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\textsuperscript{[12]}

- Modified version of Lowest ID clustering
  - Primary parameters - Node degree
  - Secondary parameter - Lower node ID
DCA & DMAC \cite{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]
DCA & DMCA – Pros & Cons

- Pros
  - Simple to implement
  - Non-overlapping clusters
  - Each node broadcast only 1 cluster message
  - Can handle node dynamics

- Cons
  - Assume each node knows about its neighbors
  - Produce large no of clusters
  - Energy blind
Clustering for wireless sensor networks

- Energy efficient hierarchical clustering
- LEACH
- HEED
- IEEE 802.15.4 cluster tree
- Zigbee cluster tree
Energy Efficient Hierarchical Clustering\cite{9}

- Each node becomes a CH with probability $p$
- Then advertise itself 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.)

$p = 0.1, k = 2, \text{Range} = 1 \text{ with } 500 \text{ nodes}$

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 $p_1$, $p_2$, $p_3$ 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

- 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

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

- 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\textsuperscript{[10]}

- PAN coordinator can be a FFD with more resources

Source: [10]
IEEE 802.15.4 Cluster Tree

Source: [10]
Zigbee Cluster Tree\cite{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

Source: [11]
Cluster Tree

- DD - Designated Device

Source: [11]
Cluster Tree (cont.)

Source: [11]
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
References


Thank you...