Empirical Study of 802.11b Wireless Networks in the Presence of Bluetooth Interference

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Outline

• Current Wireless Technologies

• The Interference Problem

• Throughput Testing
  – Setup/Methodology
  – Results
Current Wireless Technologies

Two bands commonly used for wireless networking

2.4 GHz Band

5 GHz Band
Current Wireless Technologies

5 GHz Band

- 5.15 – 5.35 GHz and 5.725 – 5.825 GHz
- 300 MHz total
- Home to...
  - 802.11a (54 Mbps)
Current Wireless Technologies

2.4 GHz Band

- 2.4 – 2.483 GHz
- 83 MHz total
- Home to…
  - Bluetooth (1 Mbps)
  - 802.11b (11 Mbps)
  - 802.11g (54 Mbps)
Current Wireless Technologies

• Two big players
  – 802.11b (aka Wi-Fi)
    • 11 Mbps
    • Used for medium-range wireless networks
      – 100 m nominally
    • 15 – 20 dBm power output
Current Wireless Technologies

• Two big players
  – Bluetooth
    • 1 Mbps
    • Frequency-hopping
    • Included with many cell phones and PDAs
    • Used for short-range cable replacement
      – Syncing PDAs with computers, wireless headsets, connecting cell phones with PDAs/laptops
• Three power classes
  – 0 dBm: 10 cm range
  – 4 dBm: 10 m range (most common)
  – 20 dBm: 100 m range
The Interference Problem

Bluetooth and 802.11b are **complementary** (not competing) technologies that need to coexist...

**BUT**

Since they use the same 2.4 GHz frequency band, there will be some level of interference
The Interference Problem

2.483 GHz

802.11b Data Transmission

2.4 GHz

Time

Frequency

802.11b Packet

802.11b Packet
The Interference Problem

2.483 GHz

Bluetooth Data Transmission

2.4 GHz

Frequency

Time
The Interference Problem

Combined Data Transmission

2.483 GHz

Frequency

802.11b Packet

2.4 GHz

Time

802.11b Packet

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The Interference Problem

2.483 GHz

Combined Data Transmission

2.4 GHz

Time

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The Interference Problem

How do Bluetooth devices affect the speed of nearby 802.11b links?
Throughput Testing

• Previous work
  – Simulations
  – Laboratory Experiments
    • idealized conditions
  – Few real-world empirical studies
Throughput Testing

• Our work
  – Speed measurements under real-world conditions
  – Multiple Bluetooth interferers
Throughput Testing

• Our Testing – Basic Idea
  – Set up an 802.11b link
  – Vary its SNR
  – Measure the link speed without interference
  – Activate some Bluetooth devices and measure the speed again
Throughput Testing

In other words, we want to fill in this matrix with speed numbers

<table>
<thead>
<tr>
<th>Number of Interferers</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11b SNR (dB)</td>
<td>50</td>
<td>45</td>
<td>40</td>
<td>35</td>
</tr>
<tr>
<td>measured before interference</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$802.11b$ SNR (dB) measured before interference
Throughput Testing

• How to measure the SNR?
Throughput Testing

• How to measure the link speed?
  – Network testing application (Chariot) would have been easiest
  – FTP works just fine (and is free)
    • Send a file over the wireless network
    • Speed = (File Size)/(Time)
Throughput Testing

Test Setup – Hardware

802.11b Access Point

FTP Server
(connected via 100 Mbps Ethernet to the Access Point)

802.11b-equipped Laptop
Throughput Testing

Test Setup – Hardware

Throughput bottleneck is the wireless link – speed is not limited by the FTP server or the Ethernet segment.

100 Mbps

11 Mbps

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Throughput Testing

Test Setup – Hardware

Pair of Bluetooth-equipped computers (Interferers)
Throughput Testing

Test Setup – Hardware
Data Rate – No Interference
Results

Data Rate – One Interferer

![Graph showing speed vs. SNR of 802.11b connection with one Bluetooth Interferer](image)
Results

Data Rate – One Interferer
Results

Percentage Network Speed Lost

Median Percentage of Network Speed Lost with One Bluetooth Interferer

SNR of 802.11b Network

Percentage Lost

0 10 20 30 40 50 60 70 80 90

50 45 40 35 30 25 20 15 10
Results

Data Rate – Multiple Interferers

![Graphs showing speed vs. number of Bluetooth interferers for different SNR levels.](image-url)
Results

• Single Interferers
  – 50% network speed lost at SNR of 25 dB

• Multiple Interferers
  – Effects are highly dependent on SNR