Fault-tolerant and 3-dimensional Distributed Topology Control Algorithms in Wireless Multi-Hop Networks

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Outline

- Power Minimization and Distributed Topology Control.
- Problem Statement
- Distributed Algorithm for connectivity
- Fault-tolerant topology control
- Preserving k-connectivity
- Optimizations and 3-Dimensional case
- Future Works: Theoretical Problems

Power Minimization

- Wireless Multi-hop Networks and Sensor Networks
- Power Optimization: power needed to send a message via distance r is r^x (where $2 \leq x \leq 4$)
- Topology Control: minimizing power consumption and preserving some properties in the network.
- Crucial property: Connectivity

Distributed Topology Control Algorithm

- Need a distributed algorithm

- Providing global Information is hard

- Local decisions (algorithms) lead to a global property (i.e. connectivity)

Problem Statement

- Network of n nodes on the plane.
- Each Node can send a message within distance at most R
- Graph G^R: $(u,v) \in E(G^R) \to dist(u,v) \leq R$
- Assumption: G^R is connected
- Problem: for each node u, find $r(u) \leq R$ such that G' is connected where $(u,v) \in G' \to dis(u,v) \leq \max(r(u), r(v))$

Distributed Algorithm

- Idea: each node increases its distance until the angle between two consecutive neighbors of a node is less than α.

- Implementation: Local decisions based on angles of the neighbors of a node

Definitions

- Given G^R, G_α is the subgraph of G^R such that for each node $u : r(u) = R$ or the angle between two consecutive neighbors of u is at most α.

- Distributed Algorithm to construct G_α

Preserve Connectivity

- Theorem[Li et. al.] **If** G^R is connected, $G_{\frac{2\pi}{3}}$ is connected and $\frac{2\pi}{3}$ is necessary.

- Proof:...

- Distance between nodes will increase at most by a constant factor in G_R

Fault-tolerant Topology Control

- Node failures make the graph disconnected.
- Design networks that after failure of some nodes, the network remain connected.
- k-connectivity: G is k-connected iff after removing any $k-1$ vertices from the graph, G is still connected.
- k-connectivity is equivalent to having k vertex-disjoint paths between every two nodes.

Preserving k-connectivity

- Theorem: if G^R is k-connected, then $G_{\frac{2\pi}{3k}}$ is k-connected as well.

- Moreover, $\frac{2\pi}{3k}$ is necessary if k is even and $\frac{2\pi}{3(k-1)}$ is necessary if k is odd.

- α for preserving k-connectivity.

  - k odd: $\frac{2\pi}{3k} \leq \alpha \leq \frac{2\pi}{3(k-1)}$

  - k even: $\alpha = \frac{2\pi}{3k}$

Proofs

- $\alpha = \frac{2\pi}{3k}$ is sufficient: Follows from the fact that $\frac{2\pi}{3}$ preserves connectivity.

- $\alpha = \frac{2\pi}{3k}$ is necessary: Using Harary Graphs (k-regular k-connected graphs).

Optimization and 3-dimensional

- Problem: The radius of boundary nodes will be R.
- Optimization: Increase the radius while the angle improves.
- These results can be extended to 3-dimensional space.

Future Work

- Finding the optimum solution! (NP-Complete $\rightarrow$ approximation)

- There is a 12-approximation, improving this bound.

- Finding the k-connected subgraph with minimum cost.

- Tradeoff between capacity and power assumption in the network.