Wireless Data: patience has its rewards

Christopher Rose
WINLAB
the Wireless Information Networks LABoratory
at Rutgers University
Dept of Electrical and Computer Engineering

WINLAB IAB Fall 2000
Before I Put You to Sleep

- Cellular was optimized for voice
- Low cost cellular data – oxymoron?
- Discontinuous coverage (Infostations) – dividends for data
- One at a time access is best
  - at RF MAC level
  - at packet delivery level
The Cellular Problem

- Limited spectrum
- Ubiquitous coverage
- Voice traffic at POTS QoS
- Mobile users
The Cellular Solution

- Anytime anywhere SINR Targets
- Licensed spectrum with re-use
- Fixed network structure
- Standard modulation formats
- Coordinated channel assignment

Centralized structure probably essential for mobile provision of delay sensitive service
A Picture of Cellular Wireless

mobile path

Coverage Region

Base Station Antenna
Vague Cellular Economics

- Startup Costs High
  - substantial portion of system must be deployed to be useful
  - expensive spectrum license
  - expensive easements (real estate)
  - environmental issues for wide area (high power) coverage
    (stealth-shrub or tricky-tree antennae)

- Service types usually limited
  - need volume and simplicity to recap startup costs
Cheap Cellular Data (even 3G) Might Be Doomed!

• A voice call consumes about 10kb/s (and probably always will)
• A voice call costs \( v \) cents per minute
• A 1MB transfer will always cost 13\( v \) (\( \approx \$1.30 \) at current rates)
• Some comparisons:
  - 30 minutes of MPEG3 music: 30MB — 390\( v \)
  - Synching a disc: 100MB — 1300\( v \)
  - A typical powerpoint presentation: 3MB — 39\( v \)
• Even at 1 or 0.1 cents/minute these do not encourage carefree use (as we have come to expect when using the Internet)
• At 0.1 cents/minute, cellular’s revenue stream (voice) disappears
• NO difference for 3G wireless because 13\( v \) is 13\( v \) is 13\( v \).
The Solution?

Make wireless bits FREE

(sounds ridiculous, doesn’t it?)
Topsy Turvy Assumptions

- Unlicensed Radio Spectrum
- Nonstandard Modulation
- Delay insensitive traffic
- Manytime and Manywhere
Cellular Without Cells

mobile path

Base Station Antenna
A Simple Abstraction

mobile path

Base Station Antenna
Information Theory

Mobile at position $x = vt$ with energy budget $E$, $G(x) \equiv$ gain factor, $W \equiv$ bandwidth, $N_0 \equiv$ noise spectral density

$$C(x) = W \log \left( \frac{P(x)G(x)}{N_0W} + 1 \right)$$

$$\bar{C} = \frac{1}{2A} \int_{-A}^{A} C(x)dx$$

$$E = \int_{-A/v}^{A/v} P(vt)dt$$

Maximize $\bar{C}$ subject to and energy/power constraint (Borras, Yates and Goodman).
General Rule: waterfill for capacity
Discrete High-Rate Coverage is Capacity-Optimal!

- Solution: either ON or OFF (exaggerated)
Rough Numbers

- Parameters:
  - $N_0 = 4.21 \times 10^{-21} W/Hz$, $W = 100 MHz$
  - $R^2$ propagation (line of sight)
  - closest approach to base, 10 meters
  - 50mW radiated power

- Peak Rate: > 1 Gbps
**Generalization: Downlink**

\[
R_1 \leq W \log \left( \frac{\alpha PG_1}{WN_0} + 1 \right) \quad (1)
\]

and

\[
R_2 \leq W \log \left( \frac{(1 - \alpha)PG_2}{WN_0 + \alpha PG_1} + 1 \right) \quad (2)
\]

Maximize \( R_1 + R_2 \) subject to power constraint \( P \)

Solution: \( \alpha = 0 \) or \( \alpha = 1 \) (largest gain wins)

**PUNCHLINE: Don’t share downlink**
Generalization: Uplink

\[ C = \lim_{T \to \infty} \frac{W}{T} \int_{-T/2}^{T/2} \log \left( \frac{P_1(t)G_1(x_1(t)) + P_2(t)G_2(x_2(t))}{WN_0} \right) + 1 \right) dt \]  \(3\)

\[ \bar{P}_i = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} P_i(t) dt \]

\[ = \int_{\mathcal{A}} \int_{\mathcal{A}} \Pi_1(x_1) \Pi_2(x_2) p_i(x_1, x_2) dx_1 dx_2 \]  \(4\)

Ergodic user motion (gain processes):

Maximize \( C \) subject to power constraints (the usual)
Multiple User Extremals

\[
F = \Pi_1(x_1)\Pi_2(x_2) \left[ \log \left( \frac{P_1(x_1, x_2)G(x_1) + P_2(x_1, x_2)G(x_2)}{WN_0} + 1 \right) \right] - \lambda_1 (P_1(x_1, x_2) - \bar{P}_1) - \lambda_2 (P_2(x_1, x_2) - \bar{P}_2) \tag{5}
\]

Eul(er) it and – A Conundrum!

\[
P_1(x_1, x_2)G(x_1) + P_2(x_1, x_2)G(x_2) = \frac{G(x_1)}{\lambda_1} - WN_0 \tag{6}
\]

\[
P_1(x_1, x_2)G(x_1) + P_2(x_1, x_2)G(x_2) = \frac{G(x_2)}{\lambda_2} - WN_0 \tag{7}
\]

PUNCHLINE: Don’t share uplink either (unless stationary or other more outre’ circumstances)
Identical Users, Uniform Finite Roaming

- Closer user gets access (no cellular-style sharing)
Quick Summary

- Delay tolerated → discontinuous, one-at-a-time coverage
- Higher aggregate data rates
- Maybe also a simplified MAC
What’s in the Cards?

- NSF smiled on us (ITR $1.8M/3 years)
  - Short range channels
  - Modulation formats for high speed radios
  - File delivery methods
  - MAC protocols
  - Testbed playtime