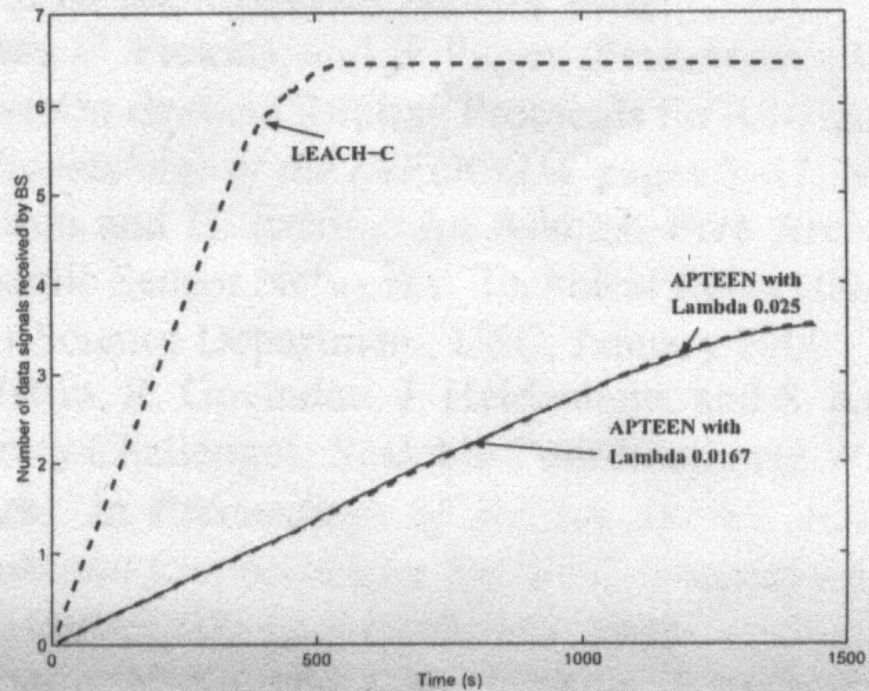
Results(6)

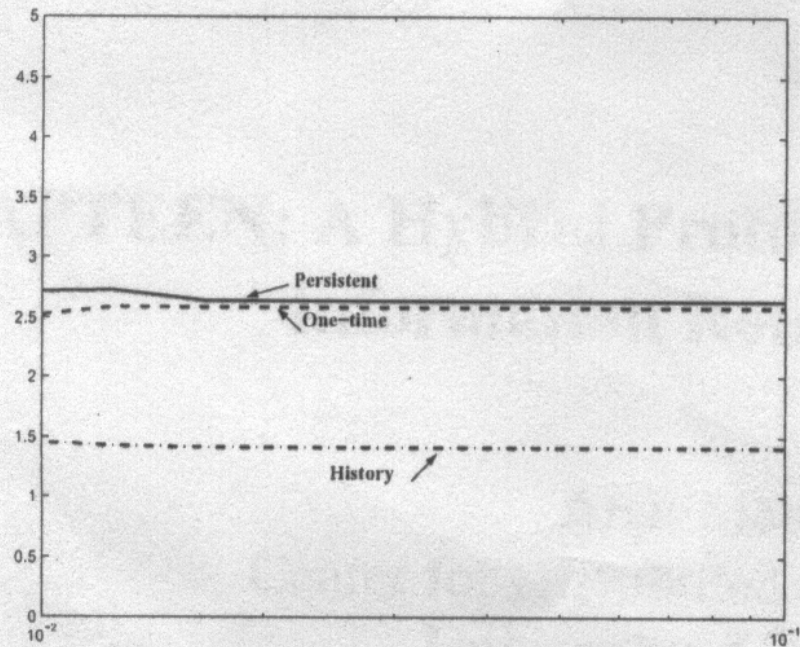**Figure 13.** *Effect of queries on the total data re-ceived*

Results(7)

Figure 14. *Variation in response time with* λ

Conclusions

- we have introduced Hybrid protocol APTEEN which combines the best features of both proactive and reactive networks

- provide periodic data collection as well as near real-time warnings about critical events

- our query model is suitable for a network with evenly distributed nodes

- it can be extended further to sensor networks with uneven node distributions