Clustering for Sensor and Ad-hoc Networks

EE658 – Internet Engineering

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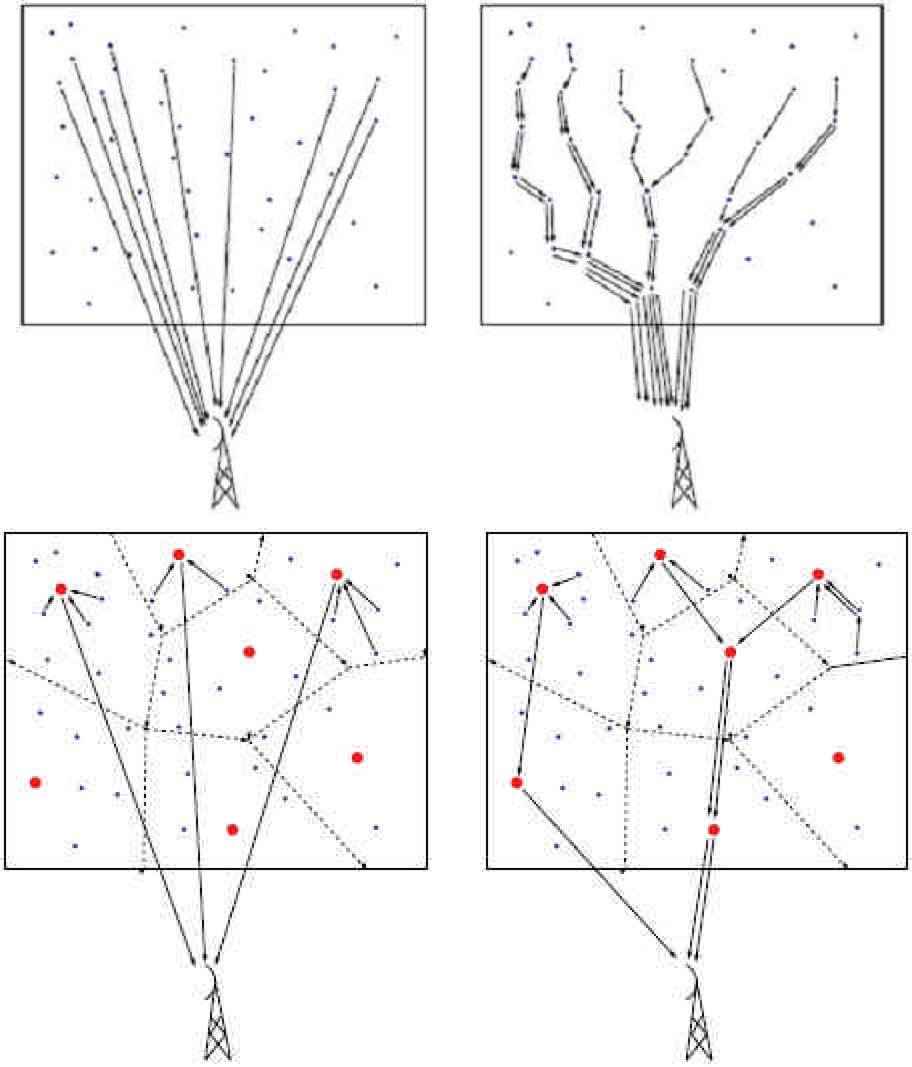
Outline

- Clustering - Why?
- Clustering for wireless ad-hoc networks
  - Lowest ID clustering
  - COINED
  - DCA & DMAC
- Clustering for wireless sensor networks
  - Energy efficient hierarchical clustering
  - LEACH
  - HEED
  - IEEE 802.15.4 cluster tree
  - Zigbee cluster tree
- Research challenges

Clustering - Why?



Source: [8]

Clustering - Pros & Cons

- Pros
  - Increased network lifetime
    - Load balancing by changing roles
  - Reduce channel contention & collisions
  - Suitable for large sensor fields
- Cons
  - Overhead of cluster formation & maintenance
  - Nodes near the CH get overloaded

Source: [1]

Comparison

- Ad-hoc Wireless Networks
  - Less energy constrained
  - Any-to-any
  - Mobile
  - Larger communication range
  - High bandwidth - Mbps
- Wireless Sensor Networks
  - Energy constrained
  - Mostly many-to-one
  - Static or quasi static
  - Lower communication range
  - Low bandwidth – Kbps
  - Autonomous

Process of Clustering

1. Cluster Head (CH) selection
   - Property - Node ID
   - Probabilistic
   - Weight based – residual energy, node degree
2. Execution of the algorithm
   - Centralized, distributed
3. Formation of a hierarchy/tree
4. Intercluster & intracluster communication
5. Handling network dynamics
   - Periodic, event driven

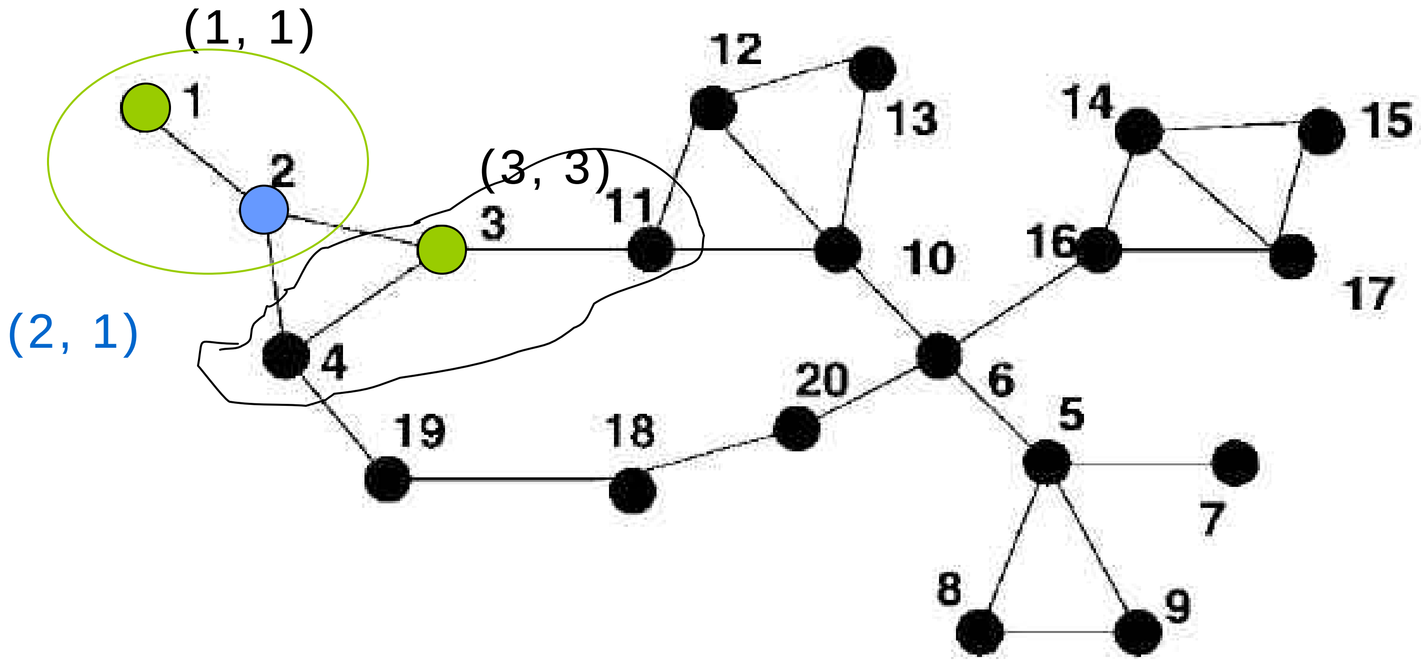
Clustering for Wireless Ad-Hoc Networks

- Lowest ID clustering
- COINED
- DCA & DMAC

Lowest ID Clustering [2]

- Designed for multimedia communication
- Assume information about 1 hop neighbors are available
- Node with the smallest ID becomes the CH
  - Cluster ID = NID of the CH

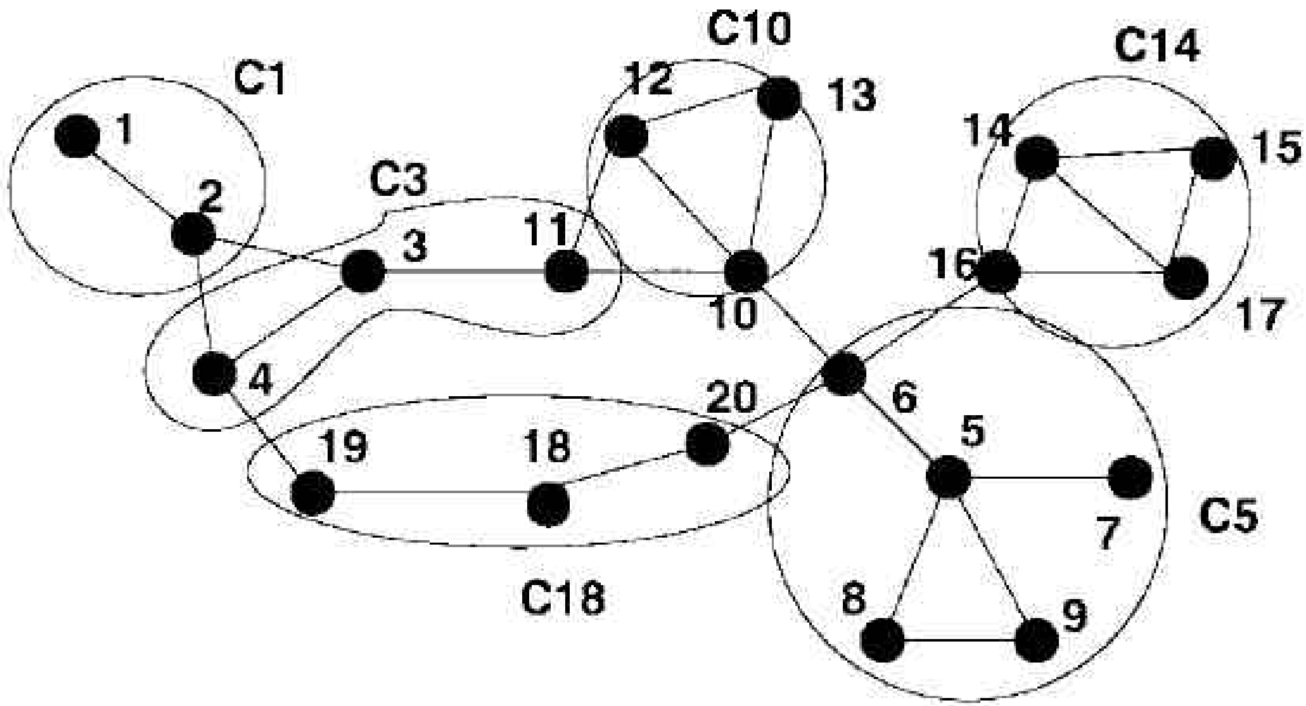
Lowest ID Clustering (cont.)



- Each node waits until their lowest ID neighbor decides its role

Source: [2]

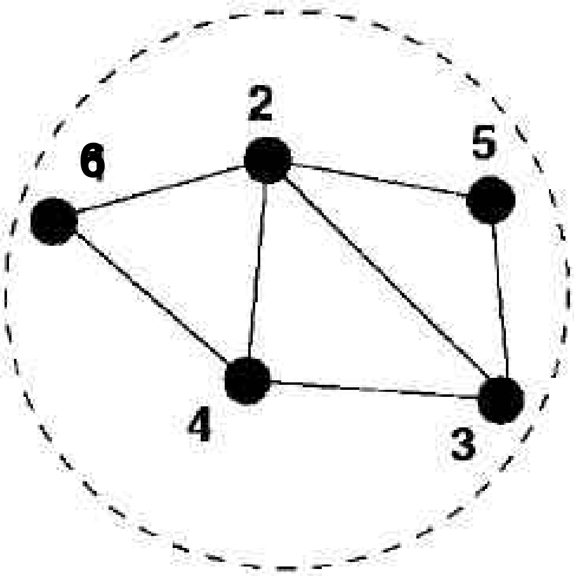
Lowest ID Clustering (cont.)

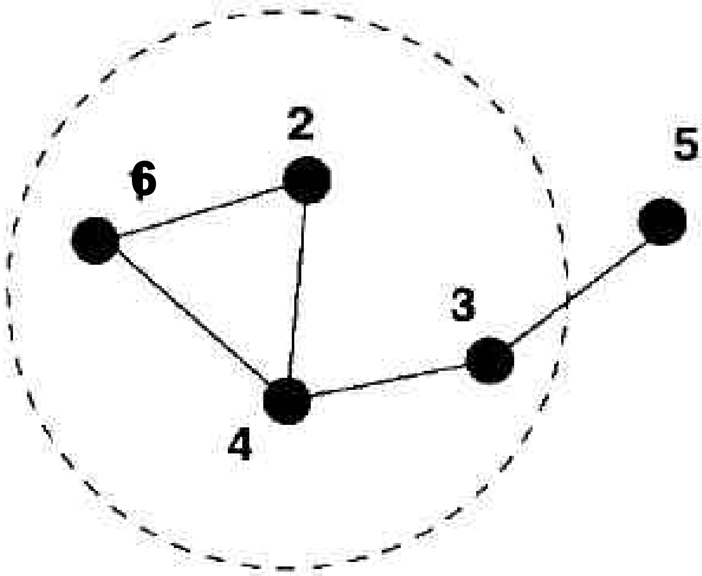


Source: [2]

Lowest ID Clustering – Reclustering

- Each node keeps the locality information
  - Within a cluster, nodes can communicate at most 2 hops away
  - The new/moved node needs to join a new cluster or form its own cluster





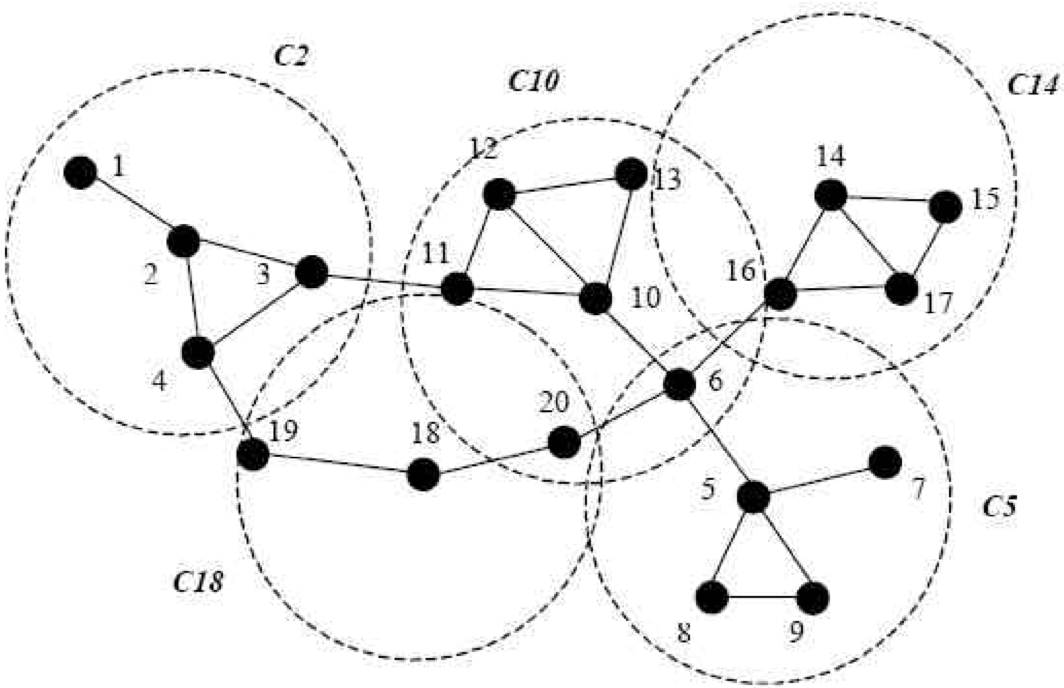
Source: [2]

Lowest ID Clustering – Pros & Cons

- Pros
  - Simple to implement
  - Non-overlapping clusters
  - Each node broadcast only one cluster message
  - Can handle node dynamics
- Cons
  - Assume each node knows about its neighbors
  - Produce large no of clusters
    - Doesn't consider node connectivity
  - Energy blind

Connectivity ID – COINED[12]

- Modified version of Lowest ID clustering
  - Primary parameters - Node degree
  - Secondary parameter - Lower node ID

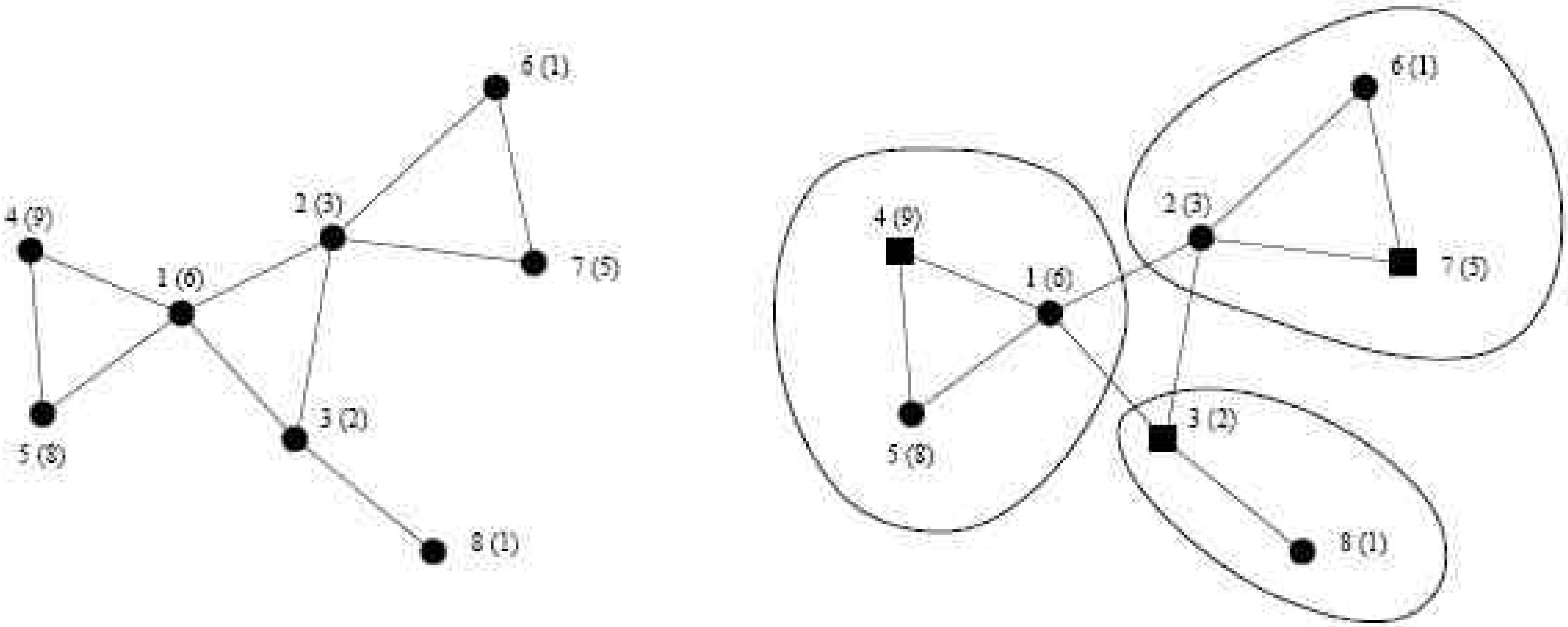


Source: [12]

DCA & DMAC [3]

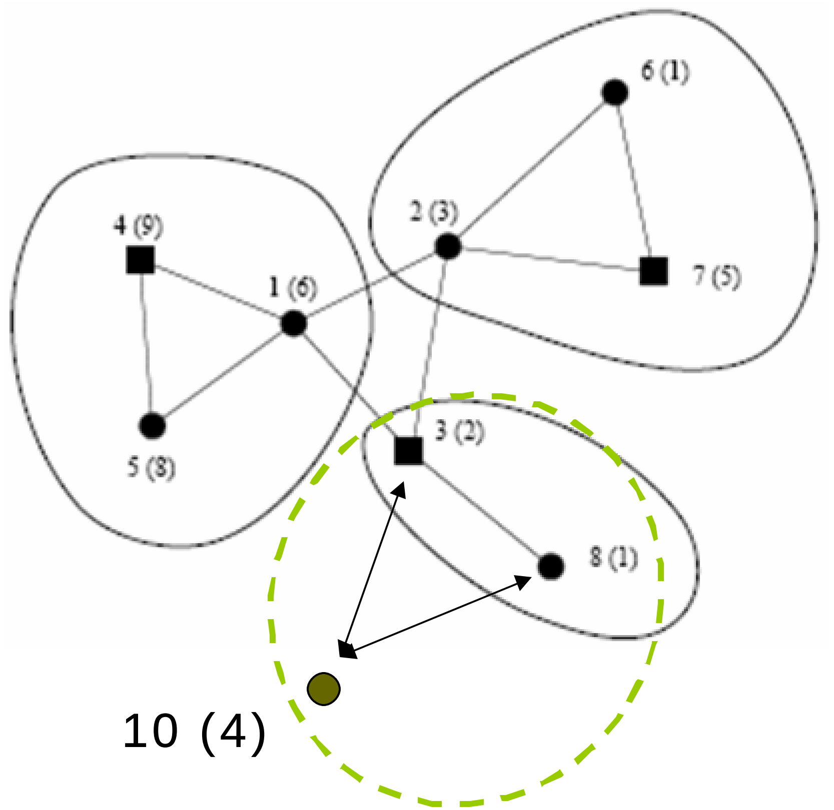
- DCA - Distributed Clustering Algorithm
- DMAC - Distributed Mobility Adaptive Clustering
  - Event driven
- Wight based CH selection
  - Select the CH with highest weight within 1-hop
- Assume 1-hop neighbor information is available
- Algorithm executes in each node
  - Node decide its role when its 1-hop neighbors with higher weighs decide their role

DCA – Cluster Formation



Source: [3]

DMAC – Handling Triggers



Source: [3]

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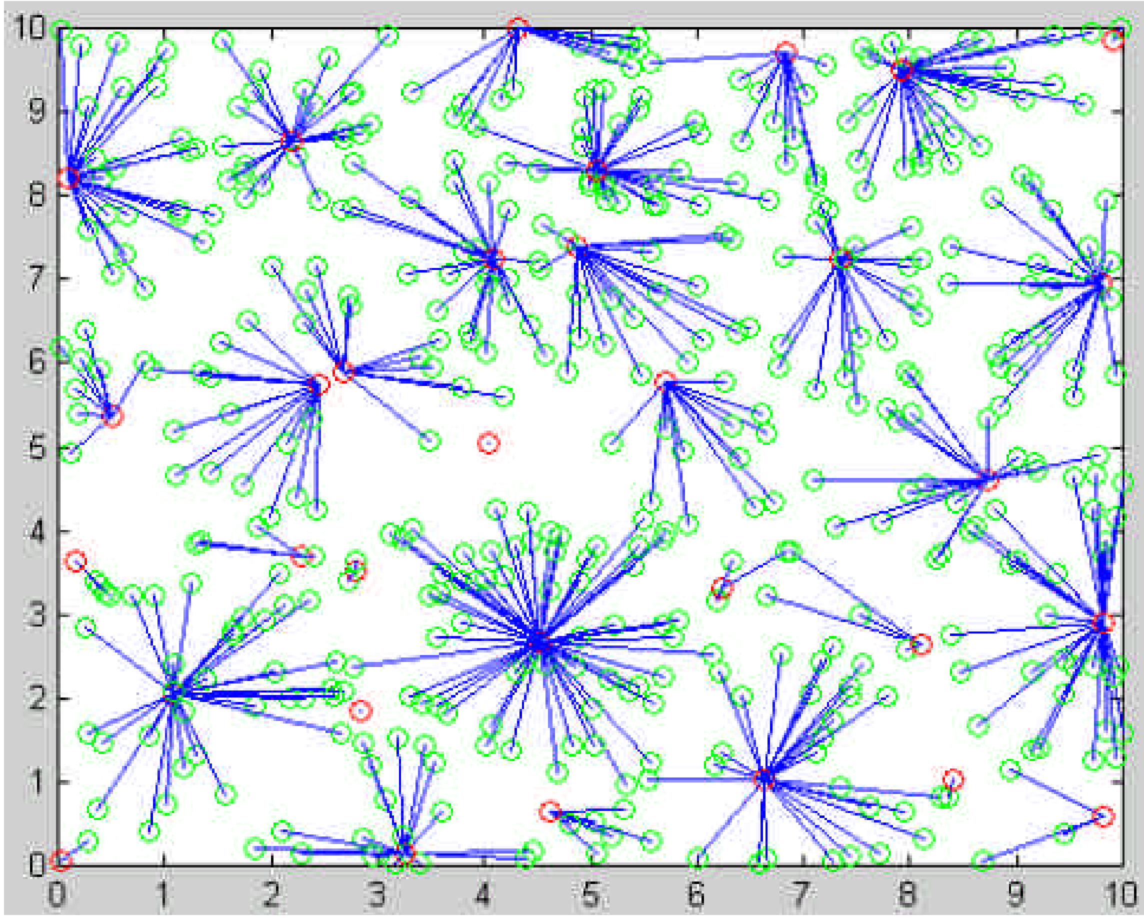
Clustering for wireless sensor networks

- Energy efficient hierarchical clustering
- LEACH
- HEED
- IEEE 802.15.4 cluster tree
- Zigbee cluster tree

Energy Efficient Hierarchical Clustering[9]

- Each node becomes a CH with probability *p*
- Then advertise it self to all the nodes within *k*-hops
- Nodes receiving the advertisement join the CH
- Nodes that don't have a CH at the end are forced to become CHs
- Minimum energy depends on parameters *k* & *p*
  - Need to be calculated in advance

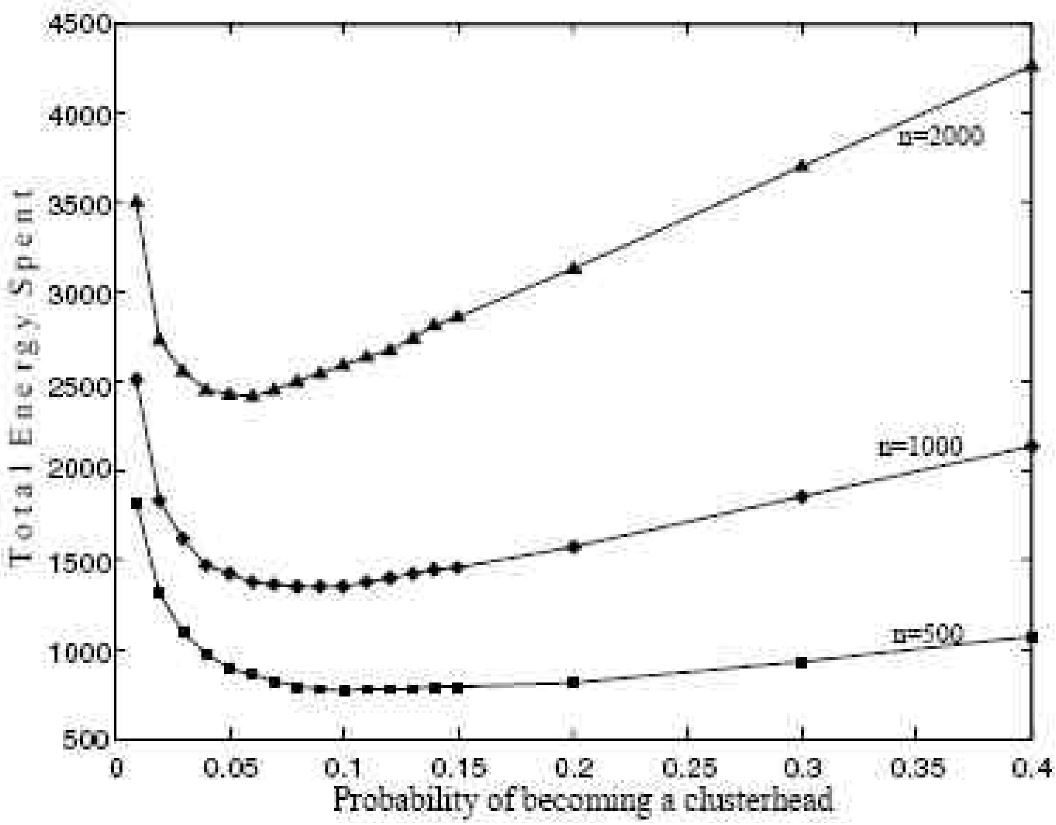
Energy Efficient Hierarchical Clustering (cont.)



p = 0.1, k = 2, Range = 1 with 500 nodes

Source: [9]

Total Energy Spent vs. Probability of Becoming a CH

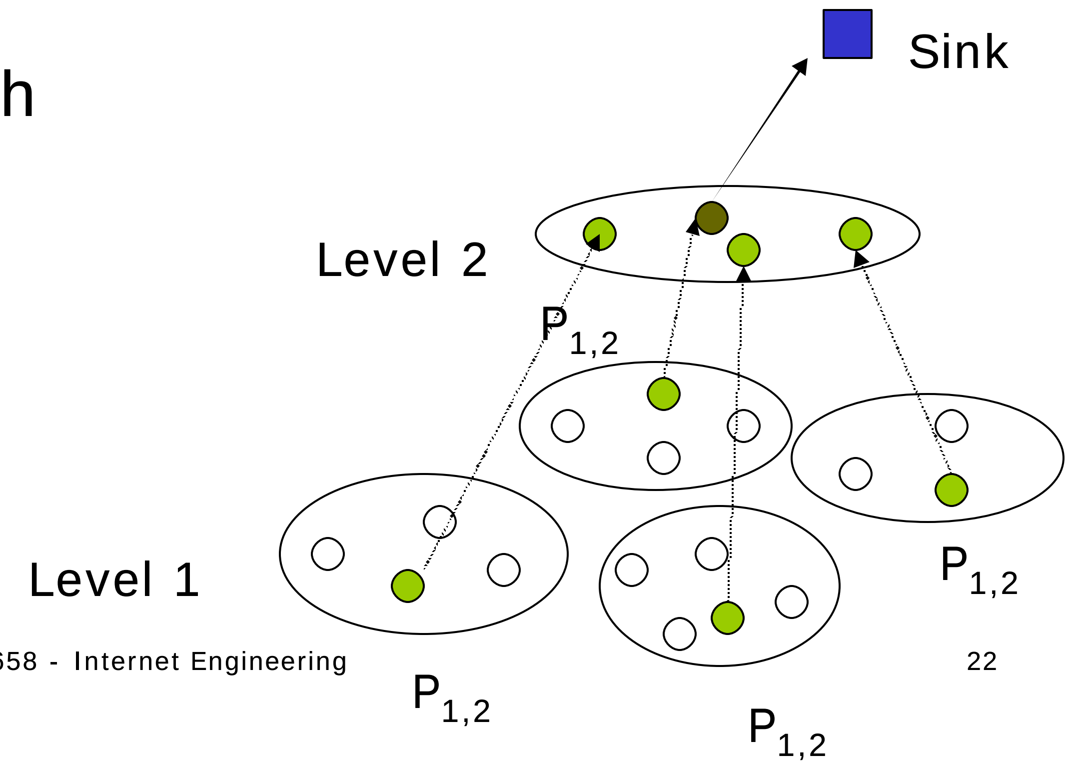


- For a certain value of *p* energy spent is minimum

Source: [9]

Hierarchical Clustering

- Data is aggregated at
  - level 1 & passed to level 2 then from level 2 to 3.....
  - Level h sends it to the sink
  - Each node has multiple probabilities p1, p2, p3 of becoming a CH
- Bottom up approach



Energy Efficient Hierarchical Clustering – Pros & Cons

- Pros
  - Simple to implement
  - Distributed solution
  - Larger clusters
    - Multi-hop
- Cons
  - Ties need to be break
  - Suboptimal clusters
  - Parameters *k* & *p* need to be calculated in advance
  - Energy blind

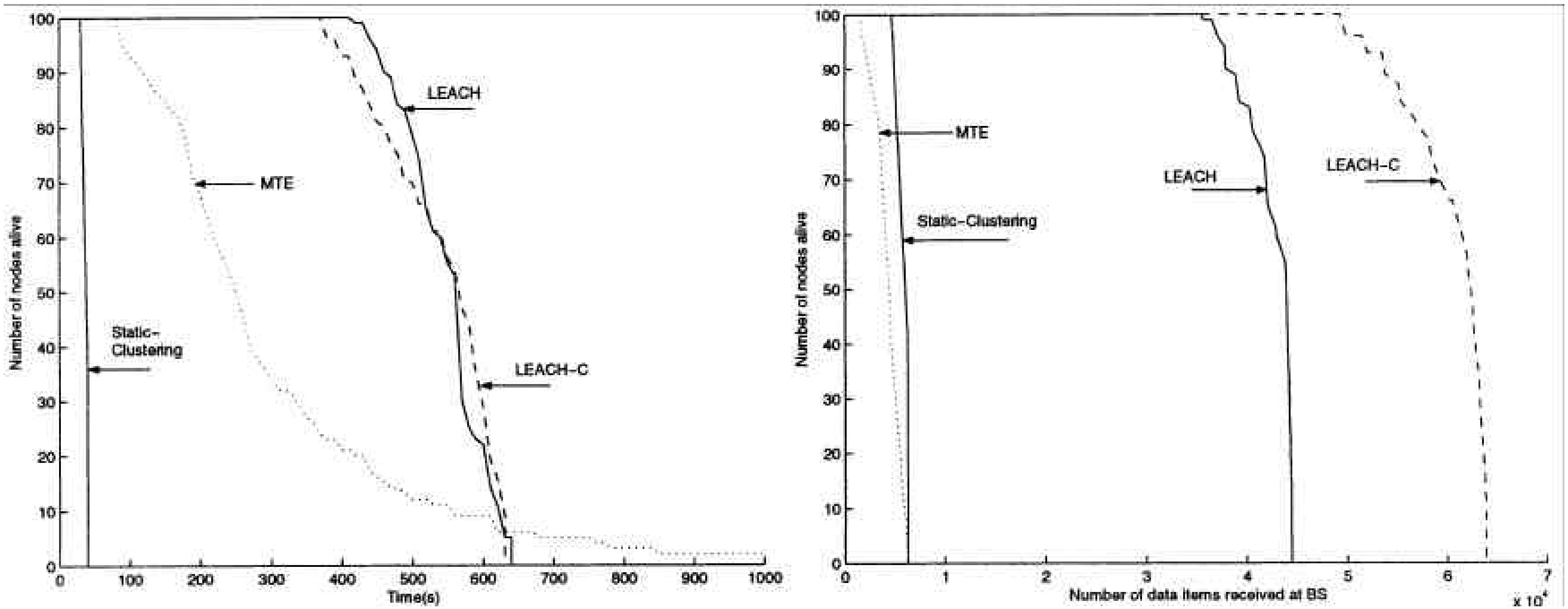
LEACH – Low Energy Adaptive Clustering Hierarchy [6]

- Goal is to divide the network such that there are *k* clusters
- Each node has an initial probability of becoming a CH, that depends on *k*
- Successive CH probabilities are function of residual energy

$$P_i(t) = \min\left\{\frac{E_i(t)}{E_{\text{total}}(t)}k, 1\right\}$$

- A node will not be a CH in successive rounds
- Long range communication with sink
- Nodes within multiple hops can join the cluster
  - Node joins a CH with least communication cost

Lifetime of the Network & Amount of Data Delivered



MTE - Minimum Transmission Energy

LEACH-C – Centralized LEACH

Source: [6]

LEACH – Pros & Cons

- Pros
  - Can reduce energy consumption up to x8
    - Use minimum transmission power
    - Nodes walkup only during their assigned TDMA slot
    - Aggregation & compression
  - Longer network lifetime & larger data capacity
    - Rotation of roles
- Cons
  - Application specific
  - Need to know no of neighbors (N) to calculate k
  - Need to know energy level of all the nodes
  - LEACH - C - too much overhead

HEED – Hybrid Energy Efficient Distributed Clustering [7]

- CHs are selected based on
  - Primary parameter - Residual energy
  - Secondary parameter – Node degree, Average Minimum Reachability Power (AMRP)

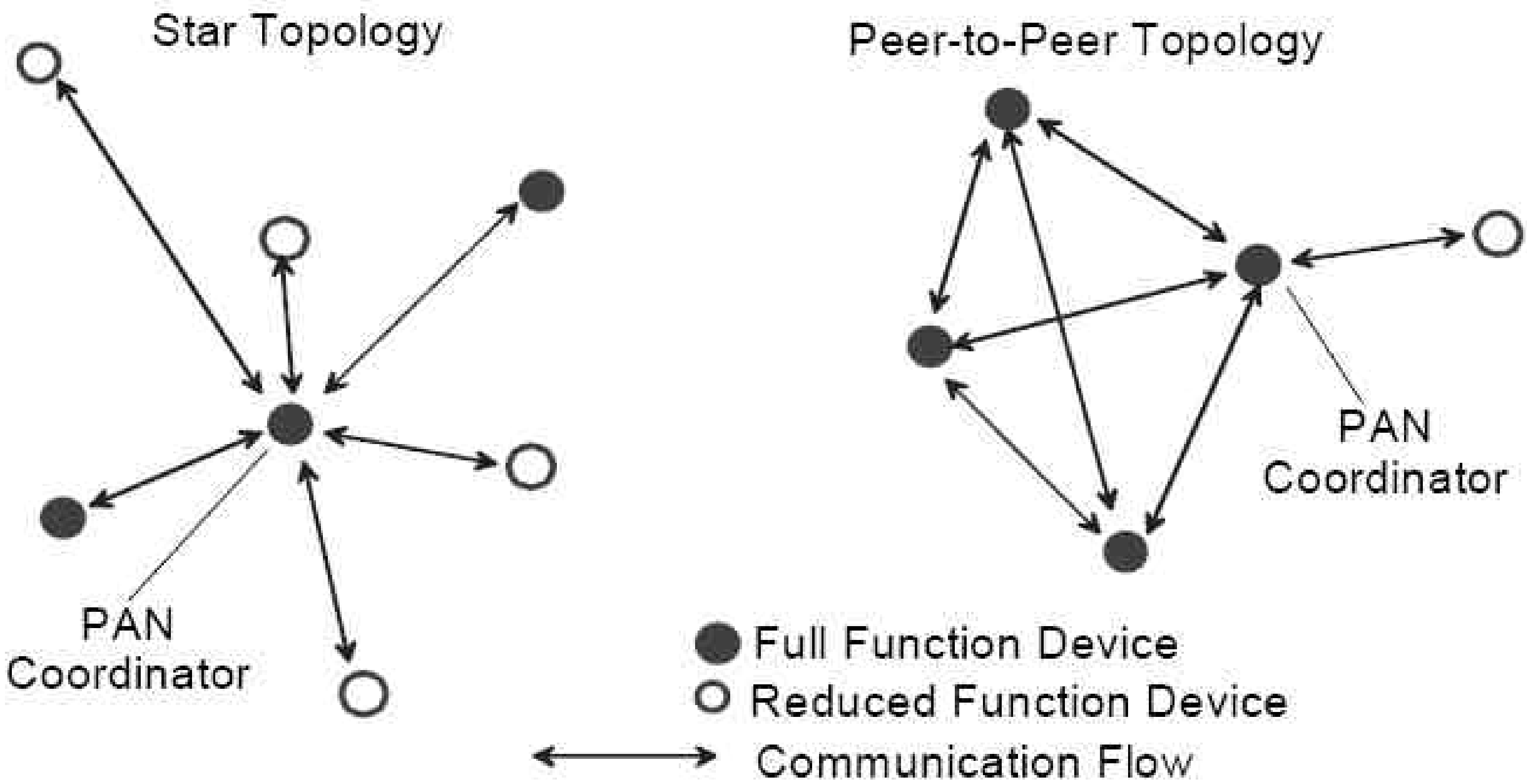
$$CH_{prob} = C_{prob} \times \frac{E_{residual}}{E_{max}}$$

  - If p = 1 it will be a CH
  - Else it will be a tentative CH
  - If not selected to be a CH, for next round p = 2p
  - If a node doesn't hear from a CH it will become a CH
  - Node joins a CH with least communication cost

HEED – Pros & Cons

- Pros
  - Local decision to become a CH
  - Longer life time than LEACH
  - Independent of network size
- Cons
  - Can't guarantee that the node with the highest energy will become the CH
  - Smaller clusters
    - Single hop

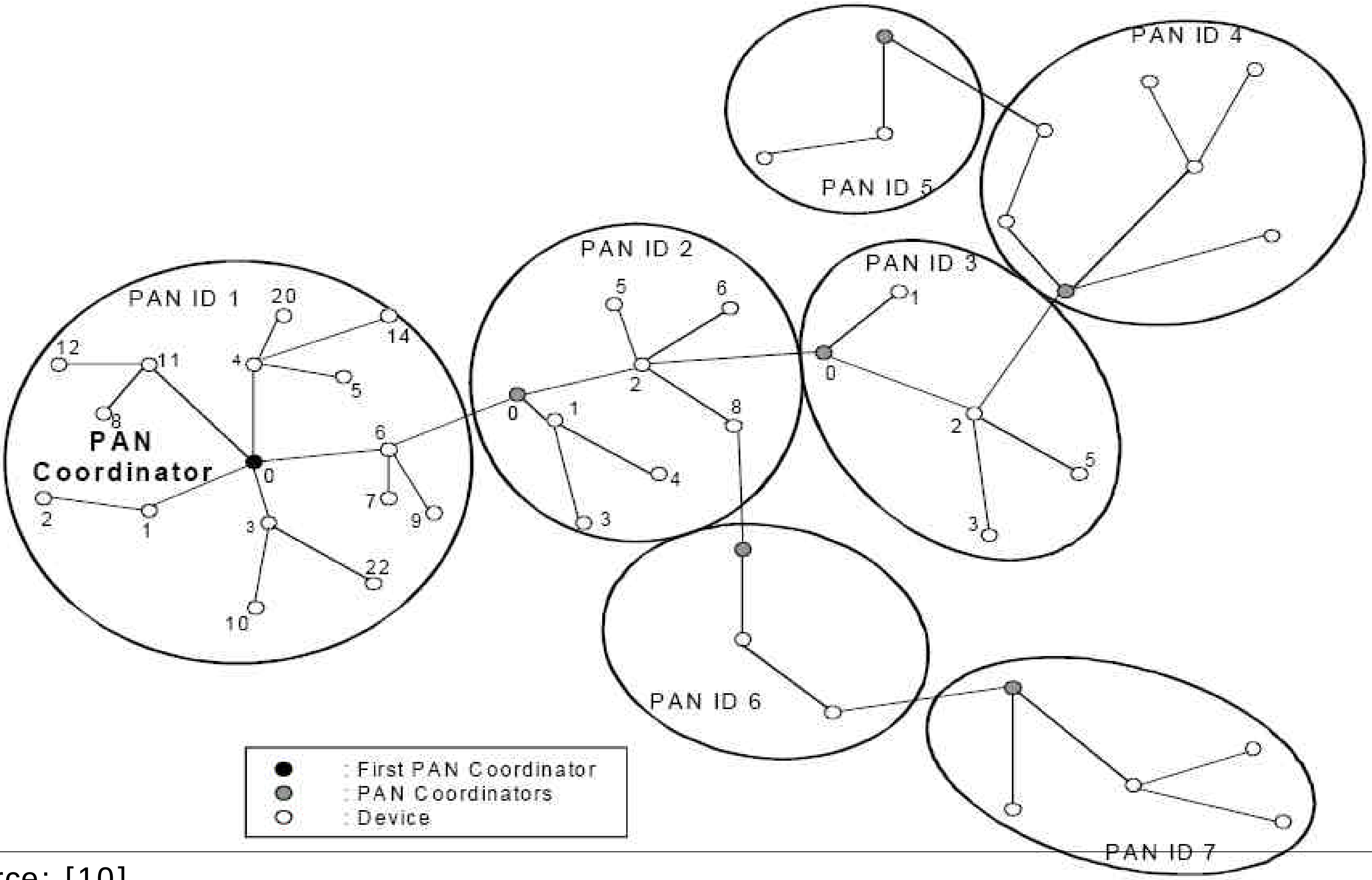
IEEE 802.15.4 Clustering[10]



- PAN coordinator can be a FFD with more resources

Source: [10]

IEEE 802.15.4 Cluster Tree

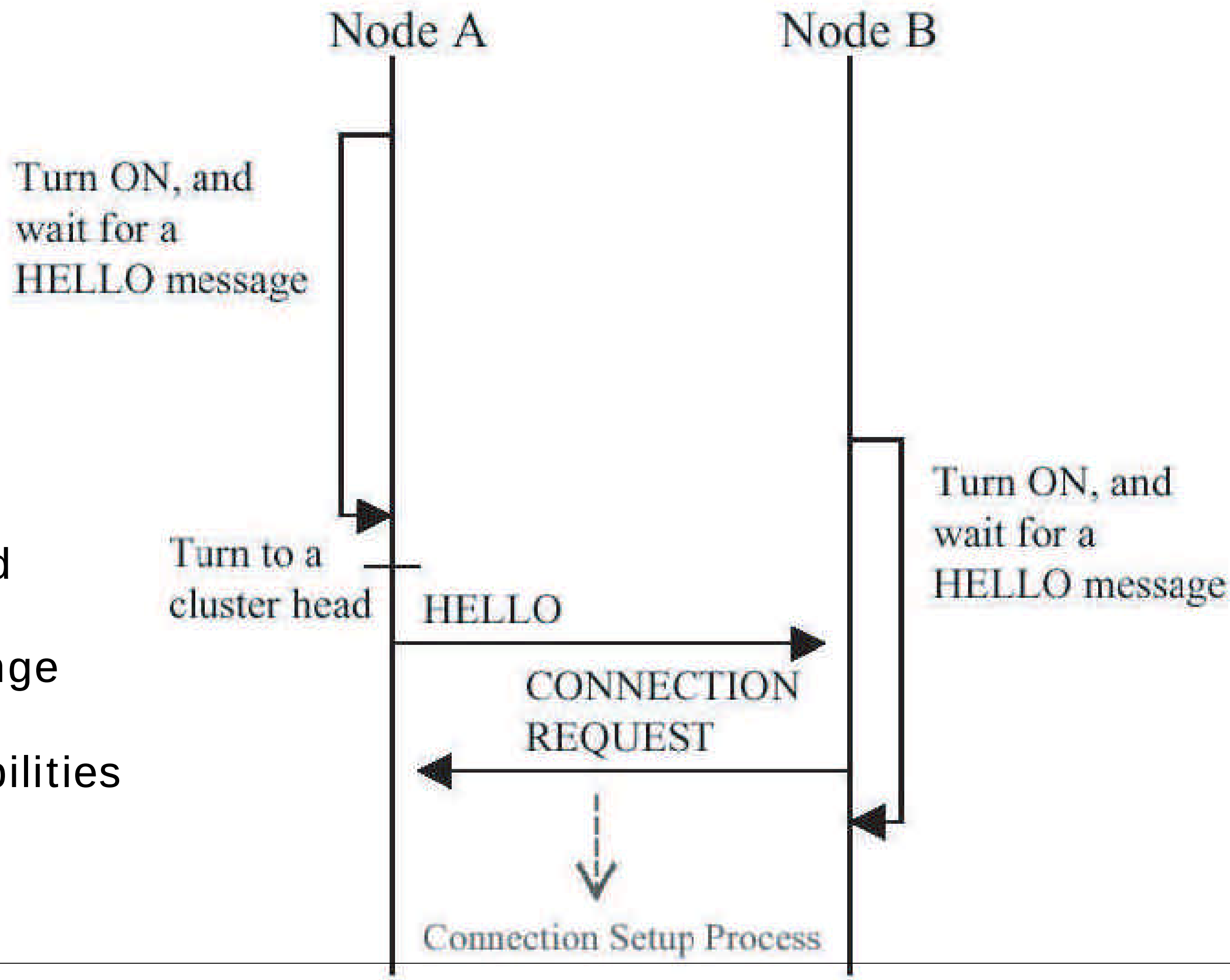


Source: [10]

Zigbee Cluster Tree[11]

- ZigBee is an industrial standard for enabling reliable, cost-effective, low-power, wireless, monitoring & control products
- Propose an implementation for IEEE 802.15.4
  - Based on Motorola cluster tree algorithm
- Two step process
  - Cluster formation
  - Tree formation

Selecting the CH

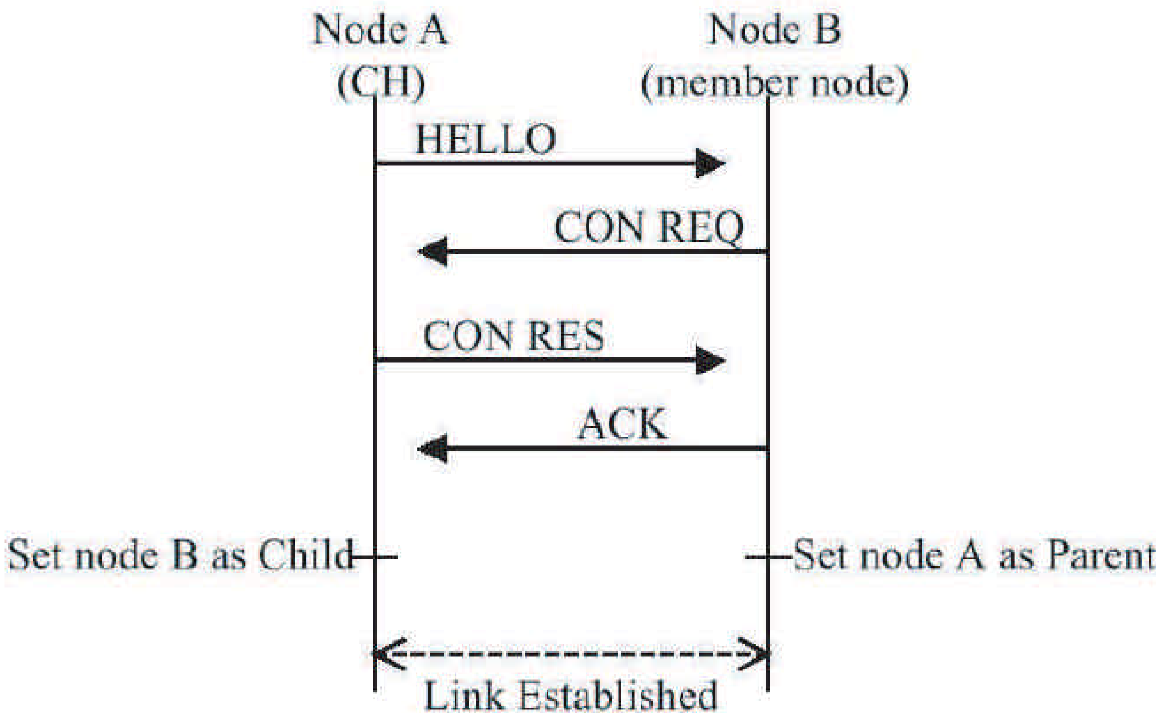


CH can be selected based on:

- Transmission range
- Power
- Processing capabilities

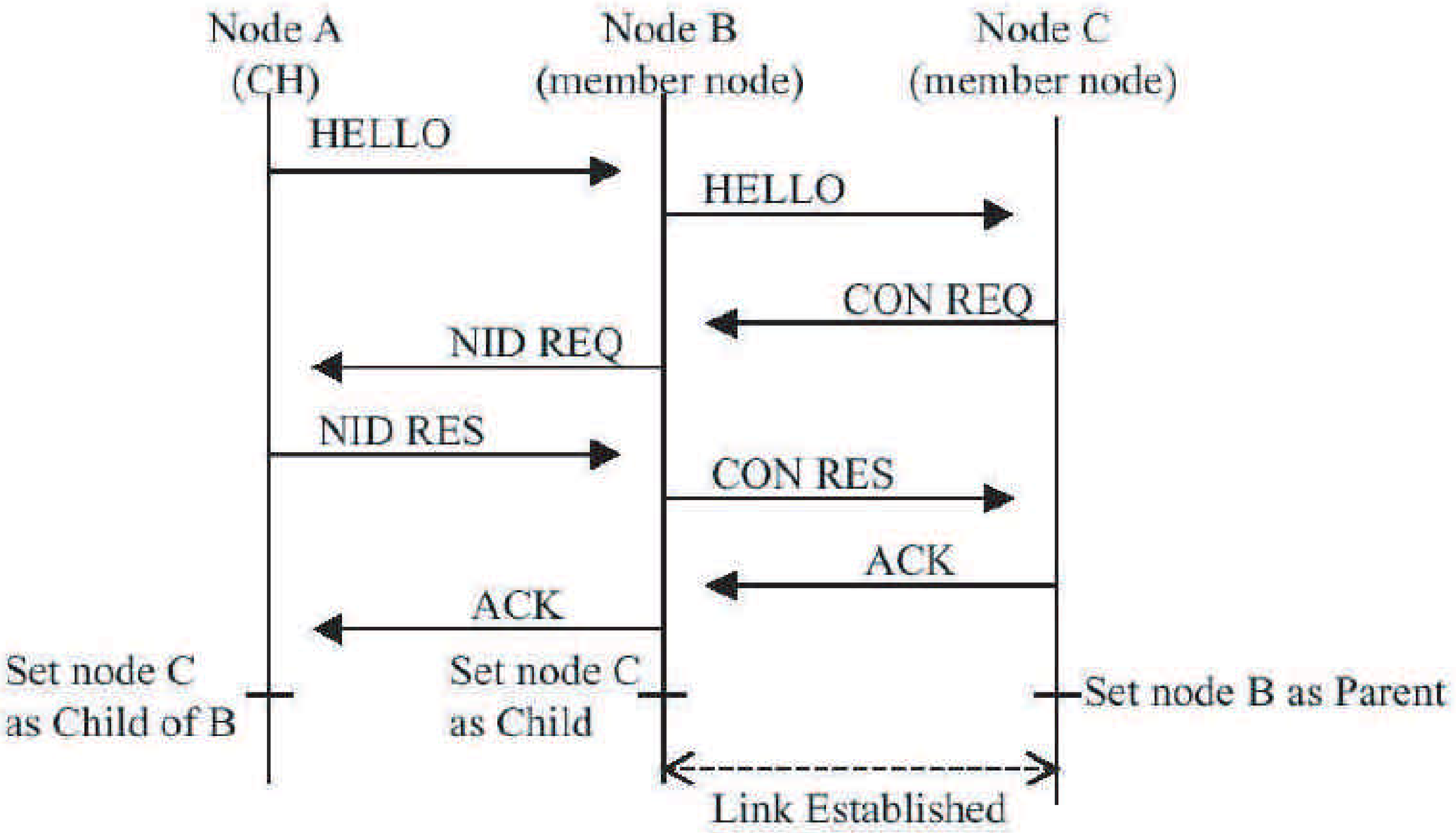
Source: [11]

Link Setup



Source: [11]

Multi-hop Cluster Setup



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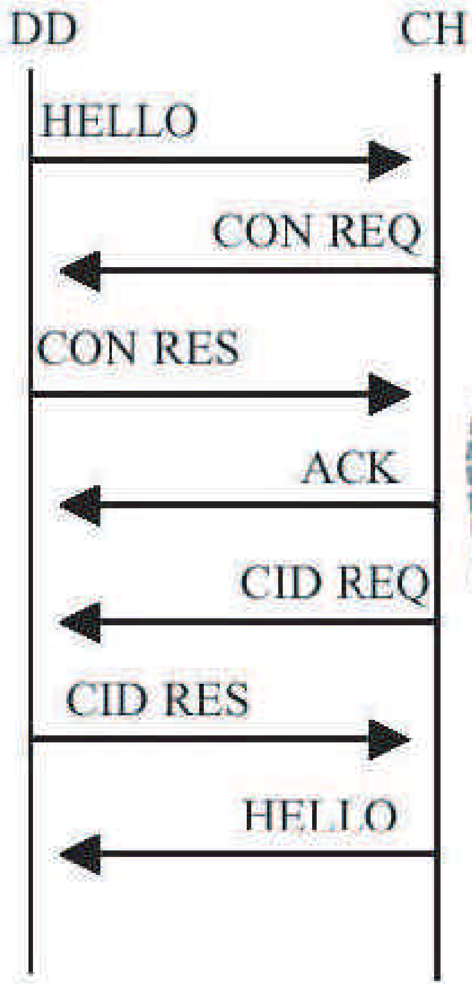
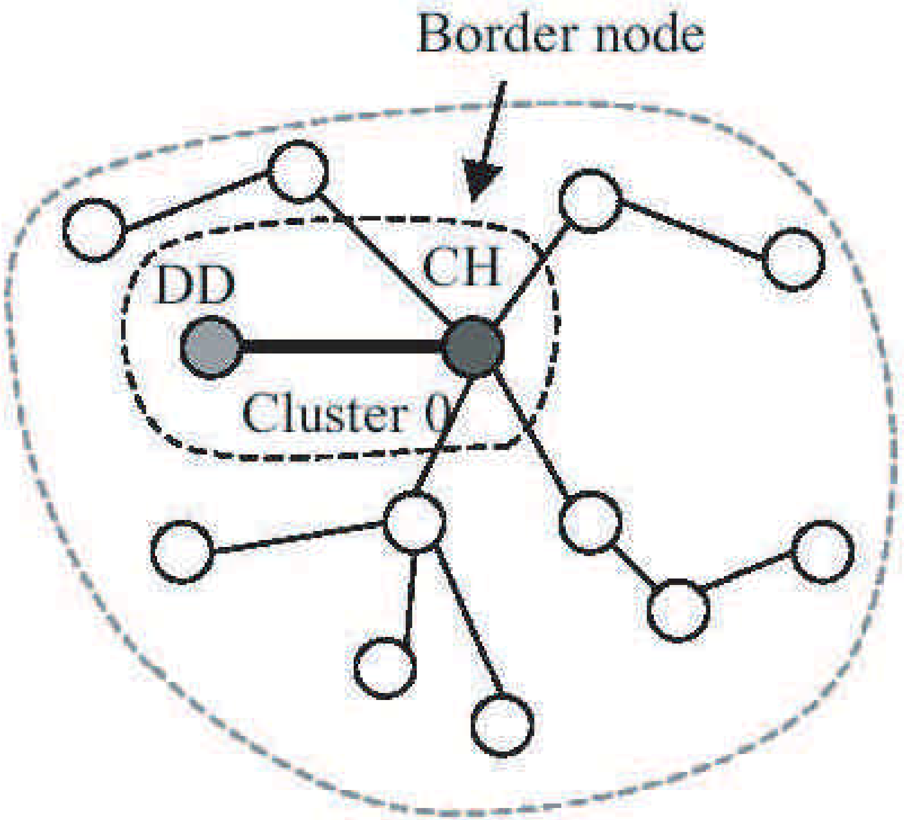
Cluster Tree

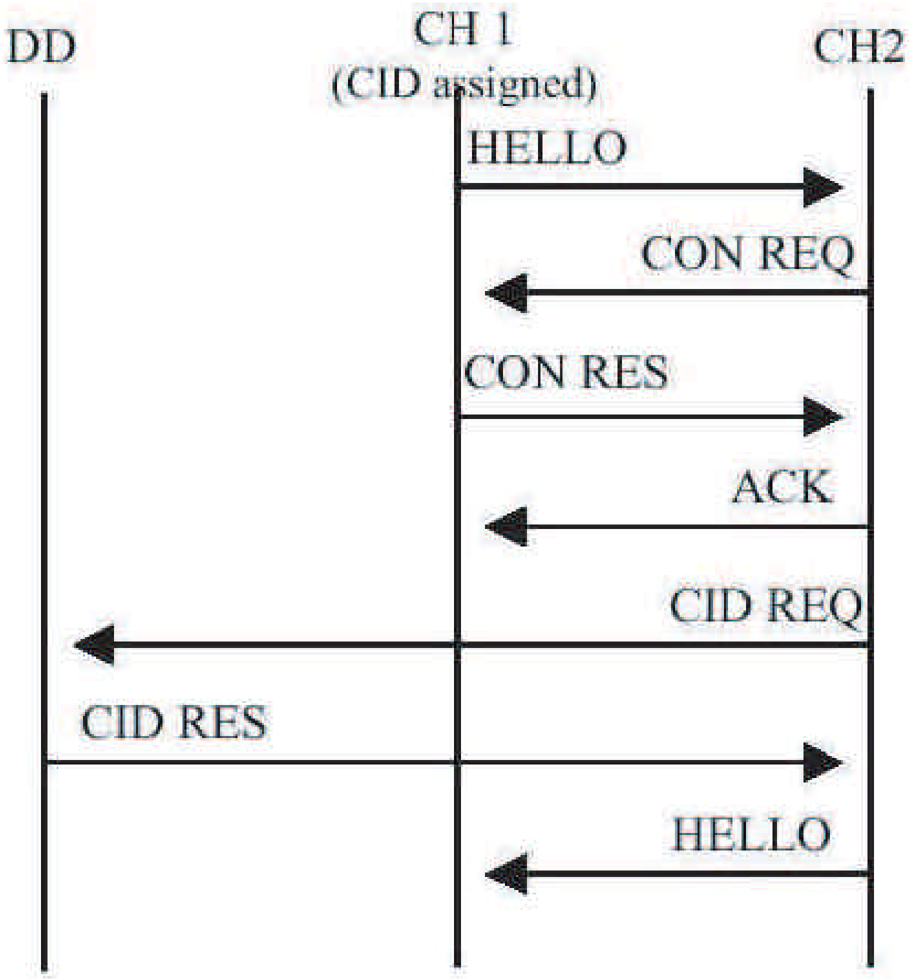


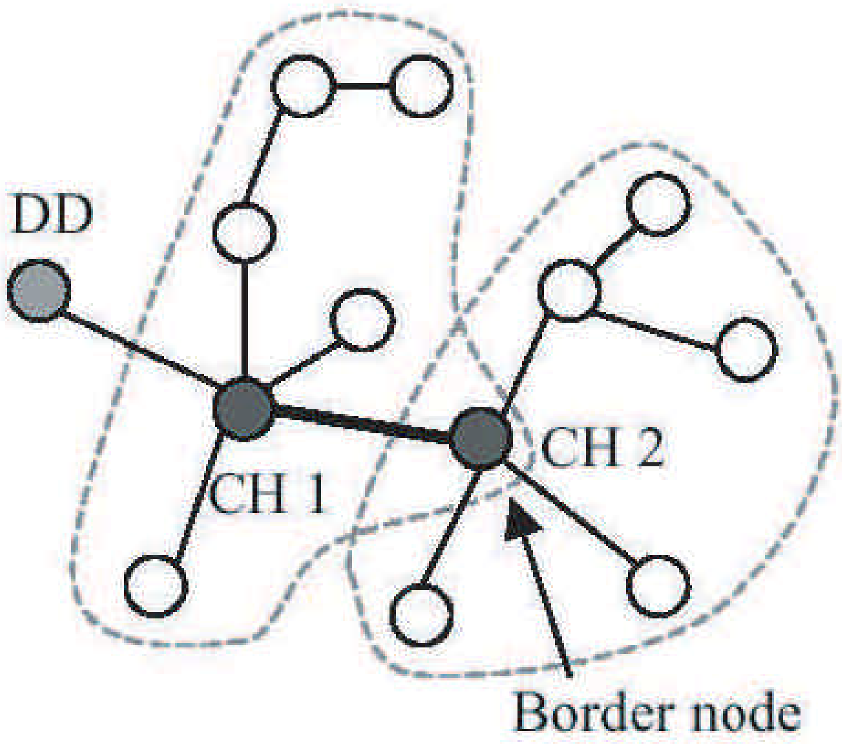
- DD - Designated Device



Source: [11]

Cluster Tree (cont.)





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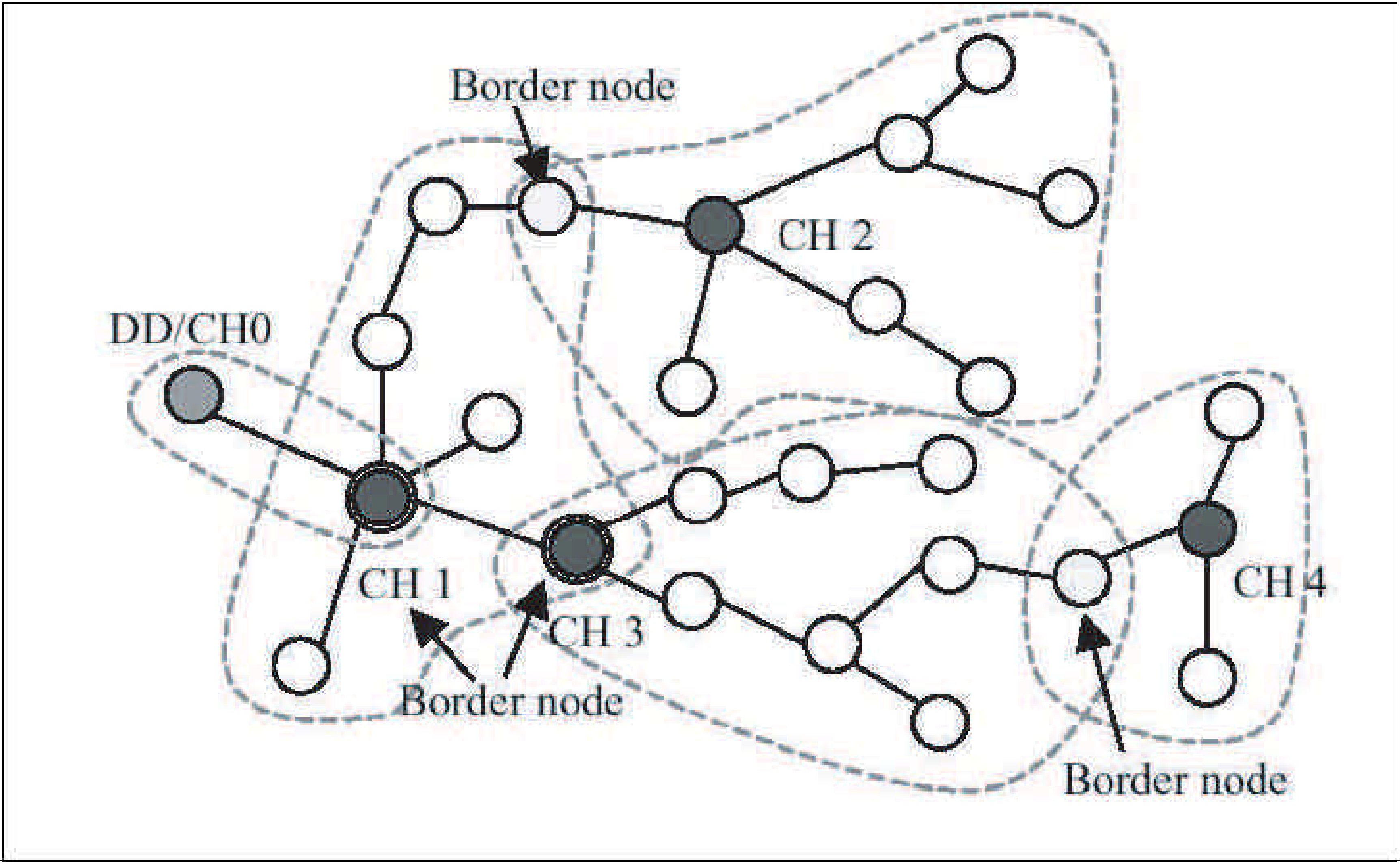
Cluster Tree (cont.)



Source: [11]

Zigbee Cluster Tree – Pros & Cons

- Pros
  - Support network dynamics
    - CH periodically send HELLO messages
  - Multi-hop communication through border nodes
- Cons
  - Designated Device becomes a bottleneck
    - DD keeps the whole tree
    - Multiple DDs for fault tolerance
  - Each new cluster needs to communicate with DD
    - Cluster changes are costly

Research Challenges

- Optimal frequency of re-clustering
  - Optimal frequency of CH rotation
- Computing the optimum cluster size
- Enabling intercluster & intracluster communication using the same radio channel
- Load balancing
  - In multi hop, nodes closer to CH has to carry large load

Summary

- Key problem is finding the best CH
  - Rotating the role of CH
- Most solutions assume that a node has information about all its 1- hop neighbors
- Bottom up approach seems to be popular
- Top down approach provides more control
- Layered clustering
- Enough potential for research

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Q & A

Thank you….