A Topology Discovery Algorithm for Sensor Networks with Applications to Network Management

Author: B. Deb, S. Bhatnagar and B. Nath

Presented by: Chinh Trung Vu

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SENSOR NETWORK MANANGEMENT

- MODEL:
  - Network topology
  - Energy Map
  - Usage Pattern
  - Cost Model
  - Non-deterministic Models
- MANAGEMENT FUNCTIONS
  - Deployment of sensors
  - Setting Network Operating Parameters
  - Monitor Network States using Network Models
  - Network Maintenance
  - Predict Future Network States
  - Design of Sensor Networks

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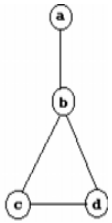
TOPOLOGY DESCOVERY

- Monitoring node (e.g., node a) initiates a "topology discovery request“ (TDR for short).
- This request diverges throughout the network
  - Through controlled flooding so that each node forwards exactly one message.
- Response action is set up
  - Each node can response with its neighborhood list
  - 3 approaches



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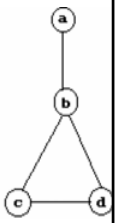
TOPOLOGY DESCOVERY (Cont.)

- Direct response.
  - When a node receives TDR, it forwards this mess. and response immediately.
- Aggregated Response
  - Wait for the children’s responses, aggregate data (include its own) and sends this to parent.
- Clustered Response
  - Divide network into clustered identified by cluster head who is in charge of responding the whole cluster’s information.
  - Giving reachability map



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CLUSTERED RESPONSE APPROACHES

- Combination of *Set Cover Problem* and *The Steiner Tree Problem.*
  - Require global information about the network
- TopDisc algorithm.
  - Based on Simple greedy *log(n)-approximation* algorithm.
  - 2 approaches:
    - Request Propagation with three colors
    - Request Propagation with four colors

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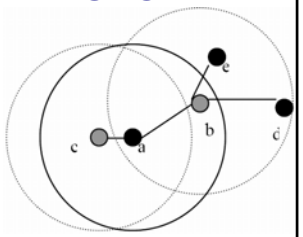
THREE COLORS APPROACH



- ***White:*** Undiscovered node.
- ***Black*****:** Cluster head node.
- ***Grey*****:** Node which is covered by at least one black node

ALGORITHM:

- Node a initiates the TDR and becomes Black
- White → Grey when receive TDR from Black node wait for random delay time before forwarding TDR.
- White → Black node with some random delay when receive TDR from Grey node (wait for message from black neighbor, if any)
- Grey and Black ignore all other TDRs.

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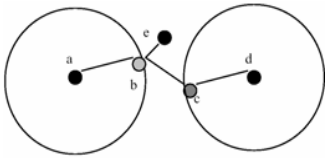
FOUR COLORS APPROACH



- ***Dark Grey*****:** Discovered but two hops away from a black node, i.e. neighbor of a grey node.
- Node a initiates the TDR and becomes Black
- White → Grey when receive TDR from Black node.
- White → Dark-Grey when receive TDR from Grey node. It starts a timer. At timeout, it become Black if no Black node covers it; otherwise, it becomes Grey node (I guess).
- White → Black with random delay when receive TDR from Dark-Grey node.
- Grey and Black ignore all other TDRs.

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AFTER CLUSTERING

- A clusters is identified by the black node.
- A Grey node knows its cluster id
- Each node knows its parent Black node.
- Each black node knows the default node to forward.
- All nodes have their neighborhood information.

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TopDisc Response Mechanism

- A node it sets up a timer to reply to the discovery request when becomes black.
- During that time, it aggregates all neighborhood lists from its children and itself
- Forwards the aggregated neighborhood list to the default node when time expires.
- All forwarding nodes in between black nodes may add their neighborhood lists to the list from black nodes.

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TopDisc Response Mechanism (Cont.)

Condition for TopDisc Response Mechanism works properly:

- Timeouts of children black nodes must expire before its parent black node → timeout is inversely proportional to the number of hops
- Need an upper bound on the tree height

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Handling Channel Errors

Problem

- On clustering step, channel error does not create a significant impact.
- But in the response step, it does make big impact since packet is returned through single path → it get worse when data is aggregated up to monitoring node.

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Handling Channel Errors

Solution:

- Assume links are symmetrical.
- A child node can hear the packet that its parent forward (toward monitoring node) to check if its packet reach the parent.
- If it do not hear anything, it retransmit the packet.

Draw back:

- Need memory to store forwarded packet.
- More energy for retransmission.

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APPLICATIONS OF TOPOLOGY DISCOVERY

- Retrieving Network State
  - Connectivity Map: provided by The direct response and the aggregated response mechanisms
  - Reachability Map: Provided by The *TopDisc* mechanism
  - Energy Model
  - Usage Model:
- Data Dissemination and Aggregation
- Duty Cycle Assignment

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Duty Cycle Assignment

- Black nodes send a packet with information about its parent cluster and children clusters to all its neighbors.
- Considering a circular region of radius R/2
- Node inside that circle can decide to be active or sleep. It inform this event (becoming active or sleep) to all its neighbors.
- In case no node is in that circle, intermediate node is used
- Black node avoid sending duplicate packet with forwarding node.

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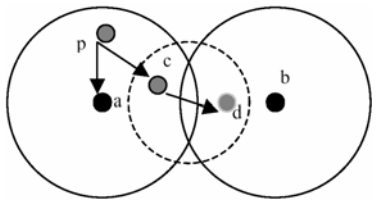
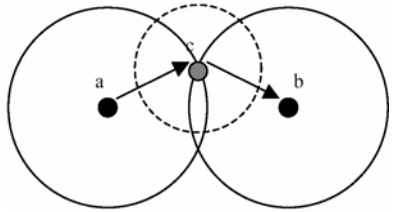
Duty Cycle Assignment - Example



Assigning up the duty cycle with location information



Assigning up the duty cycle without location information

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