Real-Time Deployment of Multihop Relays for Communication Range Extension

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Motivation & Objectives

Motivation

- Public safety operations require reliable, rapidly-deployed communications
- Frequent wireless dead spots encountered inside large buildings, in underground tunnels, and other difficult radio environments

Objectives

- Maintain network connectivity for reliable communications
- Minimize impact on user’s mission
Approach

- Extend signal coverage through a multihop network that relays data/voice between first responders and Incident Command (IC)
- Relays (●) are automatically deployed at appropriate points along path, creating a multihop network
- Link layer and routing protocols provide reliable two-way communications, transfer of user vital signs, etc.
Technical Challenges

- Automating the deployment process…When/where to deploy relays?

- Reliable end-to-end transmission
  - Link-quality-sensitive route metric
  - Link and network layer retransmission

- Adapting to changes in link quality and topology
  - Timely route updates
  - Power control
Questions & Overview

Questions to Address

- How to measure the quality of a wireless link reliably and efficiently? (in order to determine when to deploy a new relay)
- What criteria should be used to trigger deployment?
- Is real-time on-the-fly deployment feasible? (Will it result in well-connected networks capable of reliable communications?)

Remainder of Today’s Presentation

- Approach to real-time deployment
- Overview of the prototype
- Next steps

Live Demo of the Prototype: Tomorrow Morning, Mid-Century
Link Reliability Measurements

• Collected over a fixed topology on single floor of an office building
• Clear threshold ⇒ RSS/SNR as indicator of link reliability
Mobile Link Measurements

RSS vs. Time on a 900 MHz Mobile Link

SNR vs. Time on a 2.4 GHz Mobile Link

- Measured by a mobile rx moving at fixed velocity down an office corridor
- Approaches needed to tolerate multipath fading
Overview of Deployment Algorithm

1. Mobile node probes channel every $\Delta$ sec.
2. Measures SNR of each Probe ACK (bidirectional)
3. If average SNR of each responding relay is less than a threshold, trigger deployment of new relay.

![Diagram showing mobile node, base node, deployed relays, and probe ACKs.](image)
2.4 GHz Prototype Breadcrumb

- **Lithium polymer battery & charger**

**Gumstix motherboard**
- 400 MHz Linux computer
- 16 MB Flash
- 64 MB SDRAM
- 8 cm × 2 cm

**Wifistix expansion board**
- IEEE 802.11b/g
- Open source driver
- 8 cm × 2 cm
Deployment Monitor

- Next relay to be deployed continuously probes and measures link quality to its neighbors.
- Deployment monitor on mobile display:

  ![In range](image1)
  ![Drop a node!](image2)
  ![Disconnected](image3)

- When that relay is deployed, next relay is set to probe.
2.4 GHz Prototype System Features

Applications
- Two-way voice between Base and Mobile Node
- Continuous monitoring of Mobile Node’s sensors
- Display approximate location of Mobile Node
  - using RFID-assisted inertial navigation
- Video

Technical Features
- Rapid link measurement
- Real-time deployment w/ local placement assistance
- IEEE 802.11 PHY/MAC
- OLSR routing w/ ETX metric
- IP support
Ongoing and Future Work

- Systematic study of link quality measurement techniques
- Routing protocol improvements
  - Smoother route transitions
  - Incorporate new link quality metrics
- Feasibility of image/video over deployed multihop network
- Network simulation of cognitive radio relay networks
Publications


Backup Slides on Relay Deployment
Deployment Algorithm Tradeoffs

### Deployment Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
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<tbody>
<tr>
<td>$\Delta$</td>
<td>Probe period</td>
</tr>
<tr>
<td>$N$</td>
<td>Averaging filter length</td>
</tr>
<tr>
<td>$S_{th}$</td>
<td>Threshold RSS</td>
</tr>
</tbody>
</table>

### Graphs

#### $\Delta \times N = 4$ sec

- **Post-deployment RSS - $S_{th}$ (dB)**
- **Probe period, filter length ($\Delta, N$)**

#### $\Delta = 100$ ms

- **Post-deployment RSS - $S_{th}$ (dB)**
- **Filter length ($N$)**
2.4 GHz Symmetric Link Measurements

- Fixed STA “A”, mobile STA “B”
- “B” carried down 110 m corridor and back at ~ 1.2 m/s
- Sampling period: 100 ms
- Filter: Uniform moving average of last 20 samples (2 s filter)
- Data rate: 2 Mbps
2.4 GHz Asymmetric Link Measurements

Bi-Directional Filtered SNR Measurements of an Asymmetric Mobile Link

- Fixed STA “A”, mobile STA “B”
- “B” carried down 110 m corridor and back at ~ 1.2 m/s
- Sampling period: 100 ms
- Filter: Uniform moving average of last 20 samples (2 s filter)
- Data rate: 2 Mbps
Backup Slides on 900 MHz Prototype
900 MHz Experimental Platform

- Crossbow MICA2 Mote (MPR400CB)
  - ChipCon CC1000 transceiver at 916 MHz
  - 8-bit ATMega128L 7.37 MHz processor
  - 128 kB program memory, 4 kB SRAM
  - Powered by 2 AA batteries
  - 5 dBm max. RF power

- Multi-Sensor Module (MTS310)
  - Light, Temperature
  - Acoustic, Sounder
  - 2-Axis Accelerometer
  - 2-Axis Magnetometer
900 MHz Prototype System

Applications
- Continuous monitoring of Mobile Node’s sensors
- Two-way text messaging between Base and Mobile
- Display approximate location of Mobile Node
  - using RFID location tags

Technical Features
- Rapid link measurement w/ adaptive probing
- Real-time deployment w/ local placement assistance
- Modified DSDV routing with link quality metric
- Power control
Backup Slides on
2.4 GHz Prototype Testing
Test in NIST AML

- March 24 & 26, 2008
- Buildings 217, 218, and 219
Deployment Example

- 8 relays deployed
- IEEE 802.11 2-Mbps data rate
- OLSR
  - HELLO period 0.5 s
- During deployment:
  - 28 kbps full-duplex VoIP call between IC and FR
  - Ping every second
- After deployment:
  - 10 MB file transfer
  - Audio recording
During Deployment

11% Packet Loss Rate

Time (s)

Number of hops
During Deployment: Packet Losses

11% Packet Loss Rate
During Deployment: Round-Trip Time

![Graph showing round-trip time vs. number of hops]
File Transfer

- 9-hop route
- 10 MB file
- Transmission time: 8 min 3 s
  - Average throughput: 166 kbps
    - Peak throughput: 232 kbps
- Simultaneous ping:
  - Average RTT: 173 ms
  - Packet loss rate: 36%
Audio

- Reading of Gettysburg Address
- Linphone VoIP connection with 16 kHz Speex codec at 28 kbps

Simultaneous Ping Results

<table>
<thead>
<tr>
<th>Number of hops</th>
<th>Min/Avg/Max RTTs (ms)</th>
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<tbody>
<tr>
<td>6</td>
<td>29/41/55</td>
</tr>
<tr>
<td>7</td>
<td>35/54/100</td>
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<tr>
<td>8</td>
<td>40/58/94</td>
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<tr>
<td>9</td>
<td></td>
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<td>10</td>
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Time (s)