Fault Tolerant and Energy Aware Data Dissemination Protocol for Sensor Networks

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Outline

- Motivation
- Current Data Dissemination Protocols
- SPMS : Design Features
- Analytical Analysis and Theoretical Results
- Experiments and Results
- Conclusions and Future work

Motivation : Reliability against Failures

- Sensor Networks are fast becoming a part of critical applications
  - Civilian applications like Emergency rescue and relief, Health Monitoring
  - Military applications like Surveillance
- Sensor Networks are susceptible to failures and attacks
  - Due to natural causes or malicious causes
  - Temporary or permanent failures of nodes or links
- Reliability in data collection is important but hard to achieve
  - Energy Constraints
  - Delay Constraints
  - Limited capabilities in terms of storage and processing
  - Susceptible to collective failures

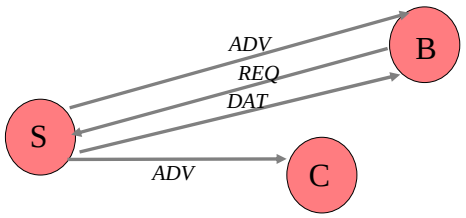
Existing Data Dissemination Protocols

- Can be broadly classified into PUSH and PULL based
  - PUSH : Sensors send the data at regular intervals to a sink node
  - PULL : Sensors store the data and data is collected using a polling mechanism either by a sink node or by a passing object (like an aircraft).
- Broadcast and Gossip have been used to provide reliability but use redundant transmission leading to wastage of energy.
- POACH:
  - Determine Servers to cache data in order to minimize the cost of data dissemination.
- TTDD
  - Sets up a grid structure and proactively determines routing from data source to sink
  - At runtime, when sink needs data it locates a close by “dissemination point” which uses pre-computed route from source to sink
  - Drawbacks: Cost of setting up entire routing grid

Example Protocols

- SPIN
  - Use meta data transmissions to reduce redundant transmissions
  - Advertise the data prior to sending the data.
  - Efficient in case of collisions.
  - Mix of Push and Pull mechanisms.

SPIN



S: Sender
B: Interested node
C: Disinterested node

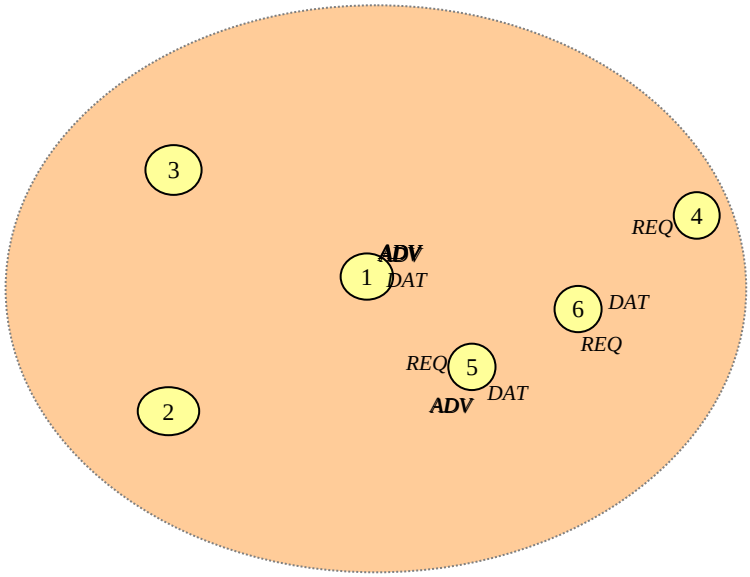
Example Protocols (Contd.)

- LEACH
  - Form clusters to send data collectively
  - Rotate cluster heads
  - Two level hierarchy
- PEGASIS
  - Extending LEACH to a three level hierarchy
  - Single node sends data to the base station.

Reliability in Existing Protocols

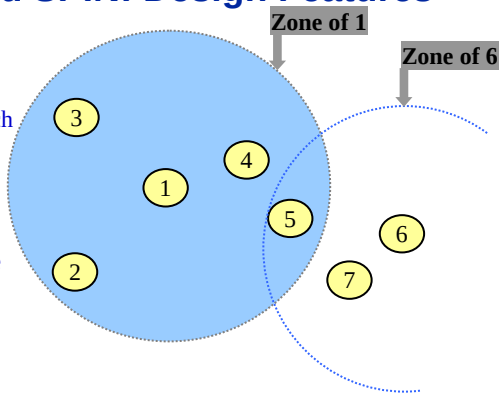
- Current Protocols are not designed to address the issue of failures in the sensors.
  - Either the data is lost in case of a failure
  - Broadcast and Gossip do address failures but are wasteful in terms of resources.
- Protocols use direct communication between the nodes and the base stations
  - Not feasible in practical larger sensor networks
  - Direct communication leads to more energy consumption. eg: SPIN, LEACH
- Several times a central controller (agency) is employed leading to a fall of the distributed nature of the protocol.
  - Setting up Grid structure in the TTDD.
- Solutions have addressed attacks in sensor networks but addressing simple and most common issue of natural failures seems to be lacking.

Shortest Path Minded SPIN (SPMS)



Shortest Path Minded SPIN: Design Features

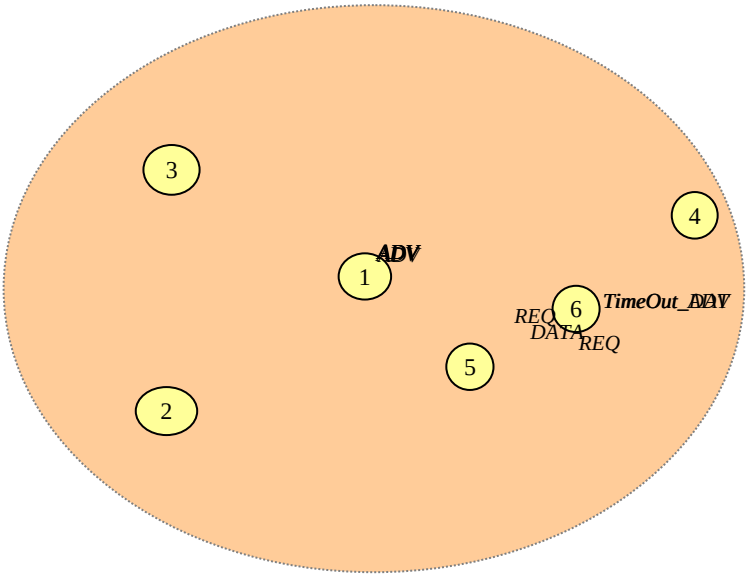
- Zone
  - Maximum distance a node can reach using the maximum power level
  - Node can adjust its power levels to reach all nodes (neighbors) in its zone.
  - Routing tables for Neighbors in the zone using Bellman Ford.
  - Tables contain the power level for each neighbor.
- Timers
  - TimeOut_ADV : Nodes wait for the data to come to the ***nearest node*** before sending REQ.
  - TimeOut_DAT: Nodes wait for the data after sending the REQ packet



SPMS Protocol : Failure Scenario

- Failure of an intermediate node
  - Could take place before or after sending the ADV
  - Not ADV a data can also be misinterpreted as failures and vice versa.
  - Node stores the neighbors which have advertised the data
    - PRONE : Primary Originator Node
    - SCONE : Secondary Originator Node
- Resilience to Failures
  - After a TimeOut_ADV node sends the request for data to PRONE through the shortest path
  - DATA is also received using the same path if there is no failure
  - Incase of a failure :TimeOut_DAT occurs
  - Node directly sends the REQ packet to PRONE
  - In case PRONE is also not responding then the REQ is sent to SCONE

SPMS : Failure Scenario



Energy and Delay: Analytical Analysis

- In case of *K* relay nodes between two nodes the delay in receiving the packet can be calculated using the inequality below

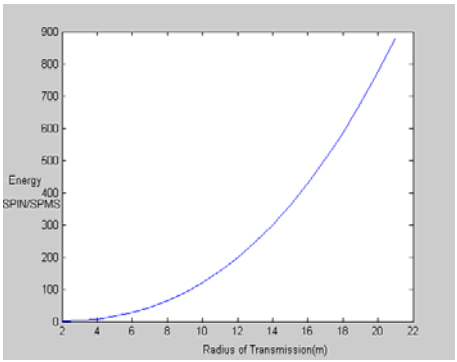
$$Delay_{failurefree} \le (K-1)T_{round} + TOut_{ADV} + T_{c2}$$

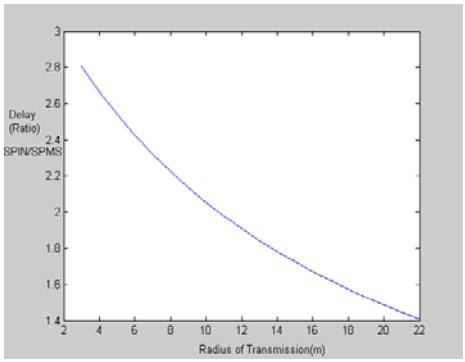
$$Delay_{failure} = (k-j)T_{round} + TOut_{ADV} + G.ns^2 + TOut_{DAT} + 2G.nj^2 + (R+D)T_{tx} + 2T_{proc}$$

- The ratio of energy between SPIN and SPMS can be given by :

$$E_{SPIN} : E_{SPMS} = \frac{E_1 + E_r}{k.f.E_1 + k.E_m + k.E_r}$$

Energy and Delay Comparisons: Equation Plots





SPIN uses more energy than SPMS as relay nodes increase.

Delay increases in SPIN than SPMS as relay nodes increase.

Simulations

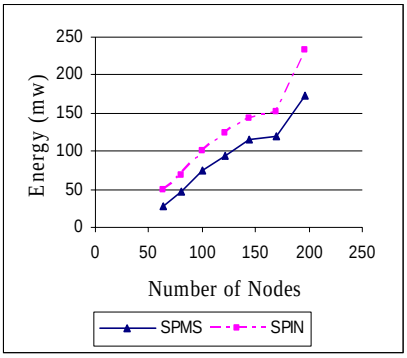
- SPMS protocol is implemented and compared with SPIN
  - Uniform density of Nodes which are placed on a Grid.
  - We vary the transmission radii and the number of nodes.
- Crossbow data sheet is used to calculate the Power spent in transmission and receiving packets.
  - Nodes can only transmit at 5 energy levels considered in our experiments.
  - ADV and REQ packet are considered to be 2 bytes and DATA packets are 40 bytes long.
  - Inter Packet arrival time is Exponential.
- Experiments are carried out for two topologies
  - **All to All communication :** Every node requests every other nodes data.
  - **Cluster Based Hierarchical Communication:** Cluster Heads collect the data and send it to the sink using SPMS.
- Experiments for failure free and failure scenarios
  - Failures are transient and follow exponential inter-arrival times

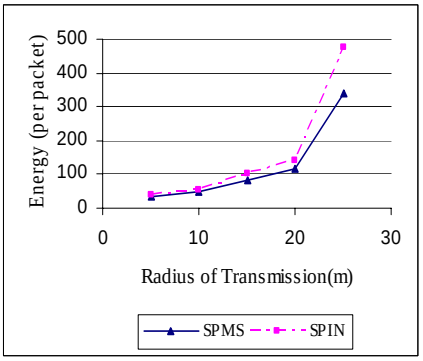
DK1

Slide 14

DK1 Leave such details out and include them in the talking points
Darpan, 06/26/2004

Results for Failure Free Scenario: Energy Metric





SPMS saves about 23-46% energy compared to SPIN with varying number of nodes

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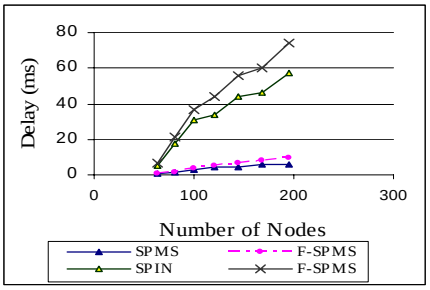
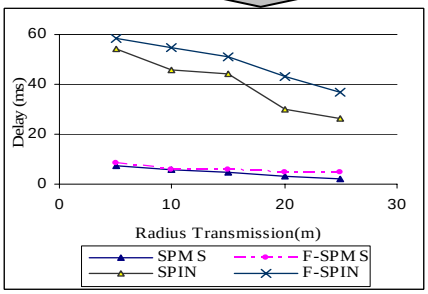
Results for Failure Free and Failure Scenario: Delay Metric

SPIN incurs 10 times more delay





- Delay gradient is more for SPIN with increasing number of nodes. SB2
- Delay difference decreases with radius of transmission for both SPIN and SPMS.
- SPMS disseminates data much faster compared to SPIN in both failure and failure free scenarios SB3

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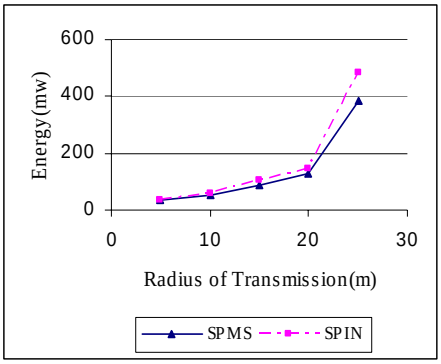
Slide 16

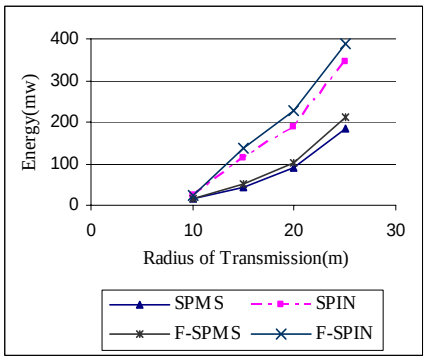
SB2 Not clear. You should probably say that the gradient for delay with # nodes is steeper in SPIN because more contention.
Saurabh Bagchi, 06/25/2004

SB3 Say why.
Do it consistently - either mention the observation and say why in the talk; or, give both observation and reason in the slide
Saurabh Bagchi, 06/25/2004

Energy Metric : Mobile Nodes and Cluster Based Communication



Mobile Nodes



Cluster Mechanism

SPMS saves about 21% energy compared to SPIN even with mobility.

SPMS saves 59% energy in Cluster Based Hierarchical communication.

Contributions and Conclusions

- Proposed an efficient protocol multi-hop protocol
  - Provide energy and delay savings
  - Operate in a distributed fashion
  - Resilience to Failures of intermediate nodes.
- Provided Theoretical and Simulation results
  - Both results are in agreement
- Can be effectively used with most applications
  - Adaptively used in many existing data dissemination
  - Varying from cluster based to even ad-hoc networks

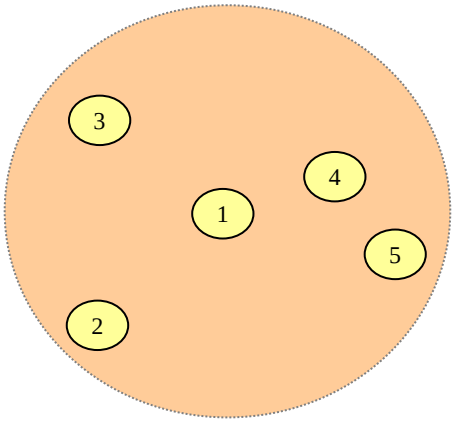
Future Work

- Implementation on actual Motes (TinyOS)
  - Evaluation can be carried out through a practical study
- Extensions
  - Adding Sleep mechanism
  - Detection of failures

Thank You

Shortest Path Minded SPIN (SPMS)

- Data Exchange
  - Sender sends ADV packet within the zone
  - Every node receiving ADV sets the sender as PRONE (and SCONE).
  - Interested ***one hop*** nodes send the REQ packet to request for the Data.
  - Nodes having sender as their PRONE are ***one hop*** away.
  - Wait for a ***nearer*** node to ADV the data.
  - Sender sends the DATA packet on receiving REQ.



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Results in a NutShell

- Static-Failure free scenarios
  - SPMS results in an overall 23-46% energy savings for failure free scenarios.
  - Delay gains are over 10 times as compared to SPIN.
- Static-failure scenarios
  - Performance in delay and energy metrics is better than SPIN.
- In mobile-failure scenarios
  - Energy savings reduce to 5-21% as compared to SPIN due to energy expended in bellman ford.
- Cluster Based Hierarchical communication
  - SPMS gains about 35-59% in energy
- SPMS ensures reliability of data dissemination even in case of failures.

Slide 22

SB5 This is not a quantitative result and should not come here.
Saurabh Bagchi, 06/25/2004