Delay and Capacity in Mobile Ad Hoc Networks

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Outline

- The beginning of the story
- The line of investigation
- Current status
- Challenges in vehicular networks
The beginning of the story

- Scalability of Ad Hoc Networks

How much information transfer a wireless network can support? Is it possible to deploy a large scale wireless ad hoc network?
The line of investigation

- Capacity Scaling law — asymptotic behavior

\[ n\lambda H \leq CR \]

- Max # of concurrent transmissions
- Transmission rate for point-to-point link
- Ave # of transmissions for each packet
- Per node throughput (packet/second)
- # of nodes in the network

\[ \lambda \]

\[ n / \text{network} \]

\[ H \]

\[ \text{Ave # of transmissions for each packet} \]

\[ \text{Transmission rate for point-to-point link} \]

\[ n\lambda H \leq CR \]
The line of investigation

- Capacity Scaling law — existing results

\[ n\lambda H \leq CR \]

<table>
<thead>
<tr>
<th>Network setting</th>
<th>H</th>
<th>C</th>
<th>( \lambda )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static random ad hoc</td>
<td>1</td>
<td>( \Theta(1) )</td>
<td>( \Theta(1/n) )</td>
</tr>
<tr>
<td>Direct transmission</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static random ad hoc</td>
<td>( \Theta(\sqrt{n}) )</td>
<td>( \Theta(n) )</td>
<td>( \Theta(1/\sqrt{n}) )</td>
</tr>
<tr>
<td>Multi-hop [1]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile random ad hoc</td>
<td>2</td>
<td>( \Theta(n) )</td>
<td>( \Theta(1) )</td>
</tr>
<tr>
<td>Two-hop relaying [2]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


The line of investigation

- Capacity Scaling law — existing results

- $\Theta(1)$ with two-hop relaying mobile
- $\Theta(1/\sqrt{n})$ with multi-hop relaying static
- $\Theta(1/n)$ with direct transmission static

Capacity scaling

Number of nodes
The line of investigation

- Capacity and Delay tradeoff

Assume appropriate scheduling and one transmission requires a distance of $c$
The line of investigation

- Mobility models affect delay and capacity tradeoff
  - Time cost on movement of relays depends on mobility model.
  - Different mobility model may cause different average delay.
  - Delay and capacity tradeoff may be different between mobility models.

Intuitively, if the node always wanders around, it is very difficult for the node to move a long distance in one direction and that will incur a large delay.
The line of investigation

- Trade-off results for i.i.d mobility [3]

<table>
<thead>
<tr>
<th>scheme</th>
<th>capacity</th>
<th>delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>no redundancy</td>
<td>$O(1)$</td>
<td>$O(N)$</td>
</tr>
<tr>
<td>redundancy 2-hop</td>
<td>$O(1/\sqrt{N})$</td>
<td>$O(\sqrt{N})$</td>
</tr>
<tr>
<td>redundancy multi-hop</td>
<td>$O(\frac{1}{N \log(N)})$</td>
<td>$O(\log(N))$</td>
</tr>
</tbody>
</table>

The line of investigation

- **Trade-off results — a global perspective [4]**

The line of investigation

- Trade-off results — a global perspective [4]
  - Node mobility has strong impact on delay-capacity tradeoff
  - There exists minimum value of delay (critical delay) which makes capacity better than that of static random ad hoc networks
  - Nodes change directions over shorter distances exhibit higher critical delay values
  - Nodes moving in same direction over longer distances show a wider delay-capacity tradeoff

Recent Status

- Exploring mobility impacts
  - Restricted mobility\textsuperscript{[5][6]}
  - Lévy Mobility\textsuperscript{[7]}

\textsuperscript{[7]} Kyunghan Lee, Yoora Kim, Song Chong, Injong Rhee, and Yung Yi, “Delay-Capacity Tradeoffs for Mobile Networks with Lévy Walks and Lévy Flights,” IEEE International Conference on Computer Communications (INFOCOM’11), Shanghai, China, April 10-15, 2011.
Recent Status

- Other network settings
  - Three-Dimensional networks\[^8^\]
  - Hierarchical cooperation\[^9^\]
  - Hybrid networks\[^10^\]
  - Multi-cast wireless networks\[^11^\]


Challenges in vehicular networks

- Mobility
  - Map-imposed, dependent movement, social feature
- Spatio-temporal variations in connectivity
- Spatio-temporal variations in vehicle density
- A large number of applications
  - Safety applications (Broadcast), user applications (Uni-cast or Geo-cast)
Some discussions on this issue

- Functional capacity: capacity with constraints
  - For example, constraint on delay or tolerance on certain packet loss
- Cars on the road: geometry study [10]
- Cars on the wheels: mobility model
- Out of sight: new architecture and methodology
  - Rethinking VANET [11]

Thanks!