Routing in Wireless Mesh Networks

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About me

- 2005-: PhD student at WIT (Kappel, IS)
  - Advisors: Dietrich (EE), Kastner (CS)
  - WP-Leader EU-Project Track & Trade
- 2001-2005: Telecommunications Research Center Vienna (ftw)
- Master: Computer Science, Specialization: Computer Engineering
- Research Interests:
  - Wireless Computing and Telecommunications
  - Wireless Mesh / Ad-Hoc Networks
- Thesis (working title): "Routing in Wireless Mesh Networks"

Overview

- My Thesis: "Routing in Wireless Mesh Networks"
  - Definition
  - State-of-the-Art
  - Approach
  - Time Plan
- Current Work
  - Ns-2 Random Generator
  - Wireless Network Modelling

Definition / 1: Wireless Mesh Network

"Wireless Backbone" instead of cables
- Less cost
- Faster deployment
- Better upgradability

Application areas:
- Military
- Disaster areas / emergency response
- Civilian: access network to the Internet

Definition / 2: Field of Research

Ad-Hoc Networks
Sensor Networks
Wireless Mesh Networks (WMNs)

Less mobility, less topology & route changes
No battery power constraints, but standard Internet protocols

Definition / 3: The Problem

Routing:
- Hop-count is a bad metric:
  - Links vary over time
  - Far links are usually worse than short links

MAC Interaction:
- Hidden node problem
- Exposed terminal problem
- Flow-in-the-middle problem
**State-of-the-Art / 1: Protocol types**

- Reactive (on-demand)
  - Build route when flow starts
  - Destroy route when flow ends
  - Drawback: route setup delay
  - Good for frequent route changes
- Pro-active
  - Build route in advance
  - Keep routes up-to-date (communicate changes)
  - Drawback: communication overhead
  - Good when routes change seldom
- Hybrid

**State-of-the-Art / 2: Protocols**

*Classical*:
- **OLSR** - Optimized Link State Routing protocol, reactive, RFC 3626 (Clausen, Jaquet, 2003), used in firmwares
- **AODV** - Ad-hoc On-Demand Distance Vector reactive, RFC 3561 (Perkins, Royer, Das, 2003)
- **DSDV** - Dynamic Destination-Sequenced Distance Vector pro-active, one of the oldest (Perkins, 1994)
- **DSR** - Dynamic Source Routing reactive (Johnson, 1994)

Nature inspired:
- Eg. Ant Hoc Net
  - hybrid (DiCaro et al, 2004)

**Ant-based Algorithms / 1**

- Inspired by nature: behavior of ants
- Single ants are quite stupid, but the whole system exhibits "intelligent" behavior
- Ant Colony Routing (ACR) – distributed version of Ant-based Algorithm, eg.:
  *AntNet* by Di Caro and Dorigo, 1998
  *AntHocNet* for MANETs by Di Caro, Ducatelle, Gambardella, 2004:
    - AntNet concept + Extensions
    - Hybrid routing approach: reactive/pro-active

**Ant-based Algorithms / 2**

1. Whenever an ant moves, it lays a pheromone trail
2. To find its way, an ant:
   - Follows existing trails if there are any.
   - Probability for choosing a trail is proportional to amount of pheromone on the trail.
   - Walks randomly if there are no trails.
3. Pheromone evaporates over time -> unused trails vanish.

- **Trail following** (state transition rule)
  - determines how the ant chooses its way depending on link cost and amount of pheromone found on the trails
- **Trail laying** (pheromone update rule)
  - determines how the pheromone is updated
- **Evaporation** (evaporation rule)
  - determines how fast pheromone evaporates

**Ant-based Algorithms / 3**

- Forward ants: regularly created, choose next link based on transition rule:
  \[ P = \text{Trans}(\text{pheromone}, \text{link cost}) \]

**Ant-based Algorithms / 4**

- Backward ants:
  - created when forward ant reaches destination node, travels back to from where it came, updates pheromone amounts and measured link costs at all nodes on way back
**My Approach**

- Simulation with ns-2 simulator
- An implementation of AntNet has just become available

**Find new algorithm:**
- Based on ant concept
- Probably hybrid between classical and ant-based
- Probably hybrid proactive/reactive routing approach – WMNs are less mobile than MANETs
- Use better cross-layer info to determine link costs
- Reduce number of ants by observing TCP traffic in the network (possible?)
- Idea: use "colored pheromones" to signify QoS classes -> different traffic takes different routes in the network

**Time Plan**

- **25.7.**: Student poster at INDIN
- **1.8.**: Book chapter of ns-2 RNG paper
- **5.8.**: Define and implement algorithm in ns2; paper for BIONETICS 2007, Budapest
- **21.9.**: Evaluation of wireless models in ns-2; SIMUTools 2008, Marseille
- **7.-9.11.**: FET (Toulouse) – short paper (wireless modelling) under review
- **12/2007**: performance evaluation; publish 2 papers about algorithm
- **05/2008**: Finish Thesis

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**Current Work: Ns-2 Random Generator**

- Martina Umlauft, Peter Reichl, *Experiences with the ns-2 Network Simulator - Explicitly Setting Seeds Considered Harmful*
  
  Presented at Wireless Telecommunications Symposium WTS '07, 26.-28. April, Pomona, CA, USA


**The ns-2 RNG**

- **ns-2 versions <= 2.1b8:** old RNG
  
  Minimal Standard multiplicative Linear Congruential Generator [Park and Miller, 1988]
  
  Period \( p=2^{31}-2 \)
  
  API: \$rng seed \$s;
  
  Sensitive to seeds [Entacher, Hechenleitner, 2002]

- **ns-2 versions >= 2.1b9 until today:** new RNG
  
  MRG32k3a [L’Ecuyer, 1999]
  
  Period \( p = 3.1 \times 10^{57} \)
  
  API: \$rng next-substream;
  
  Promises to fix seed-sensitivity -> true?

**BUT:** bad documentation -> people use old API!

**Correlation Experiment**

- Set up 3 RNGs
- Draw triplets of values
  
  \( (u(1)) \), \( (u(2)) \), \( (u(3)) \) – 1,000,000 triplets drawn
- Interpret as vector
  
  \( <u(1), u(2), u(3)> \)
Correlation Experiment

100,000 triplets drawn

Correlation Experiment

10,000 triplets drawn

Correlation Experiment

1,000 triplets drawn

Result for bad Seed Set 2

New RNG \( /w \) old method & bad seed set

Old RNG \( /w \) bad seed set

10,000 triplets drawn

Result for bad Seed Set 3

New RNG \( /w \) old method & bad seed set

Old RNG \( /w \) bad seed set

10,000 triplets drawn

Wired Topology Example / 1

\[
\begin{align*}
G_1 & \quad \text{Node 1} \\
G_2 & \quad \text{Node 2} \\
G_3 & \quad \text{Node 3} \\
G_4 & \quad \text{Node 4} \\
G_5 & \quad \text{Node 5}
\end{align*}
\]

\( \text{BW}=1 \text{ Mbps} \)

\( \text{QS}=1000 \text{ Packets} \)

\( \lambda = 8000 \text{ bits} / 41 \text{ ms} = 0.195 \text{ Mbps} \)

\( \Sigma \lambda = 0.976 \text{ Mbps} \)

\( p = \Sigma \lambda / \text{BW} = 0.976 \quad \text{utilization factor} \)

\( \rho = \Sigma \lambda / \text{BW} = 0.976 \quad \text{utilization factor} \)

Expected mean queue length:

\( q = \rho / (1 - \rho) \)

\( \mu^2 = 24.488 \text{ pkts} \)

New RNG

New method 19.2056

New RNG

Set 2 - bad 29.4527

Old RNG

Set 2 - good 24.4265

Old RNG

Set 2 - bad 24.2785

Bad seed sets: higher average queue lengths!
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**Wireless Example**

Simulation time 600s

- N1
- N2
- N3
- N4

- CBR: 50Mbps
- BW = 1Mbps
- BW = 1Mbps
- BW = 1Mbps

- Error model: $10^{-3}$, uniform
- RNG1, Seed1
- RNG2, Seed2
- RNG3, Seed3

Run lengths vs. burst lengths:

Bad seed sets: higher percentage of short run lengths!

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**Current Work: Wireless Network Modelling**

- Martina Umlauft, *Some Thoughts on Wireless Network Modelling*, Student Poster, accepted at INDIN ’07, to be presented 2007-07-25

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**Traditional Reachability Graph G**

- $n_0$
- $n_1$
- $n_2$
- $n_3$
- $n_4$
- $n_5$
- $n_6$
- $n_7$
- $n_8$
- $L_{1,3}$
- $L_{4,8}$

- Edges $L_{1,3}$ and $L_{4,8}$ seem independent
- Edges encourage thinking of links as "tunnels" between nodes

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**Some Observations**

- No "tunnel" - so what is a "link"?
  - Unicasts "do not exist" - can lead to: hidden node problem, exposed node problem
  - (Padhye et al, 2005):
    - $\exists L_{i,j} \text{ in } G \text{ iff: } n_i \cap n_j > n_j$
    - with packet loss rate below certain threshold (ETX $\leq 3$) ETX (DeCouto et al, 2003)

- Carrier sensing (CCA)
  - A node can "hear" the transmission but SINR is too bad to successfully decode the packet
  - CCA function: channel is busy! Do not send (exposed node problem)

- "Layer 2 interference" vs. "Interference" on layer 1

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**Vs. Real World Situation**

- Theoretical transmission range
- Carrier sense (CCA) range (idealized)

Example of real-world signal propagation as measured in (Kotz et al, 2003)
Proposal: new graph $G^*$ with CCA-edges

Only one paper found which informally uses such a graph (Das et al, 2006).

Transmission of Data Packet $n_1 \rightarrow n_3$

Transmission of ACK $n_3 \rightarrow n_1$

References / Wireless Network Modelling


Thank You!