

# Local, Distributed Topology Control for Large-Scale Wireless Ad Hoc Networks

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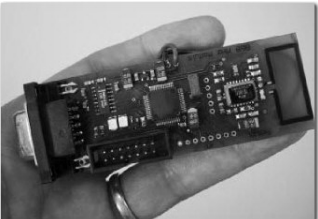
## Overview

- Introduction
  - EYES—Energy Efficient Sensor Networks
  - Topology Control
- Global view of Topology Control
  - Minimum Spanning Tree (MST) based solutions
- Local Approach: LPA
  - *Local Power Adjustment* Algorithm
  - Control nodes and local power adjustment
- Properties of LPA
  - Globally connected topology
- Results
- Conclusions and future work

## EYES

### Energy Efficient Sensor Networks

- Basic Components
  - Small intelligent devices
  - Sensing & Processing
  - Short-Range Radio:
    - Wireless Communication Topology
- Main Concern: *ENERGY*
  - Need long lifetime on single battery
  - e.g. reduce number of transmissions, compression, en-route data aggregation ...
- => Save energy by reducing signal strength
  - However, still need connectivity ☺



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## Topology of Ad Hoc Networks

- Theoretically:
  - Power levels for nodes to reach each other given as regular function of distance
    - Only valid in ideal settings: open field—no obstacles
- Practically:
  - Reflection, interference from walls and objects, direction of antenna ...
- => LPA: no localization, no “ideal” settings
  - Only information about signal strength needed to reach neighbor is known
    - e.g. RSSI, neighborhood detection schemes ...

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## Communication Graph

- Directed Graph  $G = (V, A)$ 
  - Each arc represents possible communication
  - Weights  $p(u, v) > 0$  are given to the arc  $(u, v) \in A$ , representing the signal strength needed to communicate ( $p(u, v) \leq P_{\max}$ )
- Each node  $u \in V$  can adjust its signal strength  $P_u$ 
  - Power assignment for all nodes  $\{P_u \mid u \in V\}$
  - New communication graph  $G_p$
- Induced bidirectional graph  $\bar{G} = (V, E_p)$ 
  - Only bidirectional communication considered
  - $[u, v] \in E_p \Leftrightarrow p(u, v) \geq P_u \wedge p(v, u) \geq P_v$

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## Topology Control Problem Statement

- Maximal Power Adjustment
  - Find power settings such that the resulting graph is bidirectionally connected, and
  - the **maximum** signal strength,  $\max_{i \in V} P_i$ , is minimized.
    - Minimize time to first node death
- Total Power Adjustment
  - Find power settings such that the resulting graph is bidirectionally connected, and
  - the **sum** of power levels,  $\sum_{i \in V} P_i$ , is minimized.
    - Equivalent to average signal strength

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## Global View

- Consider Minimum Spanning Tree  $T$ 
  - Adjust power levels  $P_u := \max_{\{[u,v] \in T\}} p(u,v)$
  - $\Rightarrow$  induced bidirectional graph  $P^T$  is connected
- Theorem 1:
  - The corresponding solution  $P^T$  is **optimal** for the Max. Power Adjustment problem.
- Theorem 2:
  - The corresponding solution  $P^T$  is a **2-approximation** for the Total Power Adjustment problem.

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## MST-Construction

- Distributed construction of MST in communication graph takes
  - $\Omega(|A| + n \cdot \log n)$  messages
  - $\Omega(n)$  running time
- $\Rightarrow$  **not** suited for large scale, multi-hop networks
  - Local Algorithm: nodes only interact with direct neighbors and use local information
  - Hence: LPA (*Local Power Adjustment*)

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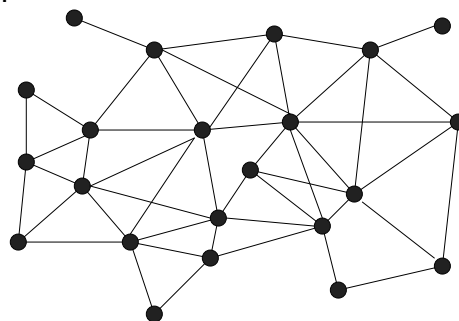
## Local Approach

- LPA works in 2 stages
  - 1.) Create local control nodes
    - Independent Set based approach
  - 2.) Control nodes perform calculations
    - Construct local MST
    - Ensure global connectivity
- => Local, overlapping MSTs are broadcast
  - all nodes adjust their power accordingly

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## Control Node Recognition

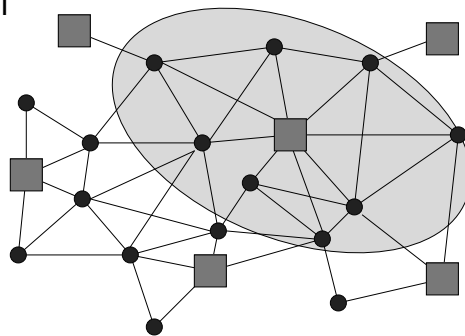
- Localized version of greedy approach to maximum independent set
  - Use (unique) node ID as decision criterion
    - Highest ID => Control
  - Only local info needed
  - Nodes transmit at full power



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## Control Node Recognition

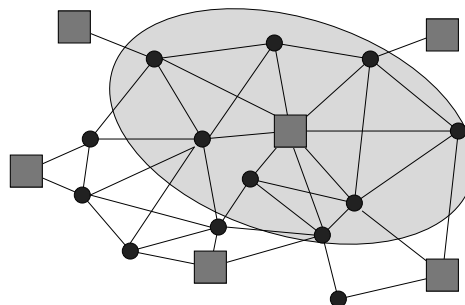
- Localized version of greedy approach to maximum independent set
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## Local Tree Construction

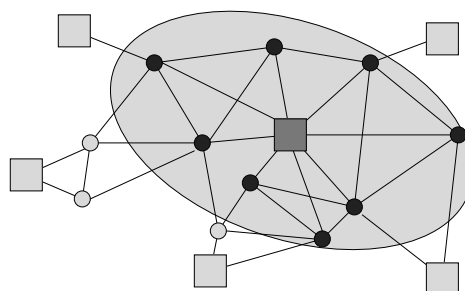
- Control Nodes learn about
  - 2-hop topology
  - 3-hop control nodes
- Reduce (local) graph to necessary information



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### Local Tree Construction

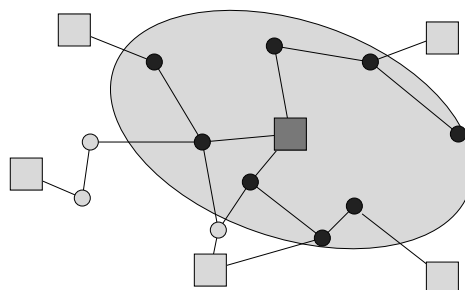
- Control Nodes learn about
  - 2-hop topology
  - 3-hop control nodes
- Reduce (local) graph to necessary information
  - Construct MST
    - Inform neighbors



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### Local Tree Construction

- Nodes adjust their signal strength according to (local) MST



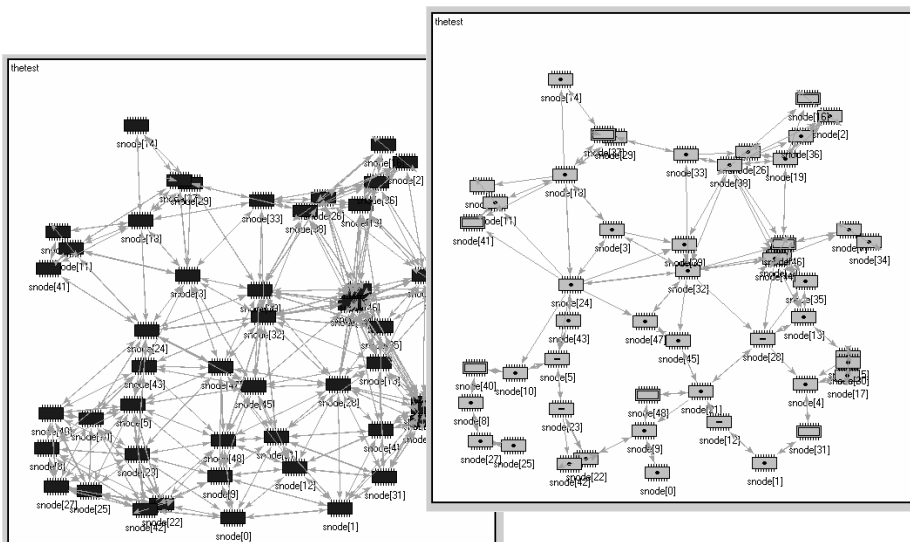
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## Properties of LPA

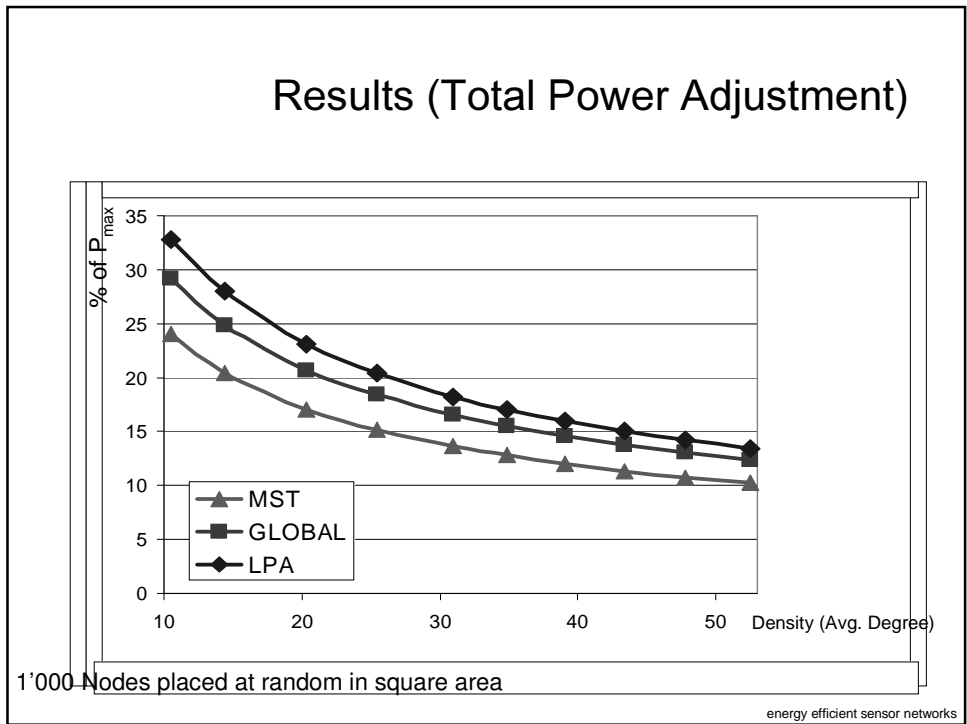
- Theorem:
  - LPA terminates in finite time.
  - Each node sends only 2 messages:
    - Control Message for Independent Set
      - fixed size
    - Regular Node => Neighborhood Information
    - Control Node => (local) MST
      - Both: bounded by #neighbors
  - Resulting graph is **bidirectionally connected**.

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## LPA: Adjusted Topology



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## Conclusions & Future Work

- Local approach to topology control
  - Creation of connected topology
    - Reduction of signal strength
  - Efficient, local algorithm
    - 2 messages per node
  - Scales well with network size
- Future Work
  - Maintenance procedures
  - Adapt to more dynamic network
    - Mobility, node failure, sleeping patterns ...

For further information:

[http://](http://eyes.eu.org)  [eyes.eu.org](http://eyes.eu.org)



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