# Topology Control of Multihop Wireless Networks Using Transmit Power Adjustment

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# Outline

- Introduction
- Problem statement
- Static networks: optimum centralized algorithm
- Mobile networks: distributed heuristics
- Experimental results
- Conclusion

# Introduction

- The topology of a multihop wireless network is the set of communication links between node pairs.
- Wrong topology will reduce the capacity, increase the end-to-end packet delay, and decrease the robustness to node failures.

# Introduction

- This paper considered the assignment of different transmit powers to different nodes to meet a globe topology property.

# Problem Statement

- *Definition 1*: A *multihop wireless network* is represented as M=(N, L), where N is a set of nodes and $L: N \rightarrow (Z_0^+, Z_0^+)$ is a set of coordinates on the plane denoting the locations of nodes.
- *Definition 2*: A *parameter vector* for a given node is represented as $P=\{f_1, f_2, .., f_n\}$, where $f_i$: $N \rightarrow R$, is a real valued adjustable parameter.
  - Transmit power of node *u* is given by *p(u)*.

# Problem Statement

- *Definition 3*: the propagation function is represented as $\gamma : L \times L \rightarrow Z$, where L is a set of location coordinates on the plane.
  - $\gamma(l_i, l_j)$ gives the loss in dB due to propagation at location $l_j \in L$, when a packet is originated from location $l_i \in L$.

# Problem Statement

- The successful reception depend on the propagation function $\gamma$, the transmit power *p*, and the receiver sensitivity *S*

$$p - \gamma(l_i, l_j) \geq S$$

- *Definition 4*: the *least-power* function $\lambda(d)$ gives the minimum power needed to communicate a distance of *d*.

$$\lambda(d) = \gamma(d(l_i, l_j)) + S$$

# Problem Statement

- *Definition 5*: given a multihop wireless network M=(N, L), a transmit power function $p$, and a least-power function $\lambda$, the induced graph is represented as G=(V,E)
  - V is a set of vertices corresponding to nodes in N
  - E is a set of undirected edges such that (u,v) $\in$ E if and only if $p(u) \geqq \lambda(d(u,v))$, and $p(v) \geqq \lambda(d(u,v))$

# Problem Statement

- We can look at the topology control problem as one of optimizing a set of cost metrics under a given set of constraints.
- This paper consider a single cost metric, namely the *maximum transmit power* used, and two constraints *connectivity* and *biconnectivity*.

# Problem Statement

- *Definition 6*: problem Connected MinMax Power (CMP).
  - Give an M=(N, L), and a least-power function $\lambda$, find a per-node minimal assignment of transmit powers $p$: N→$Z^+$, such that the induced graph of (M, $\lambda$, $p$) is connected, and $\mathrm{MAX}_{u \in N}(p(u))$ is minimum.

# Problem Statement

- *Definition 7*: problem Biconnected Augmentation with MinMax Power (BAMP).
  - Given a multihop wireless net M=(N, L), a least-power $p$: N→$Z^+$ such that the induced graph of (M, $\lambda$, $p$) is connected, find a per-node minimal set of power increase $\delta(u)$ such that the induced graph of (M, $\lambda$, $p+\delta(u)$) is biconnected and $\mathrm{MAX}_{u \in N}(p(u) + \delta(u))$ is minimum.

# Static Networks: Optimum Centralized Algorithm

**Algorithm CONNECT**

**Input:** (1) Multihop wireless network M = (N, L) (2) Least-power function $\lambda$

**Output:** Power levels $p$ for each node that induces a connected graph

**begin**

1. sort node pairs in non-decreasing order of mutual distance
2. initialize $|N|$ clusters, one per node
3. **for** each (u,v) in sorted order **do**
4. **if** cluster(u) $\neq$ cluster(v)
5. $p(u) = p(v) = distance(u, v)$
6. merge cluster(u) with cluster(v)
7. **if** number of clusters is 1 **then end**
8. perNodeMinimalize(M, $\lambda$, $p$, 1)

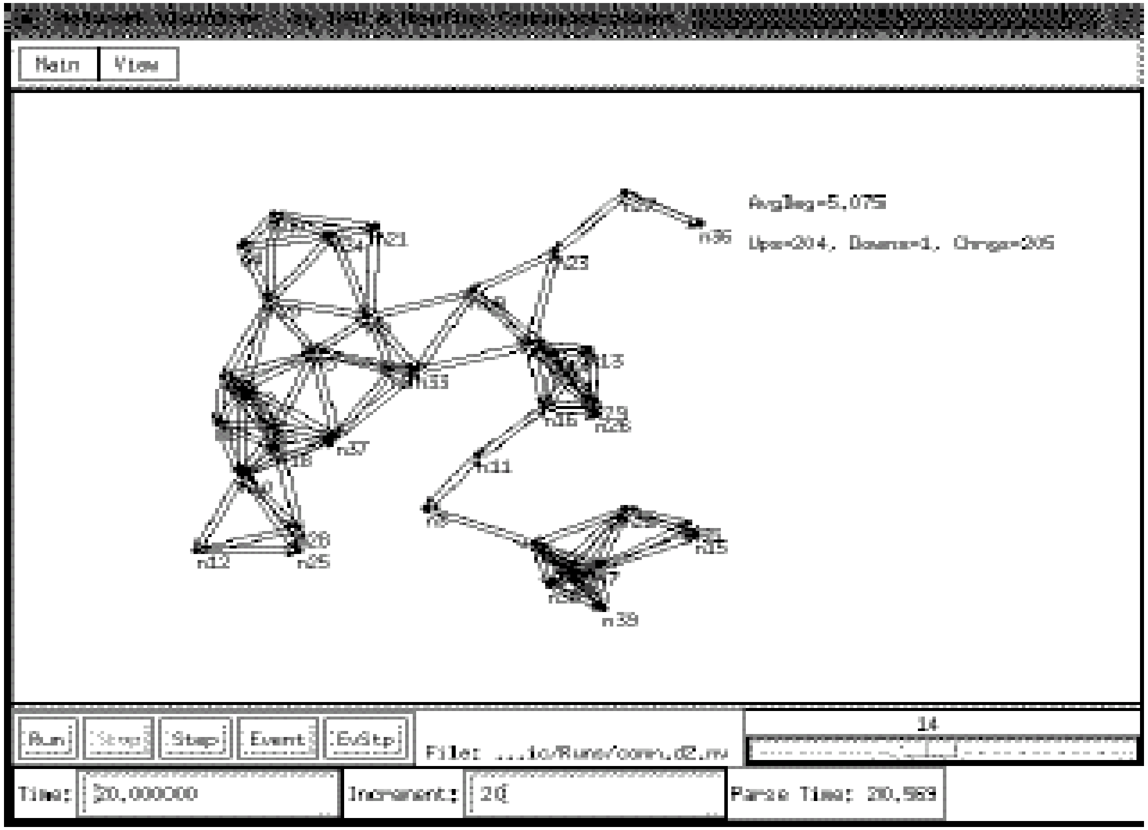
**end**

# Static Networks: Optimum Centralized Algorithm

**Procedure perNodeMinimalize**(M, $\lambda$, $p$, $k$)
**begin**
1. let S = sorted node pair list
2. **for** each node $u$ do
3. T = { $(n_1, n_2) \in$ S : $u = n_1$ or $u = n_2$ }
4. sort T in non-increasing order of distance
5. discard from T all $(x, y)$ such that $\lambda(d(x,y)) > p(u)$
6. **for** $(x, y) \in$ T using binary search **do**
7. **if** graph with $p(u) = \lambda(d(x,y))$ is not k-connected, **stop**
8. **else** $p(u) = \lambda(d(x,y))$

**end**

# Static Networks: Optimum Centralized Algorithm



# Static Networks: Optimum Centralized Algorithm

**Algorithm BICONN-AUGMENT**

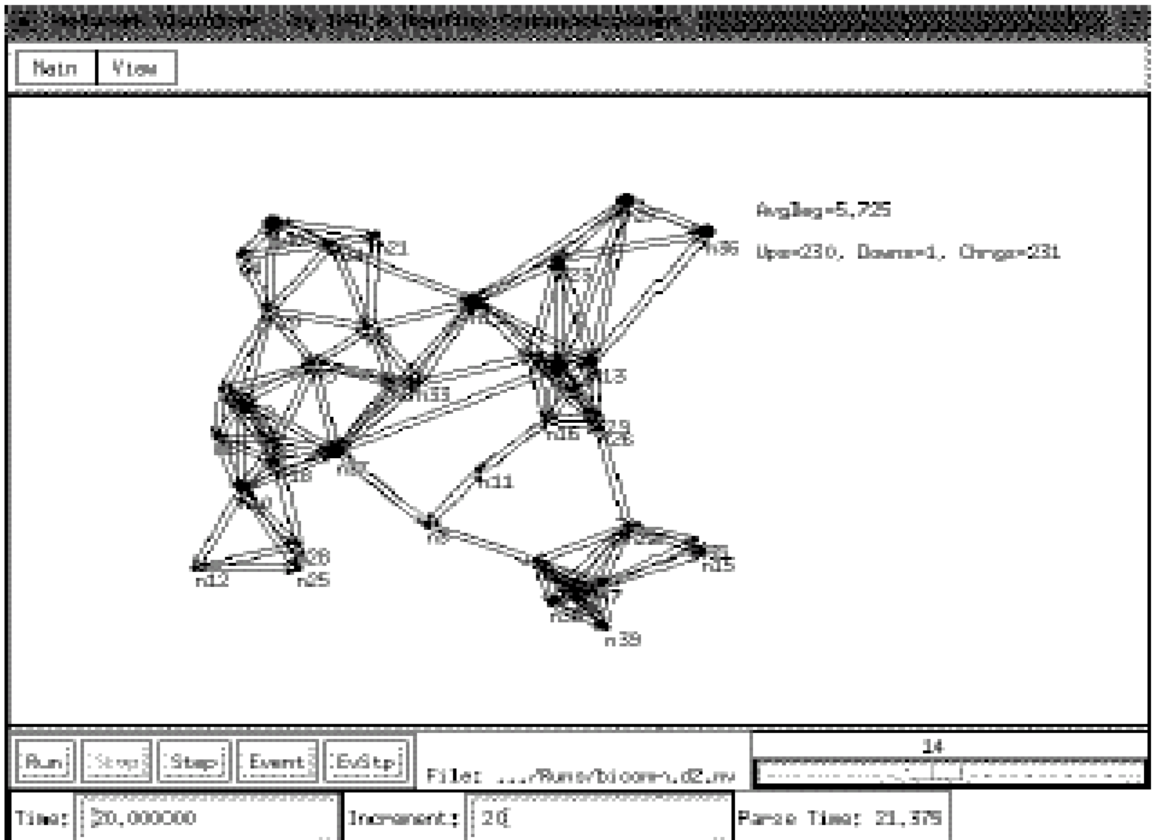
**Input:** (1) Multihop wireless network M = (N, L) (2) Least-power function $\lambda$ (3) Initial power assignment inducing connected network

**Output:** Power levels $p$ for each node that induces a biconnected graph.

**begin**
1. sort node pairs in non-decreasing order of distance
2. G = graph induced by (A, $\lambda$, $p$)
3. **for** each $(u, v)$ in sorted order **do**
4.     **if** biconn-comp(G,u) $\neq$ biconn-comp(G,v)
5.         $q = \lambda(\text{distance(u,v)})$
6.         $p(u) = \max(q, p(u))$
7.         $p(v) = \max(q, p(v))$
8.         add $(u, v)$ to G
9. perNodeMinimalize(M, $\lambda$, $p$, 2)

**end**

# Static Networks: Optimum Centralized Algorithm



# Static Networks: Optimum Centralized Algorithm

- Theorem 1:algorithm CONNECT is an optimum solution to the CMP problem

  Proof:

  - Suppose to the contrary that the power used is not optimum.
  - By line 4, this must have happened in order to connect to another node $v$ in a different cluster.

# Static Networks: Optimum Centralized Algorithm

– There is no path between *u* and *v*

$$\nexists\, path(u,v) : \forall (x,y) \in path(u,v),\ d(x,y) \leq d(u,v) \qquad (3)$$

– By line 5, we can rewrite equation 3 as

$$\nexists\, path(u,v) : \forall x \in path(u,v),\ p(x) \leq p(u) \qquad (4)$$

# Static Networks: Optimum Centralized Algorithm

- Let $p_{opt}(i)$ denote the power of node $i$ under the optimum algorithm and OPT be the optimum solution value. We can know that, OPT < $p(u)$.
- By definition:

$$\forall_i (p_{opt}(i) \leq OPT < p(u)) \qquad (5)$$

- By Eq.5 all such nodes must have powers less than p(u)

$$\exists\, path(u,v) : \forall(x) \in path(u,v),\ p(x) \leq p(u) \qquad (7)$$

  - *This contradicts equation 4*.

# Mobile Networks: Distributed Heuristics

- In a mobile multihop wireless network, the topology is constantly changing.
- This paper presented two distributed heuristics topology control:
  - Local information no topology (LINT)
  - Local information link-state topology (LILT)

# Mobile Networks: Distributed Heuristics

- LINT uses only available neighbor information collected by a routing protocol, and attempts to keep the degree(number of neighbors).
- LILT also uses the freely available neighbor information, but additionally exploits the globe topology information that is available with some routing protocols such as link-state protocol

# Mobile Networks: Distributed Heuristics

- LINT description:
  - A node is configured with three parameters
    - The "desired" node degree $d_d$
    - A high threshold on the node degree $d_h$
    - A low threshold $d_l$
  - The power change is done in a *shuffle periodic* mode, that is, the time between power changes is randomized around a mean.

# Mobile Networks: Distributed Heuristics

- Let $d_c$ and $p_c$ denote the current degree and current transmit power of a node in a network of density D. Let $r_c$ denote the range of a node with power $p_c$.
- Assume a uniformly random distribution of the nodes in the plane,

$$d_c = D \cdot \pi \cdot r_c^2 \quad (11)$$

$$d_d = D \cdot \pi \cdot r_d^2 \quad (12)$$

# Mobile Networks: Distributed Heuristics

– Let T denote the receiver sensitivity of the radio and then

$$p_c - (\gamma(r_{thr}) + 10 \cdot \mathcal{E} \cdot log(\frac{r_c}{r_{thr}})) = T \quad (13)$$

$$p_d - (\gamma(r_{thr}) + 10 \cdot \mathcal{E} \cdot log(\frac{r_d}{r_{thr}})) = T \quad (14)$$

– Equating (13)(14), and substituting for $r_c$ and $r_d$ from (11)(12), we will get

$$p_d = p_c - 5 \cdot \mathcal{E} \cdot log(\frac{d_d}{d_c})$$

# Mobile Networks: Distributed Heuristics

- LILT description:
  - Two main parts to LILT
    - Neighbor reduction protocol (NRP): maintain the node degree around a certain configured value.
    - Neighbor addition protocol (NAP): it will be triggered whenever an event driven or periodic link-state update arrives.

# Mobile Networks: Distributed Heuristics

– A node receiving a routing update first determines the of three states the update topology is in – disconnected, connected but not biconnected or biconnected.
– If biconnected, no action is taken.
– If disconnected, the node increase its transmit power to the maximum possible value.

# Mobile Networks: Distributed Heuristics

- If connected but not biconnected
  - The node find it distance from the closest *articulation point* (a node whose removal will partition the network).
  - Set a timer t that is randomized around an exponential function of the distance from the articulation point.
  - If after time t the network is still not biconnected, the node increase it power to the maximum possible.

# Experimental results

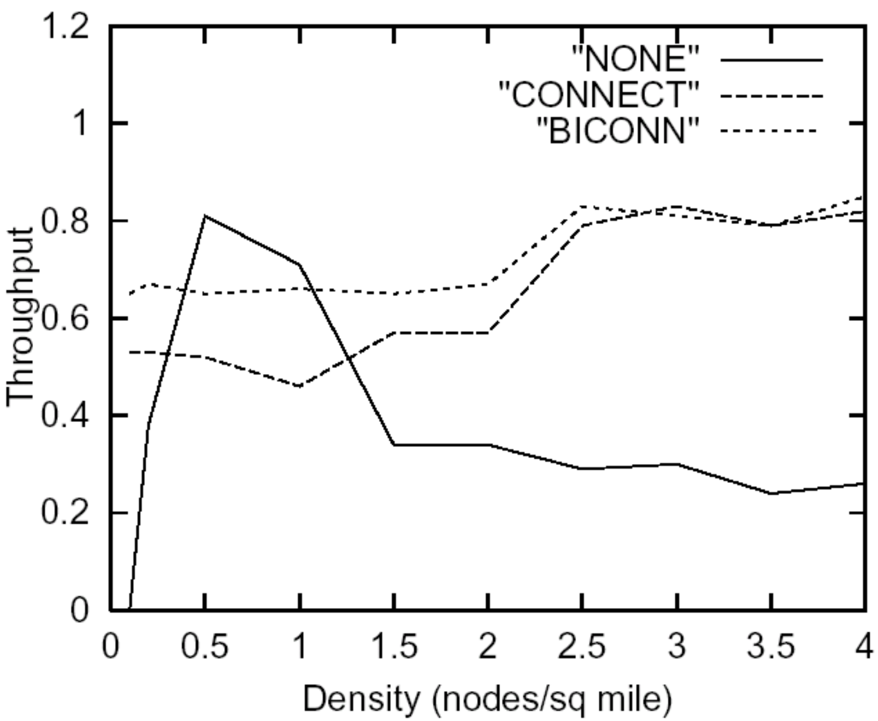



Fig. 6. Throughput vs density : Static networks

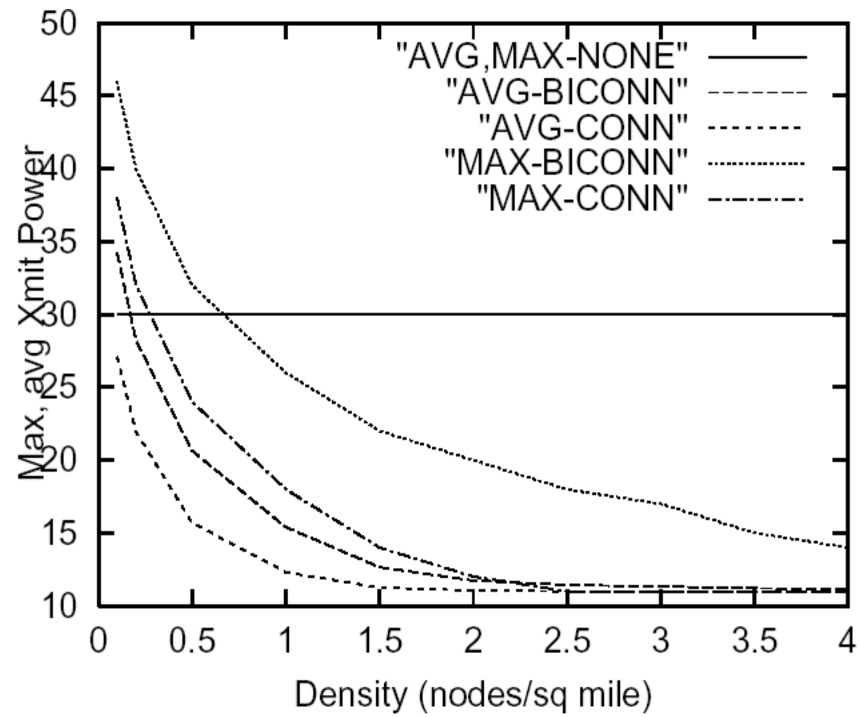



Fig. 7. Power vs density: Static Networks

# Experimental results

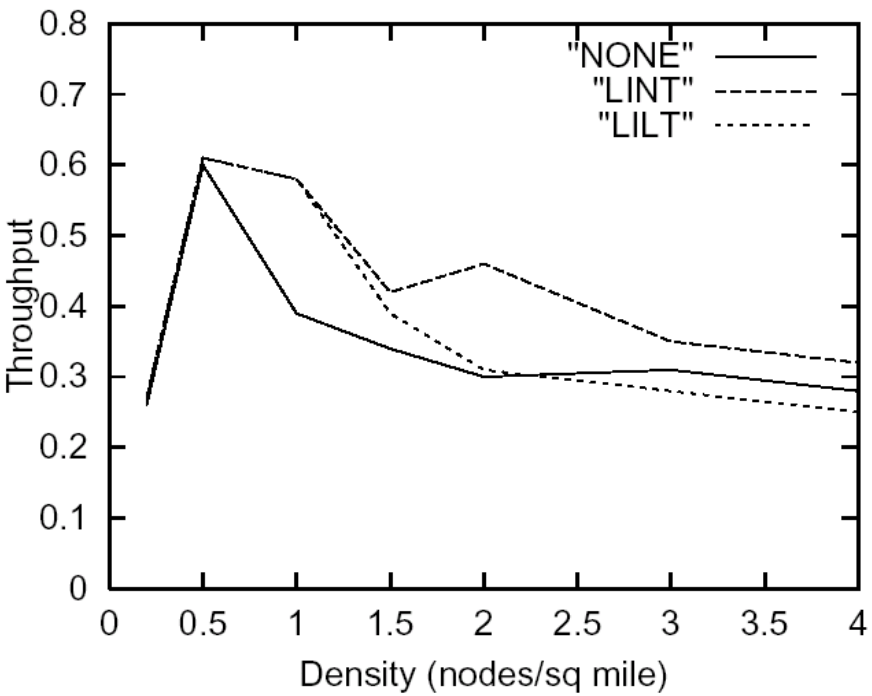



Fig. 8. Throughput vs density: Mobile networks

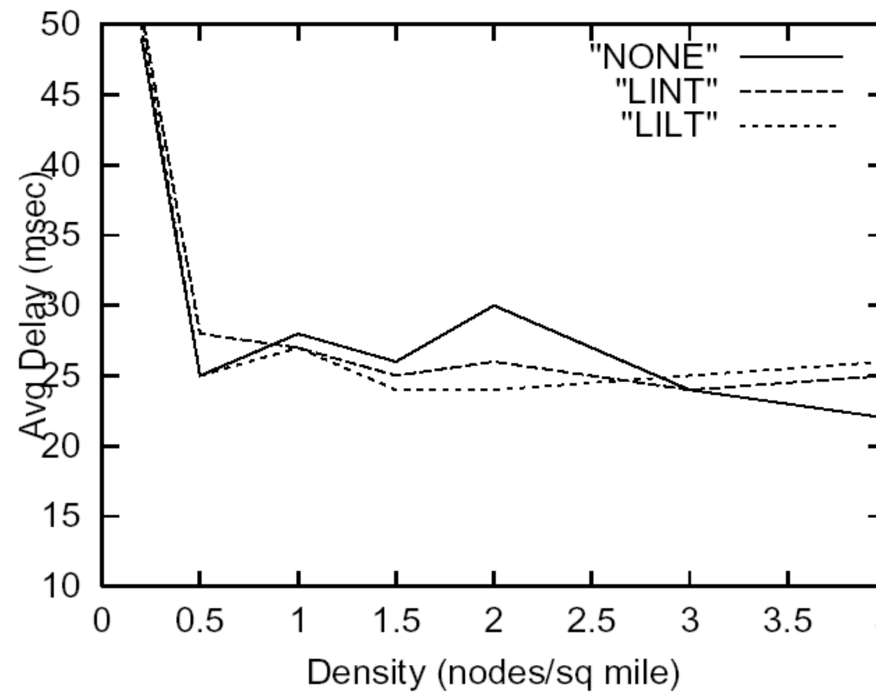



Fig. 9. Delay vs density: Mobile networks

# Conclusion

- This paper present some schemes that can control the topology by using transmit power adjustment.
- I think it is a nice reference paper.