Radio Resource Management

WINLAB IAB Meeting
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What is RRM?

- **NETWORK**
  - “Routing, Flow Control”
- **Radio Resource Management**
  - “Efficient Wireless Access”
- **PHY**
  - “Radio/Modem Technology”
Anytime Anywhere cellular voice service
Each user needs an acceptable connection:
  Channel, Base station, Transmit Power
Cellular Wireless Today

- Optimized for Anytime/Anywhere voice
  - Strict Network Control
  - Licensed Bandwidth
- Limited Wireless Data
  - Low to Moderate Rates
    \[ 9.6 - 14.4 \text{ kb/s} \rightarrow 144 - 384 \text{ kb/s} \]
- High Cost per bit
  - \[ 10 \text{ kb/s}, \ 10 \text{ cents/min} = 1.30/\text{MB} \]
Cellular = Expensive Bits

1 cent/min = 13 cents/MB

<table>
<thead>
<tr>
<th>Activity</th>
<th>Size</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill an MP3 player</td>
<td>30 MB</td>
<td>$3.90</td>
</tr>
<tr>
<td>Upload camera photos</td>
<td>32 MB</td>
<td>$4.16</td>
</tr>
<tr>
<td>Sync laptop disk</td>
<td>50 MB</td>
<td>$6.50</td>
</tr>
</tbody>
</table>

1 cent/min voice is still 100x too high for data
Internet Access = Free Bits

- Internet: Applications and attitudes are based on “free” bits
  - Fill an MP3 player: 30 MB = FREE
  - To get a lot of bits, you wait more but not pay more

- Cellular access is a toll booth
- Radio bits need to be “free”
Infostations
A system of sweet spots for free bits

- Small, separated “cells”
- Low power (~100 mw)
- Brief connections (~1 sec)
- Very high bit rate (~1 G bps)
- Simple infrastructure (LAN on a pole, IP access)
- Unlimited capacity for a flat rate?
Free Bits

• NSF ITR Multi-university Project
  - WINLAB, Princeton, NJIT

• Research Areas
  - Radio Channel Modeling
  - Transceiver Design
  - Radio Resource Management
  - Algorithm Development Testbed
RRM Research at WINLAB

- About 15 student projects
- Investigators
  - Evans, Frenkiel, Gajic, Mandayam, Mau, Raychaudhuri, Rose, Spasojevic, Yates
- Range of Systems:
  - 3G cellular, infostations, ad hoc data networks
Common Theme
Methods for Efficient Transmission

• Opportunistic Transmission
  - Transmit when/where the channel is good
  - Exploit sweet spots, delay insensitivity

• Conserve battery power

• Mechanisms for Distributed Control
  - Power Control, Interference avoidance
  - Utility functions to unify mixed objectives
15 RRM Projects

1. Interference Avoidance and Fading Channels
2. Interference Avoidance for Multiple Base Station Systems
3. Using Mobility for Delay-Tolerant Data Transmission in Ad-Hoc Networks
4. Energy and Delay Constrained Dynamic Transmission Control in Wireless Data Communications Systems
5. Access Control for Mixed Receivers, Integrated Voice/Data CDMA Systems
7. Routing in Ad Hoc Networks
8. Service Outage Based Adaptive Transmission in Fading Channels
9. Discrete Adaptive Transmission for Fading Channels
10. Downlink Interference Analysis
11. Multicast Transmission in the Downlink of Wireless System
12. Effects of Channel Models on Performance of Mobile Ad Hoc Networks
13. Power Control in Ad Hoc Networks Using Hello and Data Packets
14. OFDM Based Multiple Access Systems
15. Dynamic Nash Games for Power Control in 3-G Wireless CDMA Networks
Access Control
Sharing for Heterogeneous Services

- Access Control for Mixed Receivers, Integrated Voice/Data CDMA
  - Narayan Mandayam and Cristina Comaniciu
- Pricing and Power Control for Joint Network-Centric and User-Centric Radio Resource Management
  - Narayan Mandayam, Siun-Chuon Mau and Nan Feng
- Downlink Interference Analysis
  - Roy Yates and Mehmet Kemal Karakayali
- Multicast Transmission in the Downlink of Wireless System
  - Roy Yates and Nanyan Jiang
- OFDM Based Multiple Access Systems
  - Roy Yates and Rajnish Sinha
- Dynamic Nash Games for Power Control in 3-G Wireless CDMA
  - Zoran Gajic and Sarah Koskie
Access Control
Sharing for Heterogeneous Services

• Closely tied to receiver technology
  - WCDMA, Multiuser Detection, OFDM
• Multiple Services
  - Voice, Web, Video
• Utility Functions to unify mixed objectives
• Pricing Mechanisms to improve user’s utilities
Adaptive Transmission
Transmit When the Channel is Good

• Energy and Delay Constrained Dynamic Transmission Control in Wireless Data Communications Systems
  – Narayan Mandayam and Henry Wang
• Service Outage Based Adaptive Transmission in Fading Channels
  – Roy Yates and Jianghong Luo
• Discrete Adaptive Transmission for Fading Channels
  – Roy Yates and Lang Lin

• **Goal:** Reduce the Energy per bit
  • Increase power and rate as channel improves
  • Turn the transmitter off if channel is bad.

• **Result:** Transmit in sweet spots ⇒ Infostations
Interference Avoidance
Transmit Where the Channel is Good

Interference Avoidance and Fading Channels
  - Christopher Rose and Dimitrie C. Popescu

• Interference Avoidance for Multiple Basestation Systems
  - Christopher Rose and Otilia Popescu

• "Where" is in signal space!
  - Depends on Interference and Radio Channels of Other Users
  - Receivers find sweet spots in signal space
    - Transmitters move to the sweet spots
Ad Hoc Wireless Networks

• Using Mobility for Delay-Tolerant Data Transmission in Ad-Hoc Networks
  – Christopher Rose and Furuzan Atay
• Routing in Ad Hoc Networks
  – Roy Yates and Ivana Maric
• Effects of Channel Models on Performance of Mobile Ad Hoc Networks
  – Roy Yates and Wing Ho (Andy) Yuen
• Power Control in Ad Hoc Networks Using Hello and Data Packets
  – Roy Yates and Wing Ho (Andy) Yuen

• Theme: Disseminate data efficiently among peers
• Users in sweet spots assist others
Overlapping Research Areas

- Infostations
- Free Bits
- Adaptive Transmission
- Interference Avoidance
- Pricing
- Power Control
- Unlicensed Band
- Access Control
- Ad Hoc Networks
- Overlapping Research Areas