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
• *Drop long-range neighbors*: Reduces interference and energy!
• But still stay *connected*
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 $\Rightarrow$ low interference
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• 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
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Sender-centric perspective

Interference occurs at the receiver

Susceptible to drastic changes

\[ \text{Interference} \in O(1) \]

\[ \text{Interference} \in O(n) \]
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Towards a Robust Interference Model

• Interference model
  – Node $u$ disturbs all nodes closer than its farthest neighbor
  – Interference of node $u = \#\text{nodes whose distance to } u \text{ is at most the distance to their farthest neighbors}$

- Interference occurs at the receiver ✔
- Susceptible to drastic changes ✔

• 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]

\[
\text{Connecting linearly results in interference } O(n)
\]

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

The Highway – a High Interference Topology?

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

  Nodes connecting to the right are called **hubs**

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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

\[
\text{Interference} = \left[\frac{\sqrt{8n-15}+3}{2}\right] \in O(\sqrt{n})
\]
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 $A$

– 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

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

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 $\mathcal{A}$

  The resulting topology approximates the optimal interference up to a factor in $O(\sqrt[4]{\Delta})$

- **Proof**
  - Lower bound also applies to general highway

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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
  – $\sqrt{n}$-approximation of the optimal connectivity-preserving topology

• Future work

  Adaptation of our approach to higher dimensions