Wireless Sensor Networks

22nd Lecture

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CoNe
Freiburg

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Options for topology control

- Topology control
  - Control ***node*** activity – deliberately turn on/off nodes
  - Control ***link*** activity – deliberately use/not use certain links

- Topology control
  - ***Flat network*** – all nodes have essentially same role
    - Power control
  - ***Hierarchical network*** – assign different roles to nodes; exploit that to control node/link activity
    - Backbones
    - Clustering

Power control – magic numbers?

- **Question: What is a good power level for a node to ensure "nice" properties of the resulting graph?**
- **Idea: Controlling transmission power corresponds to controlling the number of neighbors for a given node**
- **Is there an "optimal" number of neighbors a node should have?**
  - Is there a "magic number" that is good irrespective of the actual graph/network under consideration?
- **Historically, k=6 or k=8 had been suggested as such "magic numbers"**
  - However, they optimize progress per hop – they do ***not*** guarantee connectivity of the graph!!

  $\rightarrow$ Needs deeper analysis

Controlling transmission range

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- **Assume all nodes have identical transmission range r=r(|V|), network covers area A, V nodes, uniformly distr.**
- **Fact: Probability of connectivity goes to zero if:**

$$r(|V|) \leq \sqrt{\frac{(1-\epsilon)A \log |V|}{\pi |V|}}, \text{ for any } \epsilon > 0$$

- **Fact: Probability of connectivity goes to 1 for**

$$r(|V|) \geq \sqrt{\frac{A(\log |V| + \gamma_{|V|})}{\pi |V|}}$$

if and only if $\gamma_{|V|} \to \infty$ with |V|

- **Fact (uniform node distribution, density ρ):**

$$P(\text{G is } k\text{-connected}) \approx \left(1 - \sum_{l=0}^{k-1} \frac{(\rho \pi r^2)^l}{l!} e^{-\rho \pi r^2}\right)$$

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Hierarchical networks – backbones

- **Idea: Select some nodes from the network/graph to form a *backbone***
  - A connected, minimal, dominating set (MDS or MCDS)
  - Dominating nodes control their neighbors
  - Protocols like routing are confronted with a simple topology – from a simple node, route to the backbone, routing in backbone is simple (few nodes)
- **Dominating Set:**
  - Given an undirected graph G=(V,E)
  - Find a minimal subset $W \subseteq V$ such that for all $u \in W$ there exists $v \in V$ with $\{u,v\} \in V$
- **Problem: MDS is an NP-hard problem**
  - Hard to approximate, and even approximations need quite a few messages
  - Polynomial approximable within c log n for some $c > 0$ only if P=NP
  - Polynomial approximable within a factor of $1 + \log n$.

Backbone by growing a tree

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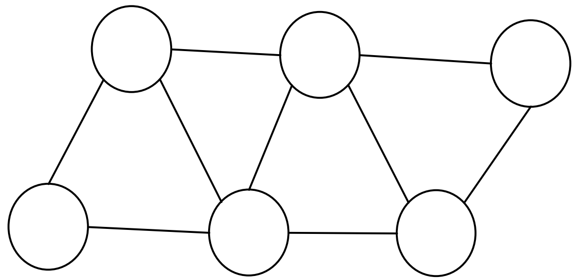
- **Construct the backbone as a tree, grown iteratively**

```
initialize all nodes' color to white
pick an arbitrary node and color it grey

while (there are white nodes) {
  pick a grey node v that has white neighbors
  color the grey node v black
  foreach white neighbor u of v {
    color u grey
    add (v,u) to tree T
  }
}
```



Backbone by growing a tree – Example

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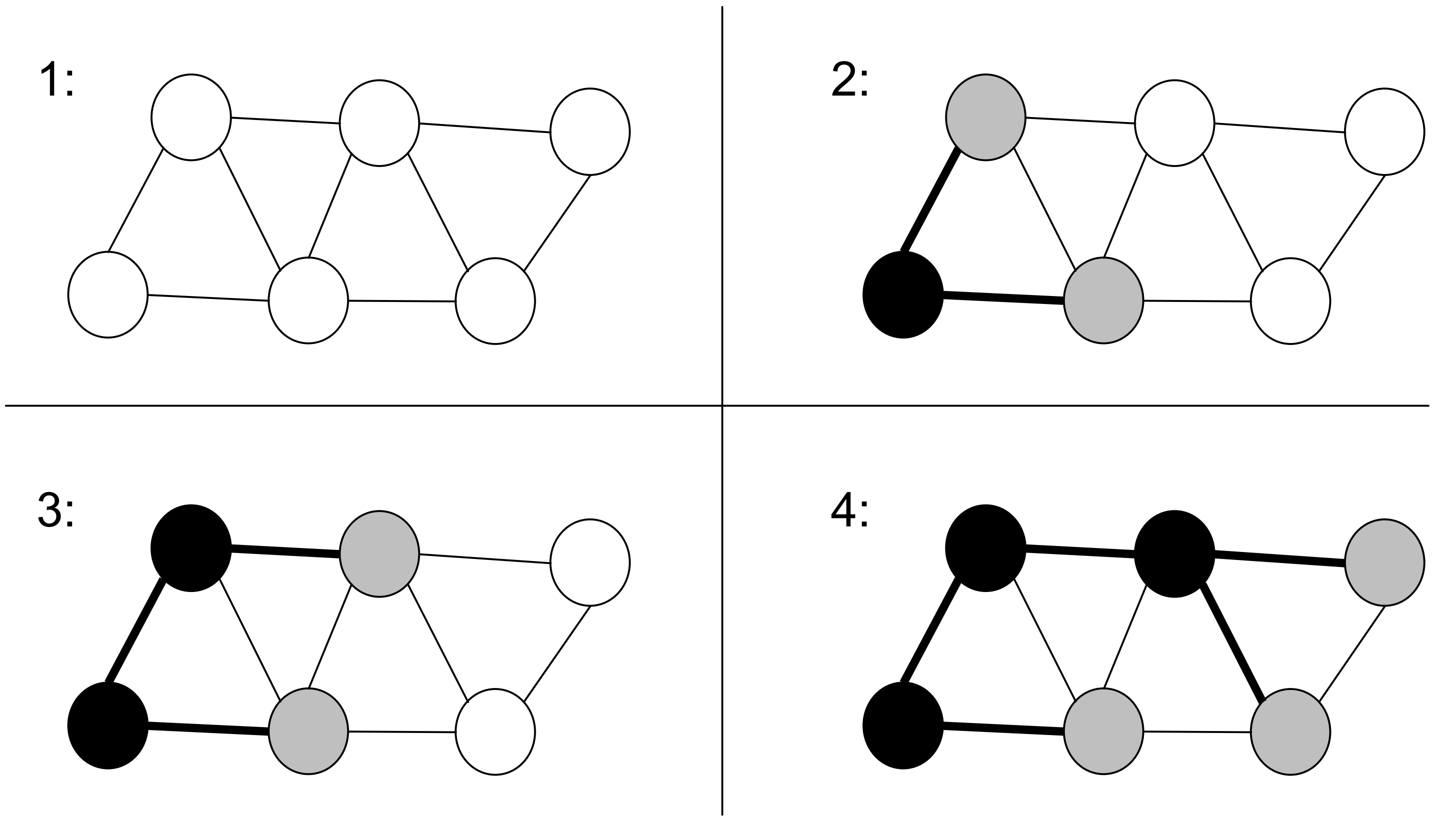

Problem: Which gray node to pick?

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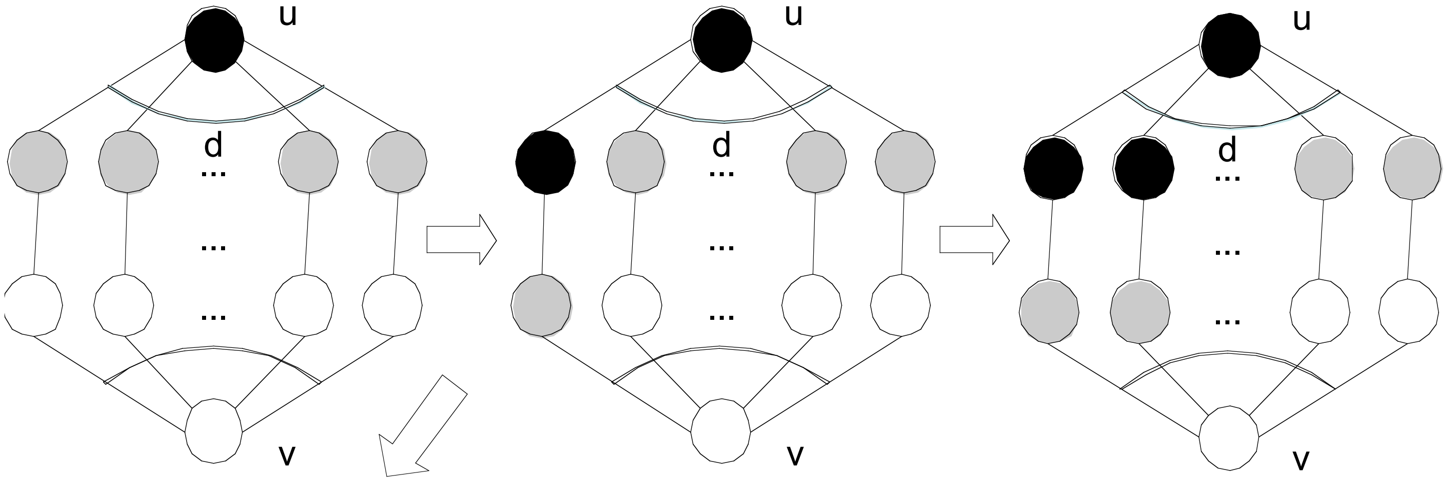
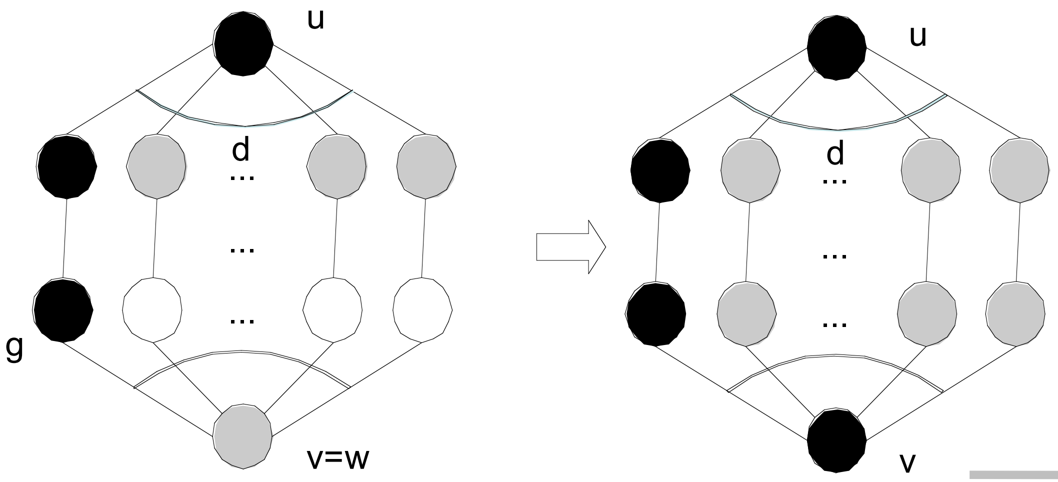
- **When blindly picking any gray node to turn black**
  - resulting tree can be very bad



Solution:
Look ahead!
Here,
one step suffices

Look-ahead using nodes g and w



Performance of tree growing with look ahead

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- **Dominating set obtained by growing a tree with the look ahead heuristic is at most a factor 2(1+ H(Δ)) larger than MDS**
  - H(·) harmonic function, $H(k) = \sum_{i=1}^{k} 1/i \leq \ln k + 1$
  - Δ is maximum degree of the graph

- **It is automatically connected**

- **Can be implemented in a distributed fashion as well**

Start big, make lean

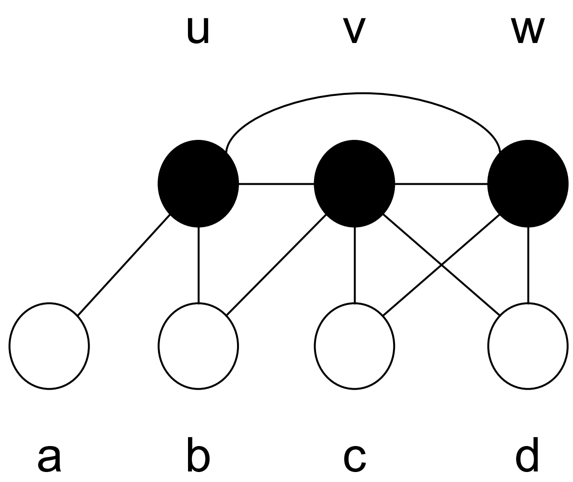
- **Idea: start with some, possibly large, connected dominating set, reduce it by removing unnecessary nodes**
- **Initial construction for dominating set**
  - All nodes are initially white
  - Mark any node black that has two neighbors that are not neighbors of each other (they might need to be dominated)

  $\rightarrow$ Black nodes form a connected dominating set (proof by contradiction); shortest path between ANY two nodes only contains black nodes

- **Needed: Pruning heuristics**

Pruning heuristics

- **Heuristic 1: Unmark node v if**
  - Node v and its neighborhood are included in the neighborhood of some node marked node u (then u will do the domination for v as well)
  - Node v has a smaller unique identifier than u (to break ties)
- **Heuristic 2: Unmark node v if**
  - Node v's neighborhood is included in the neighborhood of two marked neighbors u and w
  - Node v has the smallest identifier of the tree nodes
- **Nice and easy, but only linear approximation factor**



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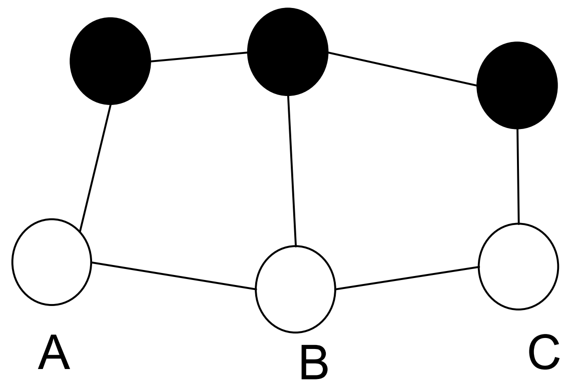
One more distributed backbone heuristic: Span

- **Construct backbone, but take into account need to carry traffic – preserve capacity**
  - Means: If two paths could operate without interference in the original graph, they should be present in the reduced graph as well
  - Idea: If the stretch factor (induced by the backbone) becomes too large, more nodes are needed in the backbone
- **Rule: Each node observes traffic around itself**
  - If node detects two neighbors that need three hops to communicate with each other, node joins the backbone, shortening the path
  - Contention among potential new backbone nodes handled using random backoff



Thank you

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