

Radio Resource Management

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What is RRM?

NETWORK

"Routing, Flow Control"

Radio Resource Management

"Efficient Wireless Access"

PHY

"Radio/Modem Technology"

Common Themes

Methods for Efficient Communication

- **Opportunistic Transmission**
 - Transmit when/where the channel is good
 - Exploit sweet spots, delay insensitivity
 - Conserve battery power
- **Distributed Algorithms**
 - Power Control, Interference avoidance, service discovery
 - Utility functions to unify mixed objectives

RRM Research at WINLAB

- 21 student projects
- Investigators
 - Evans, Frenkiel, Gajic, Greenstein, Mandayam, Mau, Raychaudhuri, Razoumov, Rose, Spasojevic, Yates
- Range of Systems:
 - cellular, infostations, ad hoc networks
- Research
 - Access control, adaptive transmission, ad hoc networks

Access Control

Sharing for Heterogeneous Services

1. Joint Network-Centric and User-Centric Radio Resource Management in Multicell Systems
Narayan Mandayam, Siun-Chuon Mau and Nan Feng
2. Pricing Mechanisms as Enablers for Forwarding in Wireless Networks
Narayan Mandayam, Siun-Chuon Mau and Omer Ileri
3. An Optimal Scheduling Algorithm for a Variable Data Rate CDMA System
Roy Yates, Leo Razoumov and Mehmet Kemal Karakayali
4. Wireless Broadcast Services
Roy Yates and Nanyan Jiang
5. OFDM Based Multiple Access Systems
Roy Yates and Rajnish Sinha
6. Dynamic Nash Games for Power Control in 3-G Wireless CDMA Networks
Zoran Gajic and Sarah Koskie
7. Interworking of UMTS/GPRS and IEEE 802.11b
Dipankar Raychaudhuri and Hamsini Bhaskaran

Receiver technology dependent, Multiple Services, Utility Functions to unify mixed objectives, Pricing to improve user's utilities

Adaptive Transmission

Transmit When/where 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, Predrag Spasojevic and Jianghong Luo*
- Discrete Adaptive Transmission for Fading Channels
 - *Roy Yates, Predrag Spasojevic and Lang Lin*
- Interference Avoidance for Multiaccess Vector Channels
 - *Christopher Rose and Dimitrie C. Popescu*
- Interference Avoidance for Multiple Basestation Systems
 - *Christopher Rose and Otilia Popescu*

Transmit in sweet spots in geographic space
(Infostations) or signal space (interference avoidance)

Ad Hoc Wireless Networks

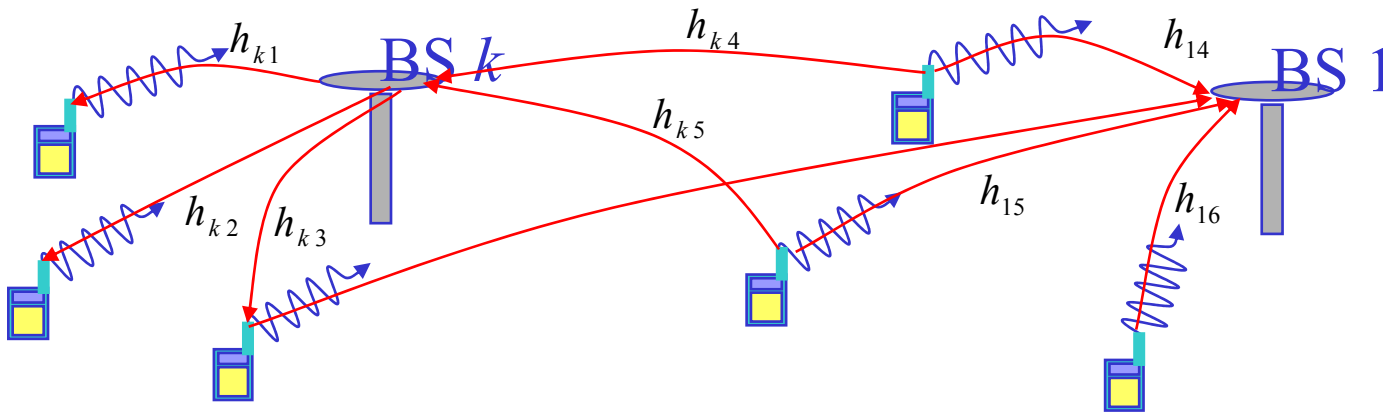
- Using Mobility for Delay-Tolerant Data Transmission in Ad-Hoc Networks
Christopher Rose and Furuzan Atay
- Routing in Ad Hoc Networks
Roy Yates and Ivana Maric
- The Effects of Shadowing of Mobile Ad Hoc Networks
Roy Yates and Wing Ho (Andy) Yuen
- Network Behavior of Mobile Ad Hoc Networks
Roy Yates and Wing Ho (Andy) Yuen
- Non Cooperative Content Distribution in Mobile Infostation Networks
Roy Yates and Wing Ho (Andy) Yuen
- Discovery Protocols for Self-Organizing Sensor Networks
Dipankar Raychaudhuri and Lalit Raju
- Hierarchical, Heterogeneous and Scalable Sensor Networks Architectures
Dipankar Raychaudhuri and Kemal Tepe
- Discovery and Multihop Routing Protocols for Self-Organizing Hierarchical Mobile Networks
Dipankar Raychaudhuri and Suli Zhao

RRM Research Areas

- Variable Rate Cellular
 - Rate/power allocation, pricing
- Infostations/FreeBits
 - Transmit when the channel is good
 - Exactly how depends on system constraints
- Mobile Infostations
- Spectrum Regulation

New

Variable Rate Cellular



- Supports Anytime/Anywhere voice
- Allocation of rate, channel, base station, transmit power

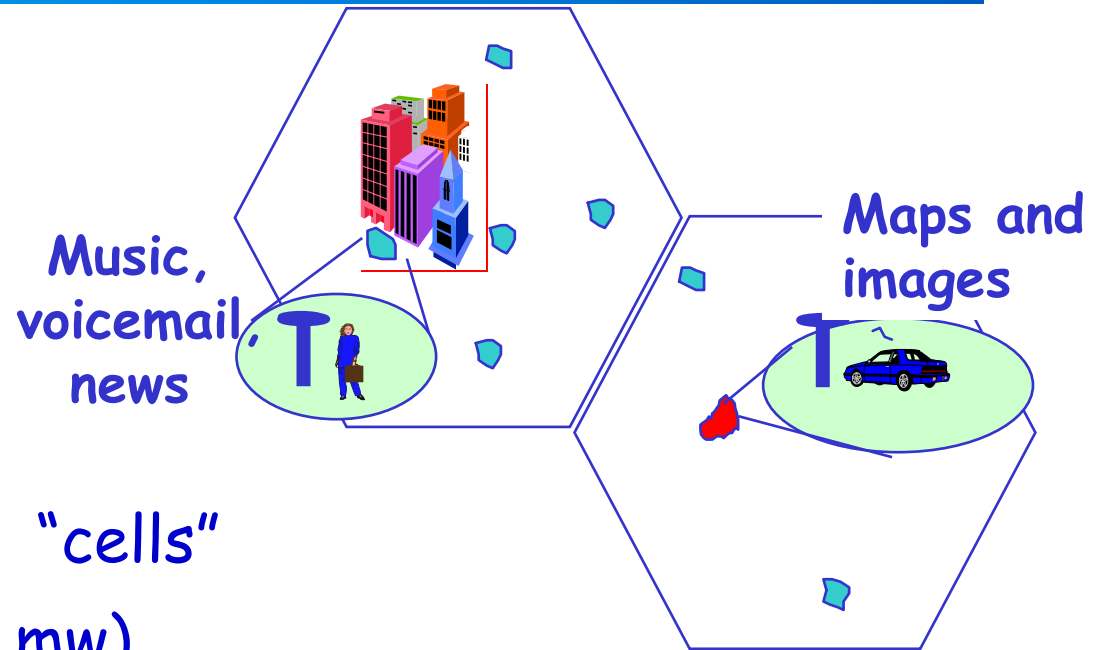
Cellular = Expensive Bits

- $V \text{ cent/min voice} = 13V \text{ cents/MB data}$
 - WCDMA: \$1.30/MB
 - GPRS: \$3/MB
- $1 \text{ cent/min voice} = 13 \text{ cents/MB}$
 - Upload 256MB photos = \$33.28
 - 1 cent/min voice is 100x too high for data

Infostations

A system of sweet spots for free bits

• Internet:
Applications/attitudes
assume "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)

Update: FreeBits Project

WINLAB, Princeton, NJIT

1. Radio Channel Measurements + Modeling
(Domazetovic, Greenstein, Mandayam, Seskar)
 - The outdoor infostation channel is very good
 - Theory: 8-10 bits/s/Hz out to 15 m
2. Transceiver Design for the Infostation Channel
 - Practice: ~3 bits/s/Hz
 - Lots of room for improvement

Beyond Infostations

- Mobile Infostations
 - Peer to Peer High Rate Comm
 - Freebits work says the channel is good
 - Everyone is an infostation
- The Future of Unlicensed Spectrum
 - Infostations share unlicensed spectrum with sensors, new networks etc
 - What happens when uses proliferate?

Radio Resource Management Modalities

Litigation (licensing)

Play Nice (power control)

Suffer in Silence (signal processing)

Dance (interference avoidance)

Mad as Hell (deliberate jamming)

Be Patient (opportunism & cooperation)

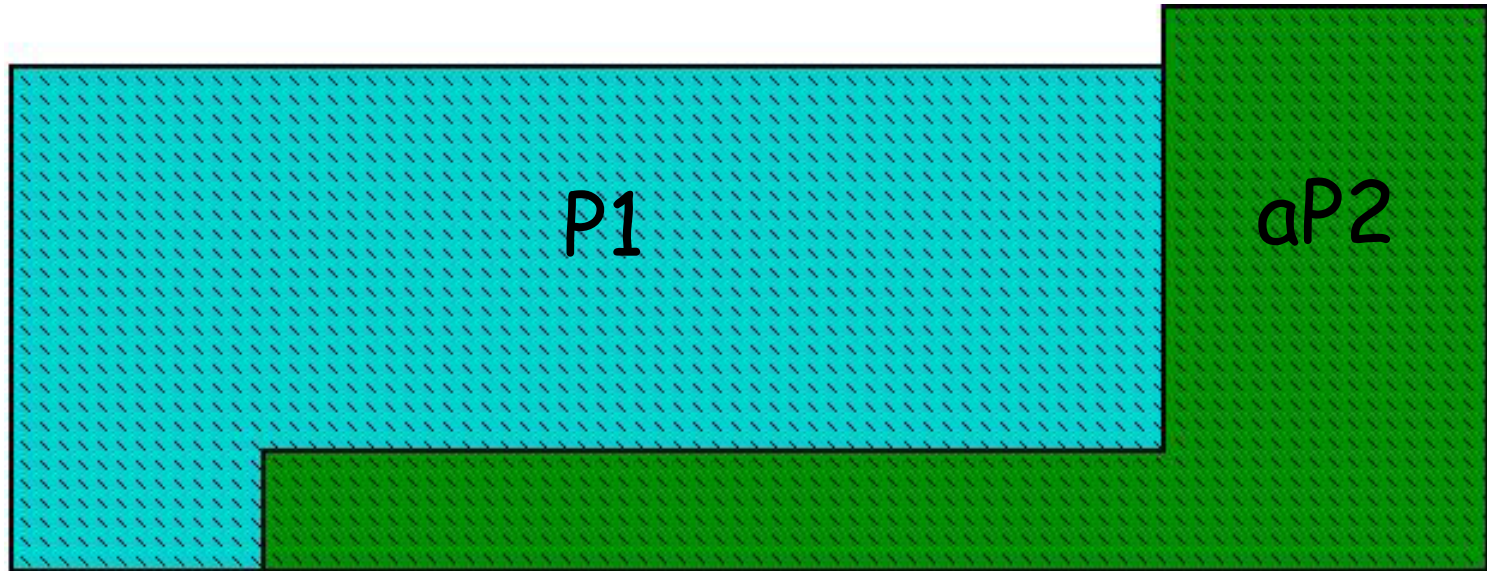
IA Review

- Find a Signal Space
- Use multicode generalized CDMA
- Adjust each codeword greedily
- Collectively Optimal
- Always works

New Multibase IA

- Cordless phone problem
- IA w/ single codes - same problem
- IA w/ multicode - converges!
- To what?
 - A variety of fixed points + IT tough
 - Some points better than others
 - Nudging can lead to better points

2 Users, 2 Bases



Signal Space Dimensions

Tragedy of the Commons

- Unlicensed Spectrum is Shared
- People are Greedy
- "Overgrazing" leads to suboptimality
- Central authority necessary?
- Or can we vest authority in users?

Pseudo Mathematica

- Happiness up
 - My usage and pasture quality
- Happiness down
 - Your usage (degrades pasture)
- We are all the same
- Problems with oblivious optimization

Greed Counterincentives



Marked for Deletion

Patience Has Its Rewards

- Mobility
 - Physical Carriage
 - Channel diversity
- Opportunistic High Rate Transmission
 - Wait for great channel (nearest node)
 - Cooperative transmission and carriage
- High Data Rates AND Low Delay?

Tying It All Together (New NSF ITR)

- Opportunism → locality
- 802.11 as simple existence proof
- Economic/policy implications of tying spectrum rights to real property?
- Organizing principles for unlicensed band use (and wealth creation)

RRM Summary

- The classical with twists
- Physics suggests opportunism
 - Exploit channel variations
 - Avoid interference
 - USE mobility to keep it simple
 - Be greedy (and carry a big stick?)
- Sculpting Spectrum Policy