Sensor Networks Routing

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Wireless Routing

- Many ad hoc wireless protocols use flooding for route discovery
  - AODV
  - DSR
- Sensor networks will be fairly dense so flooding and broadcast storm problems will have a significant negative impact
- Methods to reduce broadcast storm
  - Gossip
  - Virtual Backbone

Algorithm for Virtual Backbone

- Overview
  - Build a minimum connected dominating set (MCDS)
    - Definition: dominating set – subset of nodes, V` such that all other nodes, V – V` are adjacent to some node in V`.
    - Definition: connected – there is a path between any pair of nodes in the graph

Two Phases

- Construct a maximal independent set (MIS)
  - Definition: set of nodes such that no nodes are adjacent
  - Through the following construction each node contained in the MIS is exactly two hops from all others
- Construct a dominating tree
  - Definition: dominating set that also forms a tree

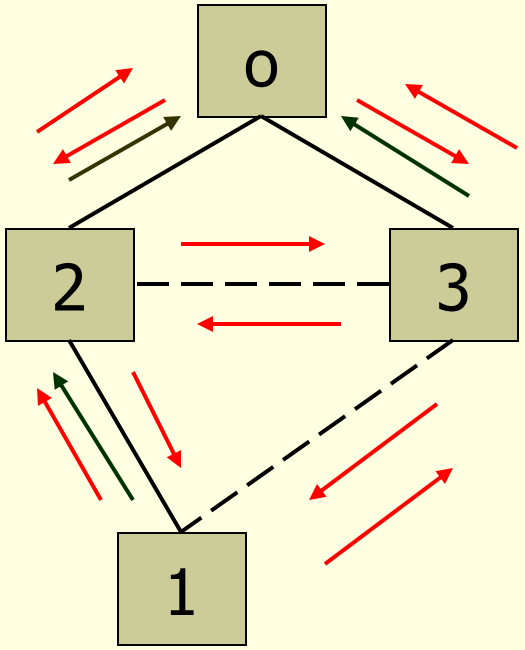
MIS

- Assume a rooted spanning tree T is given
- Each node has the following state
  - X1 - Number of neighbors whose levels have not been set
  - X2 - Number of children who have not reported completion
  - levelList - records levels of all neighbors
  - Y - number of lower-ranked neighbors

MIS Messages

- LEVEL – broadcasted down tree
  - Append sender's ID and level to levelList
  - Decrement X1
  - If sender is parent
    - Set your level to be sender's level + 1
  - If X1 == 0
    - Set y, number of lower-ranked neighbors, from levelList
  - If X2 == 0 and level has been determined
    - Send LEVEL-COMPLETE message to parent
- LEVEL – COMPLETE – directed up tree
  - Decrement X2
  - If X2 becomes 0
    - Reset X2 to number of children
    - Send LEVEL-COMPLETE message to parent

Example



ID	Level	X1	X2	levelList	Y
0	0	2	2	1,2;1,3	0
1	2	3	0	1,2;1,3	0
2	1	3	1	0,0;1,3;2,1	1
3	1	2	0	0,0;1,2;2,1	2

MIS coloring

- Coloring to finish building MIS
  - Initially all nodes are marked white and root is marked black
  - At the end all nodes will be gray or black
- Root broadcasts a BLACK message
  - BLACK message received
    - Add sender's ID to blackList
    - If white
      - Set gray and broadcast GRAY message (contains level and ID)
  - GRAY message received
    - If sender rank is lower
      - Decrement Y
      - If Y == 0
        - Set black and broadcast BLACK message

MIS coloring cont.

- When a leaf is set gray or black
  - Send MARK-COMPLETE to parent
- When MARK-COMPLETE received
  - Decrement X2
  - If X2 == 0
    - Send MARK-COMPLETE to parent
- When X2 of root is 0 the coloring is complete

Dominating Tree T*

- Node state
  - Z – boolean
    - Initialized to 0
    - Set to 1 after node joins T*
  - Parent – variable for ID
    - Initially empty
    - Set to the parent in T*
  - childrenList – list of Ids
    - Initially empty

Dominating Tree cont.

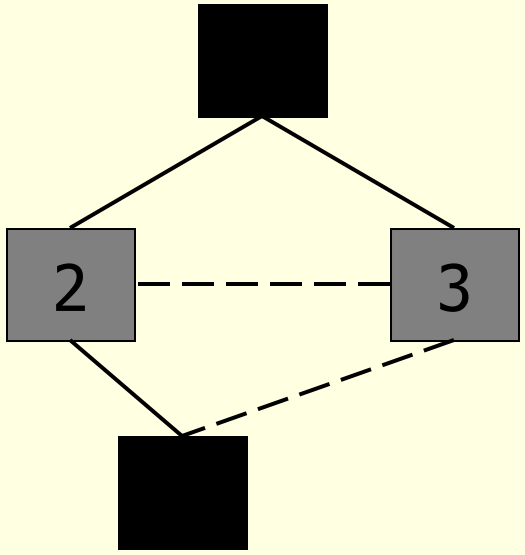
- Root of T* is (gray) neighbor of root of T that has largest number of black neighbors
- To find this node root of T resets X1 and broadcasts QUERY message and maintains
  - Root variable
  - Degree variable
- When QUERY is received
  - REPORT is sent to sender that contains
    - Number of black neighbors
- When REPORT is received
  - Decrement X1
  - If number of black neighbors in REPORT > Degree
    - Set Degree
    - Set Root
- When X1 == 0 at root of T
  - Send a ROOT message to the newly found root of T*

Dominating Tree cont

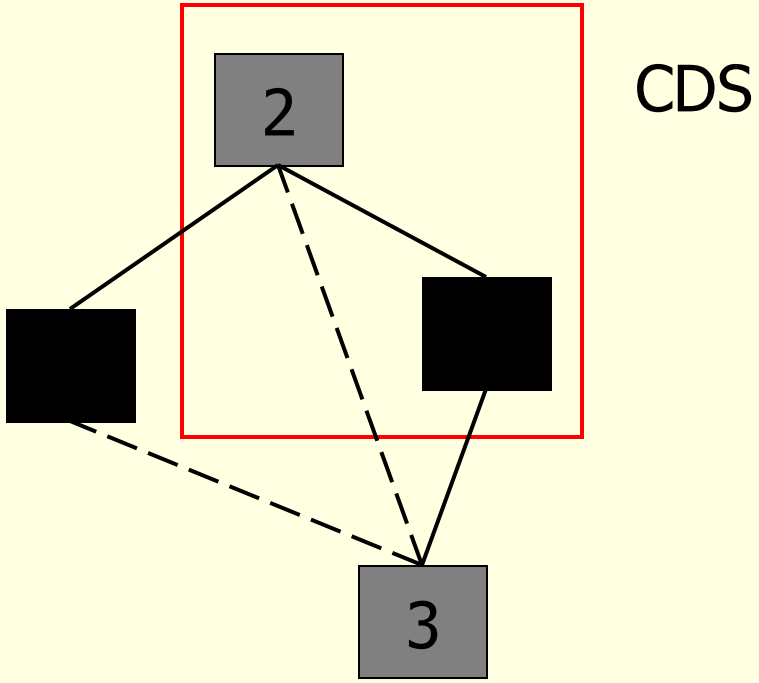
- When ROOT received
  - Set Z to 1
  - Broadcast INVITE2
- The rest of T* is built in the following manner
  - INVITE2 received
    - Black node with z == 0
      - Set z to 1
      - Parent to sender's ID
      - Send JOIN to Parent
      - Broadcast INVITE1
  - INVITE1 received
    - Gray node with z == 0
      - Set z to 1
      - Parent to the sender's ID
      - Send JOIN to Parent
      - Broadcast INVITE2
  - JOIN receive
    - Add sender's ID to childList

Dominating Tree cont.

- The connect dominating set is the internal vertices of T*

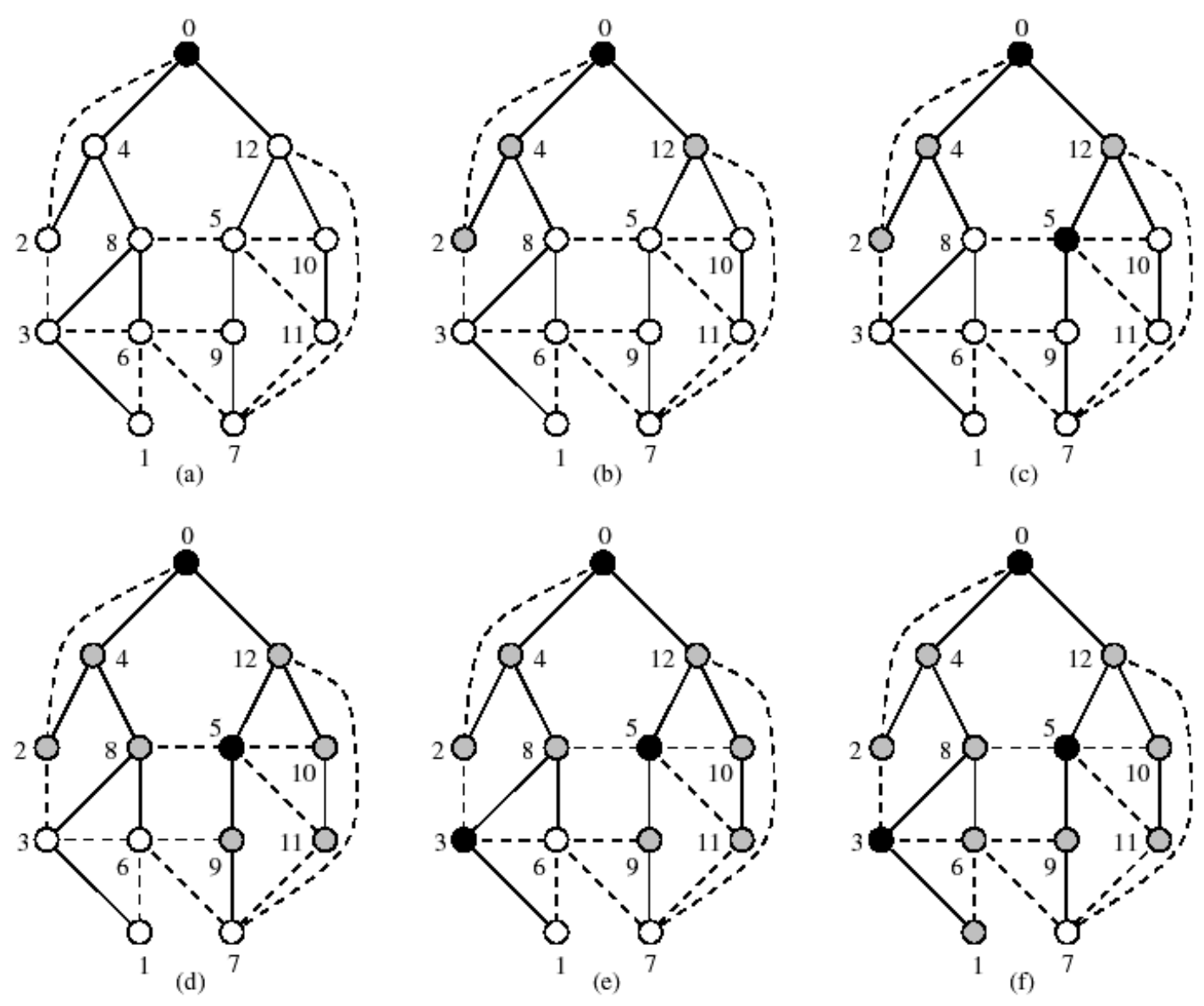


MIS

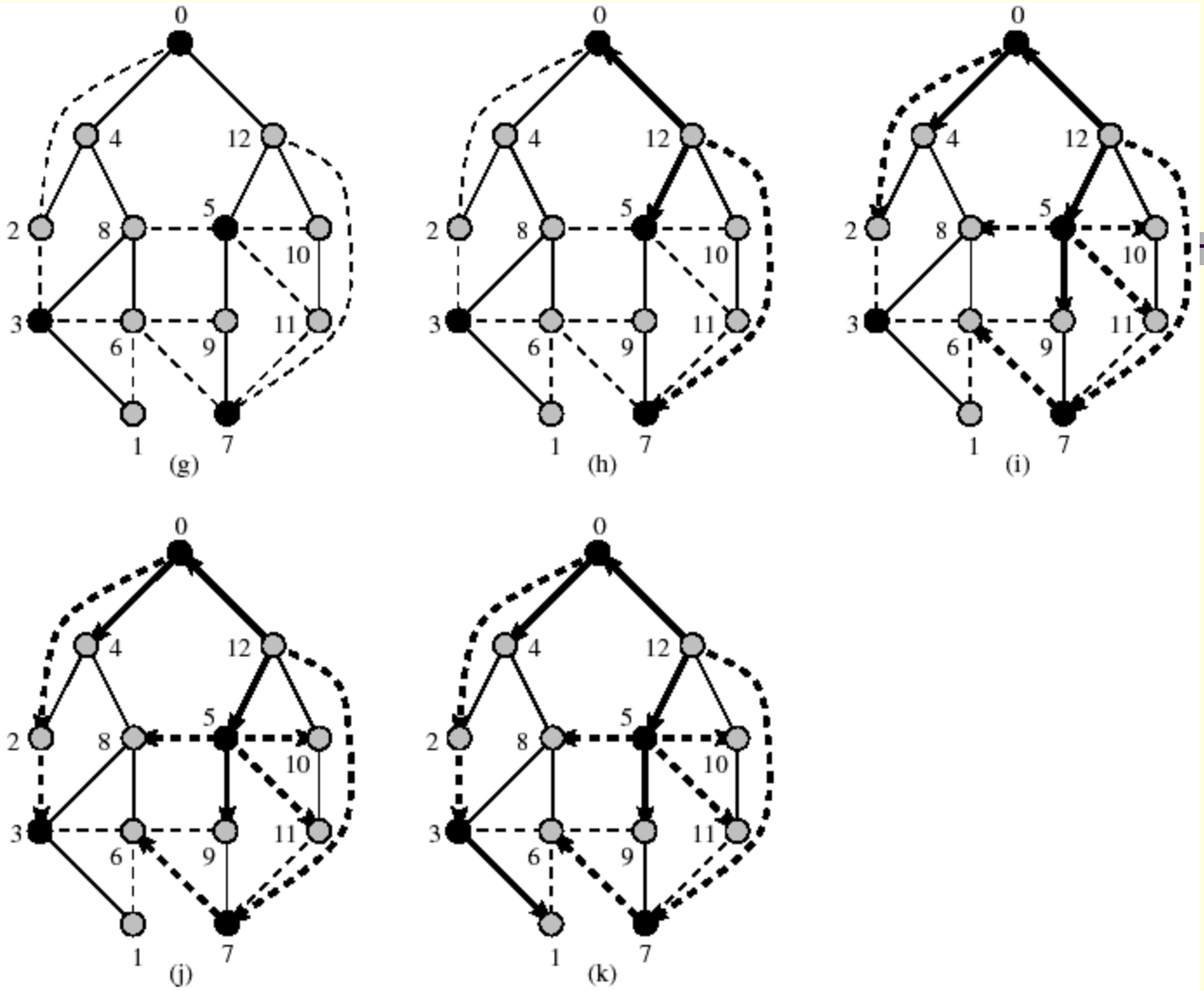


CDS

T*



Example 2



Example 2 cont.

Performance

- Since all messages were at most broadcasted locally and no messages need repeating
  - Messaging complexity – O(n)
  - Time complexity – O(n)
- However to build the initial rooted spanning tree using leader election requires
  - Messaging – O(n log n)
  - Time O(n)
- Overall performance is dominated by initial tree construction

Advantages

- Use virtual backbone to reduce messaging
  - On-demand routing over the backbone will remove the need for broadcast flooding

References

- Next Century Challenges: Mobile Networking for “Smart Dust” by J.M. Kahn, R. H. Katz, K. S. J. Pister
- Distributed Construction of Connected DominatingSet in Wireless Ad Hoc Networks by Peng-Jun Wan, Khaled M. Alzoubi, Ophir Frieder
- http://www-bsac.eecs.berkeley.edu/~warneke/SmartDust