A Robust Interference Model for Wireless Ad-Hoc Networks

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Overview

- What is Topology Control?

- Context – related work

- A robust interference model

- Interference in known topologies

- The highway model
  - Exponential node chain
  - General highway

- Conclusions
Topology Control

• Drop long-range neighbors: Reduces interference and energy!
• But still stay connected

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Topology Control as a Trade-Off

Network Connectivity

Conserve Energy
Reduce Interference

Sometimes also clustering, Dominating Set construction
Not in this presentation
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Reducing Interference by Graph Sparseness or Bounded Degree

- Constructions from computational geometry
  - Delaunay Triangulation [Hu 1993]
  - Minimum Spanning Tree [Ramanathan & Rosales-Hain INFOCOM 2000]
  - Gabriel Graph [Rodoplu & Meng J.Sel.Ar.Com 1999]

- Cone-Based Topology Control
  - [Wattenhofer et al. INFOCOM 2000]
  - [Li et al. PODC 2001, Jia et al. SPAA 2003, Li et al. INFOCOM 2002]
  - [Wang & Li DIALM-POMC 2003]

Interference is considered only implicitly!
Explicit Interference Definitions

• Diversity as an interference measure [Meyer auf der Heide et al. SPAA 2002]
  – Interference between edges, time-step routing model, congestion
  – Trade-offs: congestion, power consumption, dilation
  – Interference model based on network traffic

• Link-based interference model [Burkhart et al. MobiHoc 2004]
  – „How many nodes are affected by communication over a given link?“
  – Minimize the maximum interference & preserve connectivity
  – Graph sparseness or low node degree $\nRightarrow$ low interference
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Interference occurs at the receiver
Susceptible to drastic changes

Sender-centric perspective

Interference $\in O(1)$
Interference $\in O(n)$
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Towards a Robust Interference Model

- Interference model
  - Node $u$ disturbs all nodes closer than its farthest neighbor
  - **Interference** of node $u =$
    #nodes whose distance to $u$ is at most the distance to their farthest neighbors

- Problem statement
  - We want to **minimize maximum interference**
  - At the same time the topology must be **connected**
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Let’s Study the Following Topology!

…from a worst-case perspective
Topology Control Algorithms Produce…

- All known topology control algorithms (with symmetric edges) include the nearest neighbor forest as a subgraph and produce something like this:

The interference of this graph is $\Omega(n)!$
But Interference…

• Interference does not need to be high…

This topology has interference $O(1)$!!
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The Highway – a High Interference Topology?

• Already 1-dimensional node distributions seem to yield inherently high interference... [Meyer auf der Heide et al. SPAA 2002]

• ...but the exponential node chain can be connected in a better way
The Highway – a High Interference Topology?

- Already **1-dimensional node distributions** seem to yield inherently high interference... [Meyer auf der Heide et al. SPAA 2002]

  ![Diagram](image)  
  Connecting linearly results in interference $O(n)$

- **...but the exponential node chain** can be connected in a better way

  ![Diagram](image)  
  Nodes connecting to the right are called **hubs**
The Highway – a High Interference Topology?

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• ...but the exponential node chain can be connected in a better way

Interference = $\left\lfloor \frac{\sqrt{8n-15}+3}{2} \right\rfloor \in O(\sqrt{n})$
Can We Do Any Better?

• Observations
  – Interference $\geq$ #hubs - 1
  – Interference $\geq$ maximum degree

• Assumption
  – Optimum-interference topology yields interference $< \sqrt{n}$

\[ \Rightarrow \text{#hubs } \leq \sqrt{n} \quad \Rightarrow \text{max degree } < \sqrt{n} \]

Resulting topology is not connected

$\sqrt{n}$ is a lower bound for the interference in the exponential node chain!
The General Highway Model

- Arbitrary distributed nodes in one dimension
- Are there instances where a minimum-interference topology exceeds interference $\Omega(\sqrt{\Delta})$?

Algorithm $\mathcal{A}$
- Partition the highway into segments of unit length 1
- Every $\sqrt{\Delta}$-th node in a segment becomes a hub
- Connect hubs linearly
- Connect all other nodes to their nearest hub
- Connect adjacent segments

$\Delta = \text{maximum node degree in the UDG}$

$\Delta = \sqrt{\Delta}$

hub = node with more than one neighbor
On the Highway…

Observations

- #hubs in a segment is in $O(\sqrt{\Delta})$
- Regular nodes only interfere with nodes in the same interval
- The interference range of a node is limited to adjacent segments

The resulting topology yields interference $O(\sqrt{\Delta})$

Algorithm $\mathcal{A}$ is designed for the worst-case!
Approximation Algorithm

• Idea
  – Only apply Algorithm $\mathcal{A}$ to high interference instances…
  – …else connect nodes linearly

• Algorithm
  – Connect nodes linearly
  – If interference $> \sqrt{\Delta}$ $\Rightarrow$ apply Algorithm $\mathcal{A}$

$\mathcal{A}$ The resulting topology approximates the optimal interference up to a factor in $O\left(\frac{4}{\sqrt{\Delta}}\right)$

• Proof
  – Lower bound also applies to general highway
Conclusions

• Definition of an explicit interference model
  – Receiver-centric
  – Robust with respect to addition/removal of individual nodes

• All currently known topology control algorithms fail to confine interference at a low level

• Focusing on networks in one dimension
  – $\sqrt[\Delta]{\Delta}$-approximation of the optimal connectivity-preserving topology

• Future work
  
  Adaptation of our approach to higher dimensions
Questions?

Comments?

Distributed Computing Group