Wolfram Krause: Optimized network structure and routing metric in wireless multihop ad hoc communication

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Seminar on Theoretical Computer Science, 2006

Outline

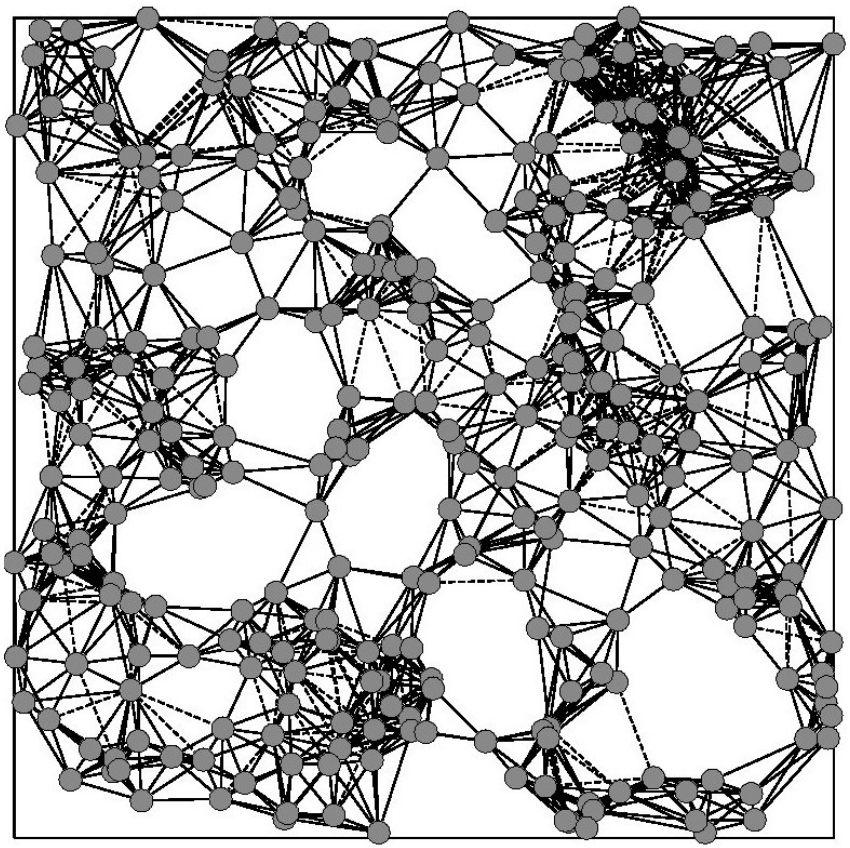
Outline

The question

How to improve throughput of an wireless multihop ad hoc network?

The model

some abstractions are needed for the network



- unit square
- nodes homogeneously distributed

The model

What makes this a wireless network?

- undesigned network topology
- multihop -connections
- transmission power issues
- agenda: resolution model that can be applied in distributive fashion

The model

Limitations

- no mobility
- uniformly distributed traffic
- fairness is not an issue
- the throughput is

Outline

What is end-to-end throughput?

- information transferred per timestep
- calculation
  - hard to do exactly
  - leads to simulations or approximations

How does throughput scale?

- obeys scaling law $T_{e2e} = (N - N_0)^{\gamma}$
- theoretical maximum is $\gamma = 0.5$
- unoptimized network has $\gamma \approx 0.22$
- can be optimized to 0.41!
- why does it scale so badly?

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How to optimize throughput?

- alter the transmission power
- alter the routes

Outline

Cumulative betweenness centrality

The definition

What is betweenness centrality?

- a property of a node
- B_i number of end-to-end routes going through node i
  - The final node is not included to the path.
- note: depends on metric used in the network

How does it cumulate?

- $B_i^{cum} = B_i + \sum_{j \in \mathcal{N}_i} B_j$, where $\mathcal{N}_i$ is the neighbour nodes of i.
- cumulative sum of routes going through the node+neigbours of the node

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CBC, So what?

What is the use of this concept

- we can approximate: sending time = relative CBC
- why? the interference
- leads to $T_{e2e} = \frac{\text{nodepairs}}{\max_i\{B_i^{cum}\}}$
  - exact with fully connected network
  - exact with central hub

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Transmission power

Basic problem with transmission powers

What to optimize?

- minimal power consumption vs. maximal connectivity
- maximal connectivity vs. minimal interference

- Short jumps and long routes?
- Short routes and long jumps?
- Leads to frustration.

Transmission power optimization

Let's iterate a solution

Initial setting

- transmission power s.t. has atleast k_{min} neigbours
- A node can ask neighbours to speak louder, if needed
- power newer goes below initial setting
- $\Longrightarrow$ strong connectivity

The optimization

- Gradient method search for local maxium
  - Test node by node for changes
- Small perturbations

Transmission power optimization

Let's iterate a... bad solution

- The results are poor:
  - first local maxium is the best
  - gets worse in every iteration
- Even worse: the structural properties make solutions useless!
  - effects are indirect
  - effects are unpredictable

Outline

Thinking out of the box

Finding a new direction

The previous approach failed – something has to be done

Cumulative betweenness cetrality

CBC is usefull for routing metric

- forget transmission powers
- don't minimize hops, avoid traffic
- leads to better utilization of the network

CBC routing metric in practice

Hey, the CBC depends on the routes itself!

The setup has to be done with care

- Initialize $B_k^{cum} = 1$
- Iterate
  - Node by node
  - dijstra-like fashion
- Experimental result: two rounds are enough
- Leads to good results

Summary

- The cumulative betweenness centrality is good for
  - making throughput estimates
  - an alternative routing metric
- Optimization by modifying of transmission powers is hard, because effects are indirect and delocalized.

For Further Reading I


W. Krause, J. Scholz, M. Greiner.
Optimized network structure and routing metric in wireless multihop ad hoc communication
arXiv:cs.NI/0503010


P. Gupta, P. R. Kumar,
The capacity of wireless networks
IEEE Trans. Info. Theory IT46 (2) (2000) 388404.