Robust data dissemination protocols in Sensor Networks

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Outline

- Features of sensor networks
- Goals of ‘robust’ data dissemination protocols
- Protocols
  - Zone Routing Protocol (ZRP)
  - LEACH
  - PEGASIS
  - TEEN & APTEEN
  - TTDD
  - SPIN
  - SPMS etc.
Features of sensor networks

- Self organizing network without a fixed network infrastructure
- Energy constraints: Powered by batteries
- Latency: Critical data may be time sensitive
- Data from neighboring nodes are correlated
- Hostile environment: Prone to node and link failures
Goals of Robust Data Dissemination Protocols

- Fault tolerant
- Minimize energy drain on batteries
- Reduce redundant energy transmissions
- Distribute data between nodes as quickly as possible
Zone Routing Protocol (ZRP)

- Paper by Zygmunt Haas & Marc Pearlman analyses the performance of query control schemes for ZRP in ad-hoc networks
- Classifies existing routing protocols as
  - Proactive
    - Continuous evaluation of routes within the network
    - Advantage: Little delay prior to transmission
    - Use a large portion of the network capacity
    - Information transmitted may be useless
ZRP (Contd.)

- Reactive
  - On-demand route determination procedure
  - Route queries are flooded across network
  - Significant delay involved to determine a route

- ZRP: Hybrid reactive/proactive scheme
- Routing ‘Zone’: Collection of nodes whose minimum distance in hops from a node is no greater than a parameter: ‘zone radius’
- Each node has its own routing zone
ZRP: Intrazone Routing Protocol (IARP)

- A node proactively maintains routes to nodes within its routing zone
- Routing zone construction requires a node to discover its neighbors (with whom a direct connection can be established)
- Neighbor discovery protocol can be used
ZRP: Interzone Routing Protocol (IERP)

- Acquires routes to nodes beyond routing zone
- Bordercasting: Efficient sending of information to peripheral nodes
- Bordercasting provided by Bordercast Resolution Protocol (BRP)
- IERP query is bordercasted and the route accumulated from source to current routing zone
Peripheral nodes further bordercast if the destination doesn’t appear in the node’s routing zone

Bordercast tree construction:
- For ‘distributed’ bordercast, each member must be able to independently reconstruct the tree
- Requires each node to proactively track an extended routing zone
When a node bordercasts a query, its entire routing zone is covered by the query.

To reduce excess query traffic, queries should be directed outward from the query source and away from covered routing zones.

Query detection to prevent query overlap.

QD1: All relaying nodes along bordercast tree detect the query.
ZRP: Query Control Mechanisms

- QD2: Eavesdropping to detect a query
- Query detection table: Query source node’s address & query id
- Early termination (ET):
  - Use extended routing zone to prune transmissions in already covered regions
  - Don’t relay a query to a peripheral node a second time
ZRP: Query Control Mechanisms

- Random Query Processing Delay (RQPD):
  - Query overlap during broadcast propagation window before detection by QD
  - Each bordercasting node schedules a random delay prior to bordercast tree construction & ET

- Results show minimization of control traffic and near-optimal route discover delay
LEACH

- Stands for ‘Low energy adaptive clustering hierarchy’
- To send data from sensor nodes to a Base Station (BS)
- Motivation:
  - Correlated data can be fused into effective data & sent to BS
  - Correlated data is more likely in closely spaced sensor nodes
LEACH: Assumptions

- All nodes can transmit with enough power to reach the BS
- Nodes can use power control to vary transmit power
- A node always has data to send to the BS whenever it is its turn to transmit
LEACH: Operation

- Nodes organize themselves into local clusters with one node as cluster head per cluster
- Non cluster head nodes transmit data to cluster-head
- Cluster head aggregates data & transmits data to the BS
- Randomized rotation of energy intensive cluster heads
Operation is divided into ‘rounds’

- **Set-up phase:** Clusters are organized
- **Steady state phase:** Data is transmitted from nodes to cluster head and on to the BS
- **Cluster head selection:** Distributed algorithm without any centralized control
- **Probability that each node becomes a cluster head depends on**
  - the number of clusters in each round (assumed constant = k)
LEACH: Operation

- Whether a node has been a cluster head previously

* Assume nodes start with equal energy then nodes will again be of equal energy after $N/k$ rounds ($N=\text{total no of nodes}$)

* If nodes have unequal amounts of energy the probability is modified so that higher energy nodes will become cluster heads more often
  - Requires an estimate of the total energy of nodes in the network
LEACH: Cluster formation

- Cluster head broadcast ADV using CSMA
- Each non-cluster head node determines its cluster head depending on strongest received signal strength
- Then sends Join-REQ message to the chosen cluster head
- Cluster head then creates TDMA schedule & sends it to other nodes in its cluster
Cluster formation algorithm: Flowchart

Source: Heinzelman et al: Ref. 2
LEACH: Steady state phase

- Frames: Node sends data to cluster-head at most once per frame during its transmission slot
- Assumption: All nodes are time synchronized
- Ensures no collisions between data messages
- Each non-cluster head node sleeps except during its transmit time
LEACH: Steady state phase (Contd.)

- Energy dissipation is reduced by power control by each non-cluster head node (based on the received strength of ADV)
- Cluster head performs data aggregation & sends to the BS (CSMA): high energy transmission
- Inter-cluster interference:
  - Each cluster uses unique spreading code in DSSS
  - Power control also reduces inter-cluster interference
LEACH-Centralized (LEACH-C)

- Central control algorithm to form clusters disperses cluster head nodes
- Setup phase: Each node sends its location & energy level to BS
- BS finds ‘optimal’ clusters and broadcasts cluster head ID for each node
- Attempt to minimize energy for non-cluster head nodes to transmit data to cluster head
- Same steady state protocol as LEACH
LEACH: Results

- LEACH-C performs better than LEACH
- Delivers 40% more data per unit energy than LEACH
- Performs better than CSMA protocols as collisions are avoided
- Better than static clustering where cluster head nodes will die quickly
LEACH: Comments

- All nodes may not need to communicate with the cluster head all the time: waste of time slot
- All nodes must be within range of BS: Limits scalability
- Proposal of ‘super-clusters’: hierarchy
- Alternative: Multihop backbone formed by cluster head nodes
LEACH: Comparison of energies

- Calculation for 100 nodes and 4 clusters:
  
  Cluster head node:
  
  Energy for reception: $1.2 \times 10^{-6}$ J/bit
  Energy for Data aggregation: $1.25 \times 10^{-7}$ J/bit
  Energy for transmitting to BS: $4.21 \times 10^{-7}$ J/bit
  
  (Assuming BS is 130 m from CH in 100*100m grid)

  Non-Cluster Head node:
  
  Energy spent: $5.397 \times 10^{-8}$ J/bit

  Ratio of energies CH/Non-CH = 32.35
PEGASIS

- Stands for ‘Power Efficient Gathering in Sensor Information Systems’
- Extension of LEACH
- Better performance over LEACH: 100-200 %
- Tries to reduce overhead of cluster formation in LEACH
PEGASIS: Assumptions

- Each sensor node has power control & it can transmit to any other sensor node or directly to the BS.
- All sensor nodes have initial uniform energy and are homogeneous.
- Every node has location information.
- No mobility.
PEGASIS: Operation

- Each node takes turns to be the leader for transmission to the BS
- Nodes form a chain which is either computed in centralized manner or by the nodes themselves assuming they have global knowledge
- Start from furthest node from BS
- Select the next node on the chain to be the closest neighbor to the previous node
PEGASIS: Operation

- Each node fuses own data with neighbor’s data and transmits to next node
- Nodes take turns transmitting to the BS
- Each round of data collection is initiated by BS with a beacon signal which synchronizes all nodes
- All nodes synchronized so a time slot approach is used
- Token passing alternative is also suggested
PEGASIS: Token passing approach

- c2 is leader and passes token to c0. c0 sends data to c1 which fuses its data with c0’s and sends it to c2.
- c2 then passes token to c4. c4 then transmits to c3 which fuses its data with it and sends to c2.
- c2 then fuses both the data it received and transmits to the BS.
PEGASIS: Operation (Contd.)

- Some nodes may have relatively distant neighbors along the chain, then they dissipate more energy.
- Prevented by setting a threshold on neighbor distance and not allowing nodes with distant neighbors to become leaders.
Energy $\times$ Delay metric

- Generally, Minimizing energy in transmission leads to an increase in delay.
- Tradeoff between energy spent and delay leads to their product being used as a metric.
- New protocols proposed for data gathering that minimize this metric for CDMA and non-CDMA sensor nodes.
Protocol for CDMA capable sensor nodes

- Such nodes can use distinct codes to minimize interference
- Hierarchy of nodes is created
- Lowest level is linear chain as in PEGASIS so adjacent nodes are nearby
- Nodes that receive at each level are the only nodes that are active in the next level
- Saves in delay as many nodes are allowed to transmit simultaneously with different codes
Protocol for non-CDMA sensor nodes

- Protocol for CDMA will lead to unacceptable interference for non-CDMA nodes
- Chain-based 3-level scheme suggested
- Start with the linear chain and divide it into $G$ groups of $N/G$ nodes each
- One node from each group is active at the second level
- In second level, $G$ groups divided into two groups
Protocol (Contd.)

- Third level has just two nodes, out of which one will transmit to BS
- This allows simultaneous transmissions far apart for minimal interference and low delay
- Best G found by experimentation to be 10 in a 100 node case
- Three levels gave best balance of energy and delay
Results

- PEGASIS achieves balanced energy dissipation
- Two-Three times no of rounds as compared to LEACH
- Chain based scheme binary scheme is about 5-13 times better than LEACH in minimizing energy*delay metric
- Chain based binary and three-level schemes achieve balanced energy dissipation
References

