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

ZRP: Interzone Routing Protocol (IERP) (Contd.)

- 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

ZRP: Query Control Mechanisms

- 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

LEACH : Operation

- 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)

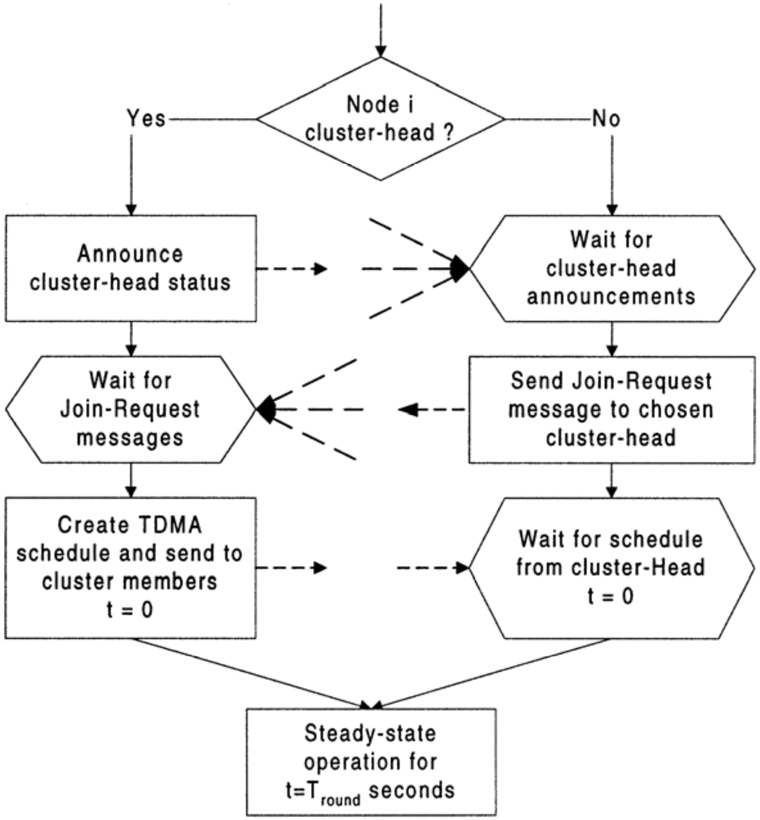
LEACH : Operation

  - 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=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: $1.2 * 10^{-6}$ J/bit

  Energy for Data aggregation: $1.25 * 10^{-7}$ J/bit

  Energy for transmitting to BS: $4.21 * 10^{-7}$ J/bit

  (Assuming BS is 130 m from CH in 100*100m grid)

  Non-Cluster Head node:

  Energy spent: $5.397 * 10^{-8}$ 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

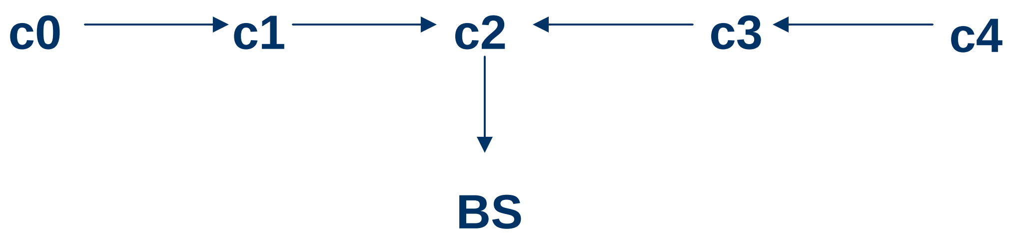
PEGASIS: Operation

- 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

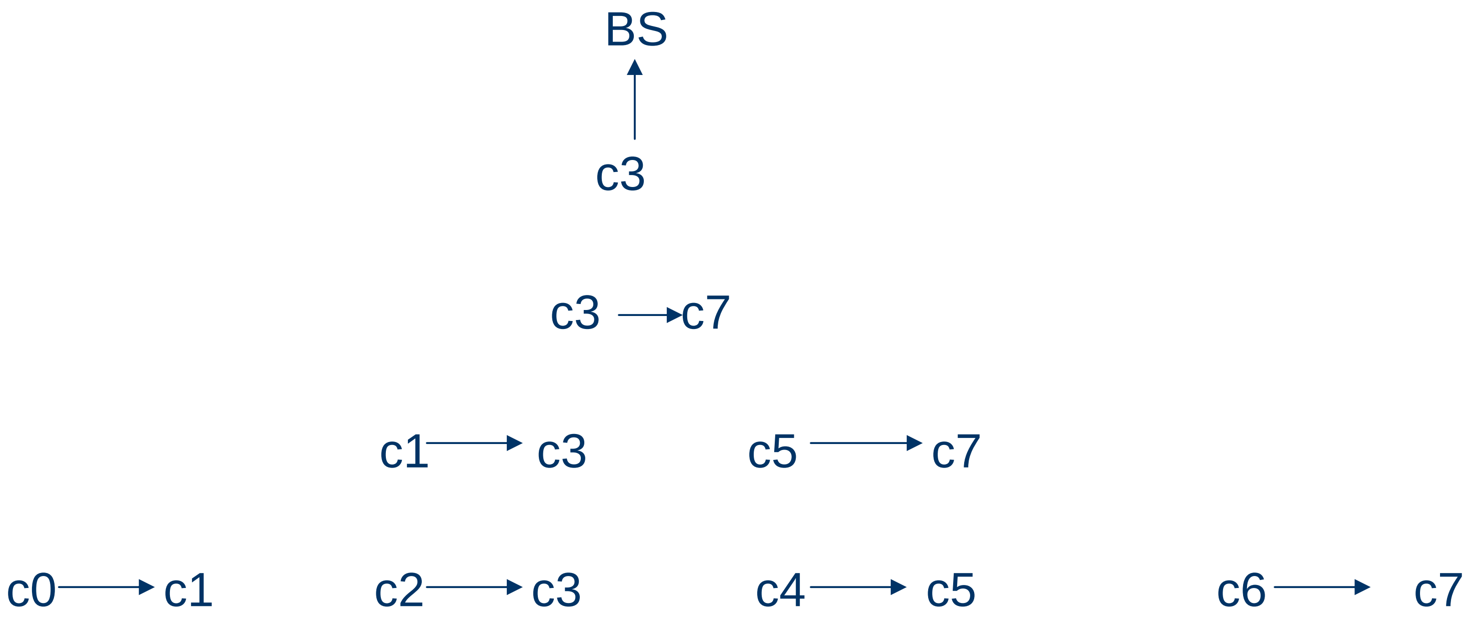
Energy $\times$ Delay metric

- Generally, Minimizing energy in transmission leads to 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 (Contd.)



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

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