Wireless Data: patience has its rewards

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

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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

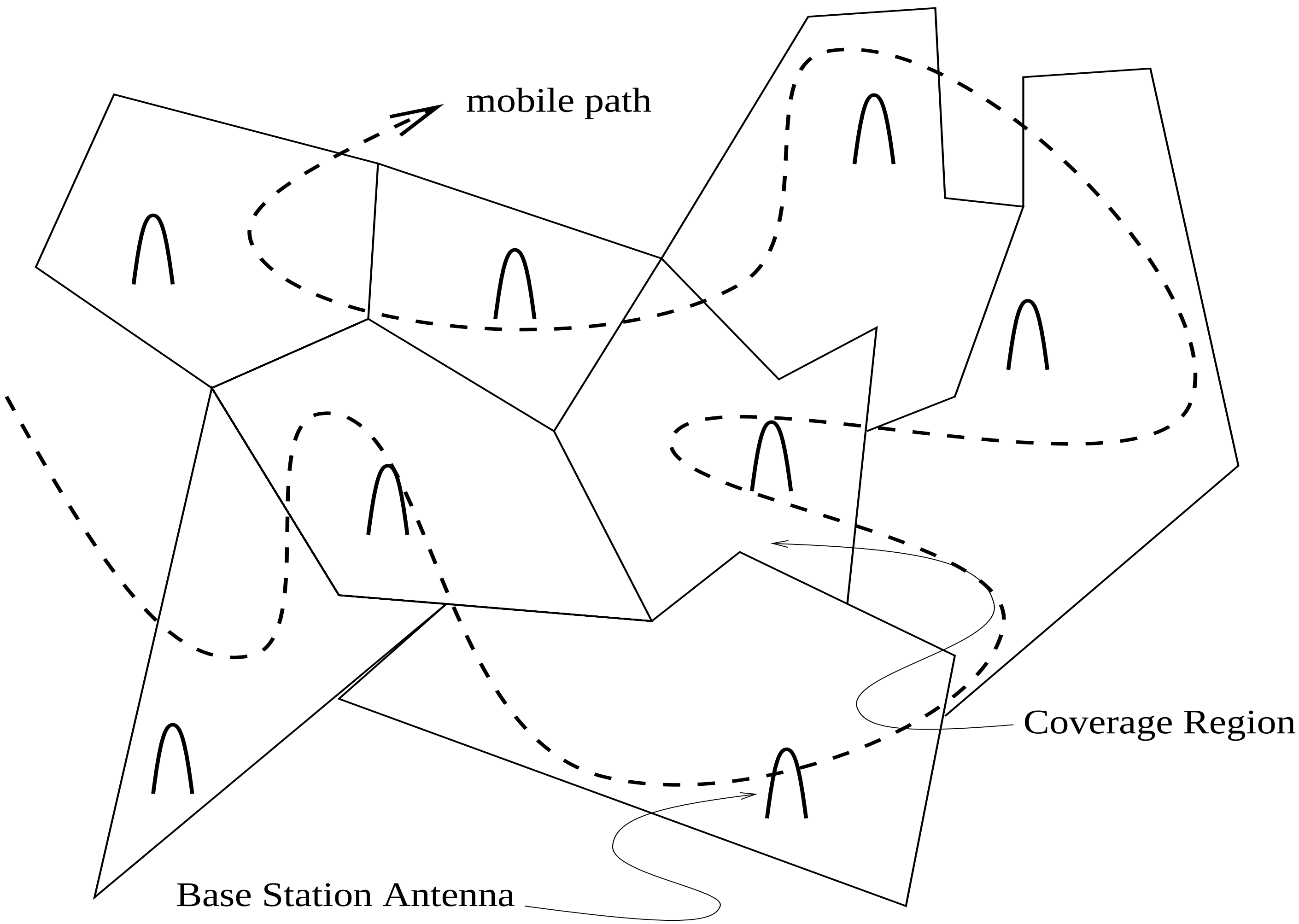
- Limited spectrum
- Ubiquitous coverage
- Voice traffic at POTS QoS
- Mobile users

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



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 13v ($\approx$ \$1.30 at current rates)
- Some comparisons:
  - 30 minutes of MPEG3 music: 30MB — 390v
  - Synching a disc: 100MB – 1300v
  - A typical powerpoint presentation: 3MB – 39v
- 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 13v is 13v is 13v.

The Solution?

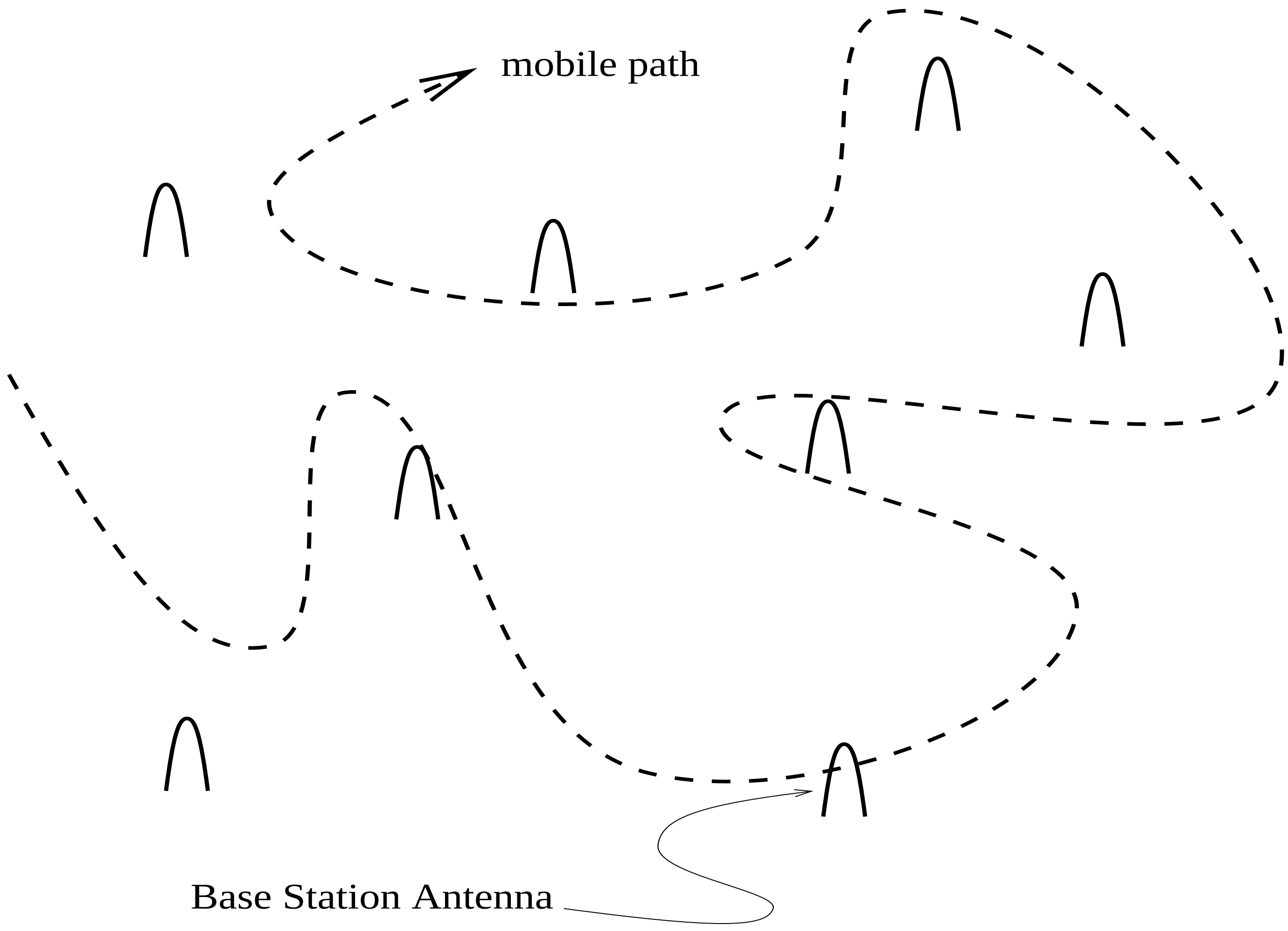
Make wireless bits FREE

(sounds ridiculous, doesn't it?)

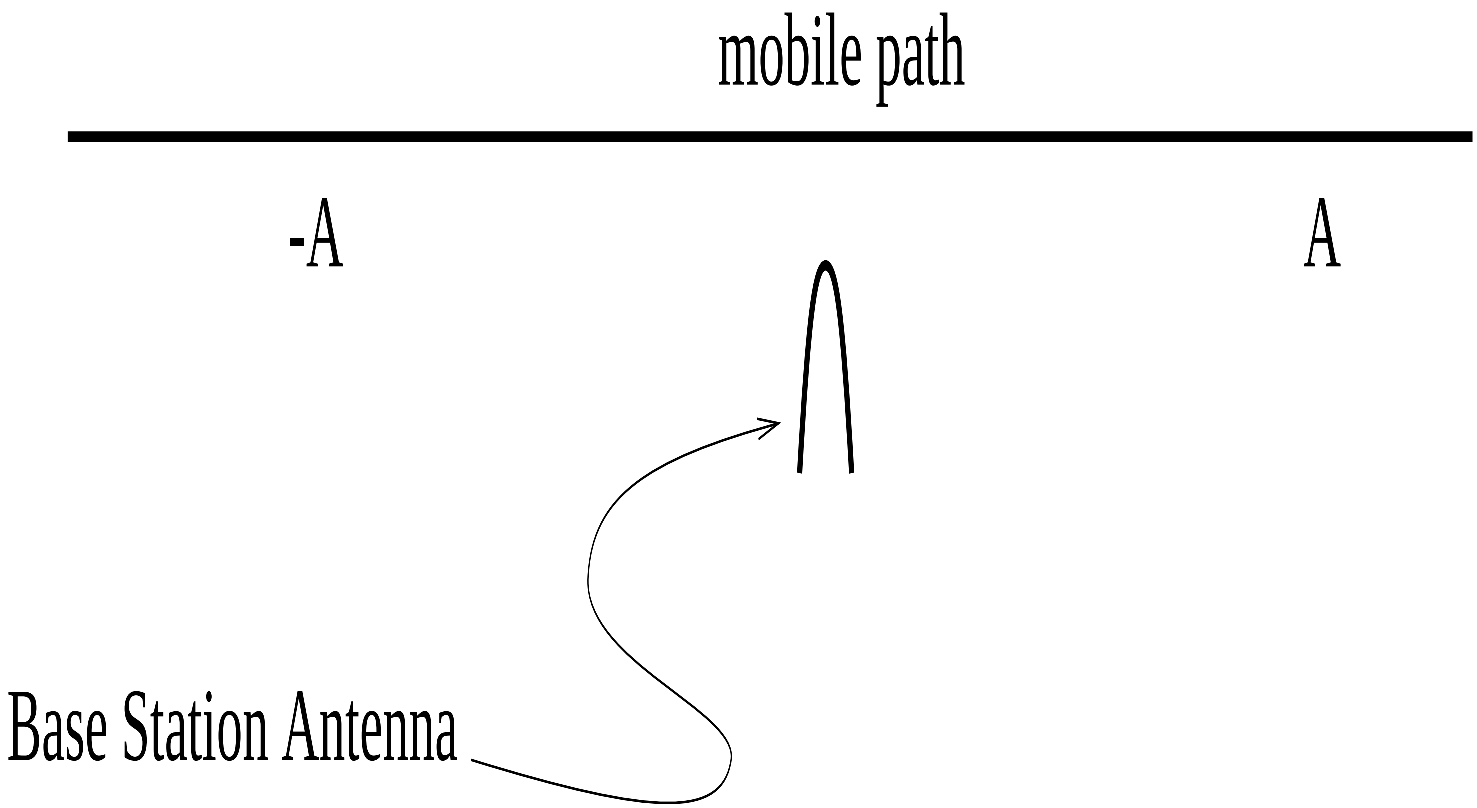
Topsy Turvy Assumptions

- Unlicensed Radio Spectrum
- Nonstandard Modulation
- Delay insensitive traffic
- Manytime and Manywhere

Celluar Without Cells



A Simple Abstraction



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

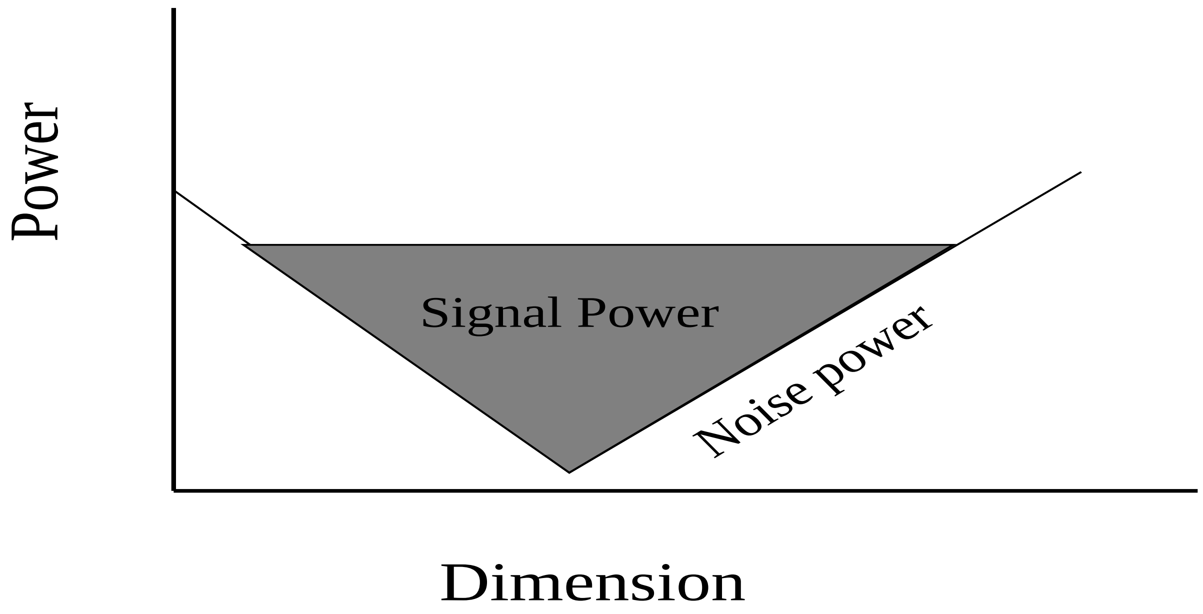
$$C(x) = W \log\left(\frac{P(x)G(x)}{N_0 W} + 1\right)$$

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

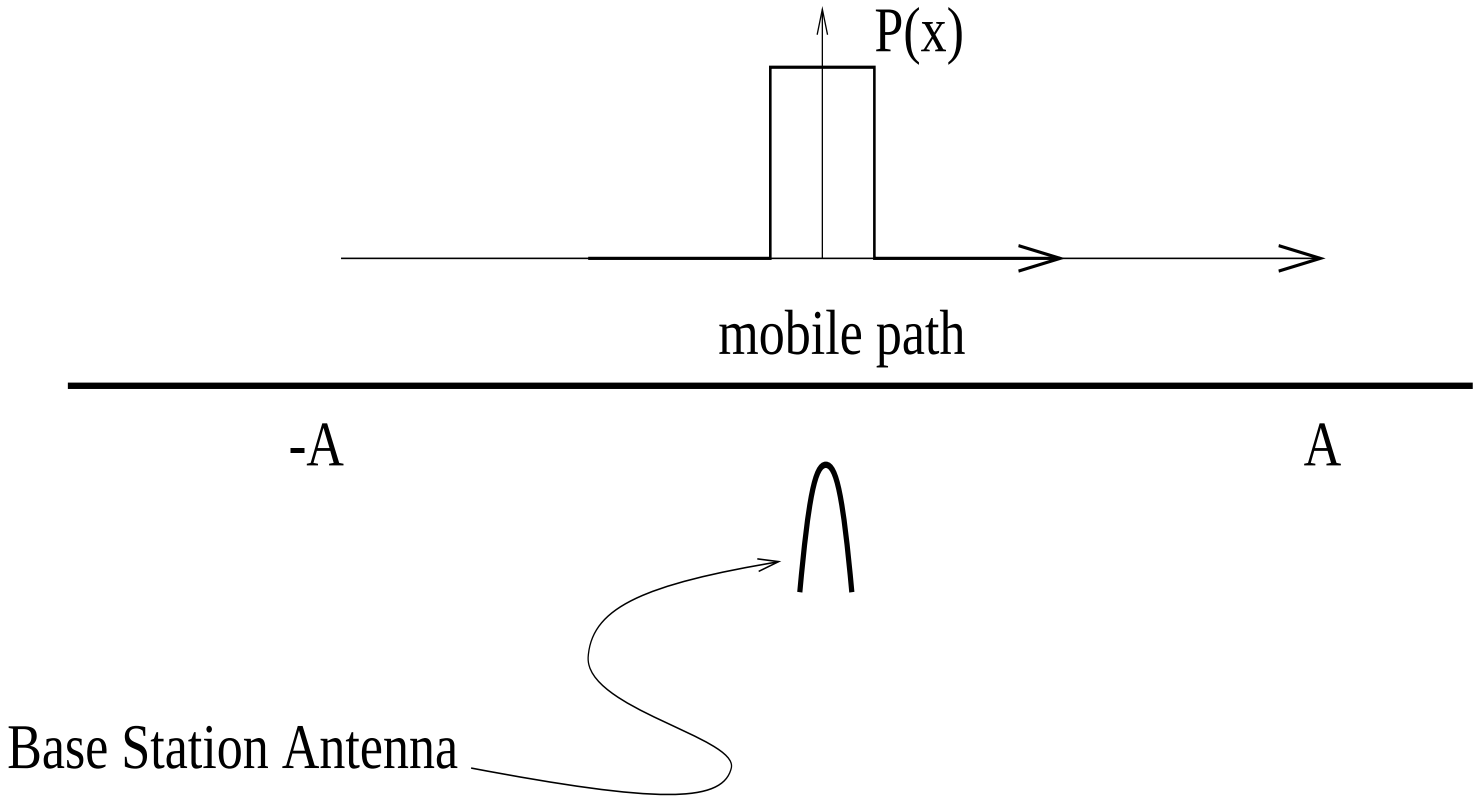
$$E = \int_{-A/v}^{A/v} P(vt)dt$$

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 (exagerated)

Rough Numbers

- Parameters:
  - $N_0 = 4.21 \times 10^{-21} W/Hz$, $W = 100MHz$
  - R^2 propagation (line of sight)
  - closest approach to base, 10 meters
  - 50mW radiated power
- **Peak Rate: $>$ 1 Gbps**

Generalization: Downlink

$$R_1 \leq W \log\left(\frac{\alpha P G_1}{W N_0} + 1\right) \tag{1}$$

and

$$R_2 \leq W \log\left(\frac{(1-\alpha) P G_2}{W N_0 + \alpha P G_1} + 1\right) \tag{2}$$

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

$$C = \lim_{T \to \infty} \frac{W}{T} \int_{-T/2}^{T/2} \log\left(\frac{P_1(t)G_1(\mathbf{x}_1(t)) + P_2(t)G_2(\mathbf{x}_2(t))}{WN_0} + 1 \right) dt \qquad (3)$$

$$\begin{aligned} \bar{P_i} &= \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} P_i(t) dt \\ &= \int_A \int_A \Pi_1(\mathbf{x}_1)\Pi_2(\mathbf{x}_2) p_i(\mathbf{x}_1, \mathbf{x}_2) d\mathbf{x}_1 d\mathbf{x}_2 \end{aligned} \qquad (4)$$

Ergodic user motion (gain processes):

Maximize C subject to power constraints (the usual)

Multiple User Extremals

$$F = \Pi_1(\mathbf{x}_1)\Pi_2(\mathbf{x}_2)\left[\begin{array}{c} \log\left(\frac{P_1(\mathbf{x}_1,\mathbf{x}_2)G(\mathbf{x}_1)+P_2(\mathbf{x}_1,\mathbf{x}_2)G(\mathbf{x}_2)}{WN_0}+1\right) \\ -\lambda_1(P_1(\mathbf{x}_1,\mathbf{x}_2)-\bar{P}_1) \\ -\lambda_2(P_2(\mathbf{x}_1,\mathbf{x}_2)-\bar{P}_2) \end{array}\right] \quad (5)$$

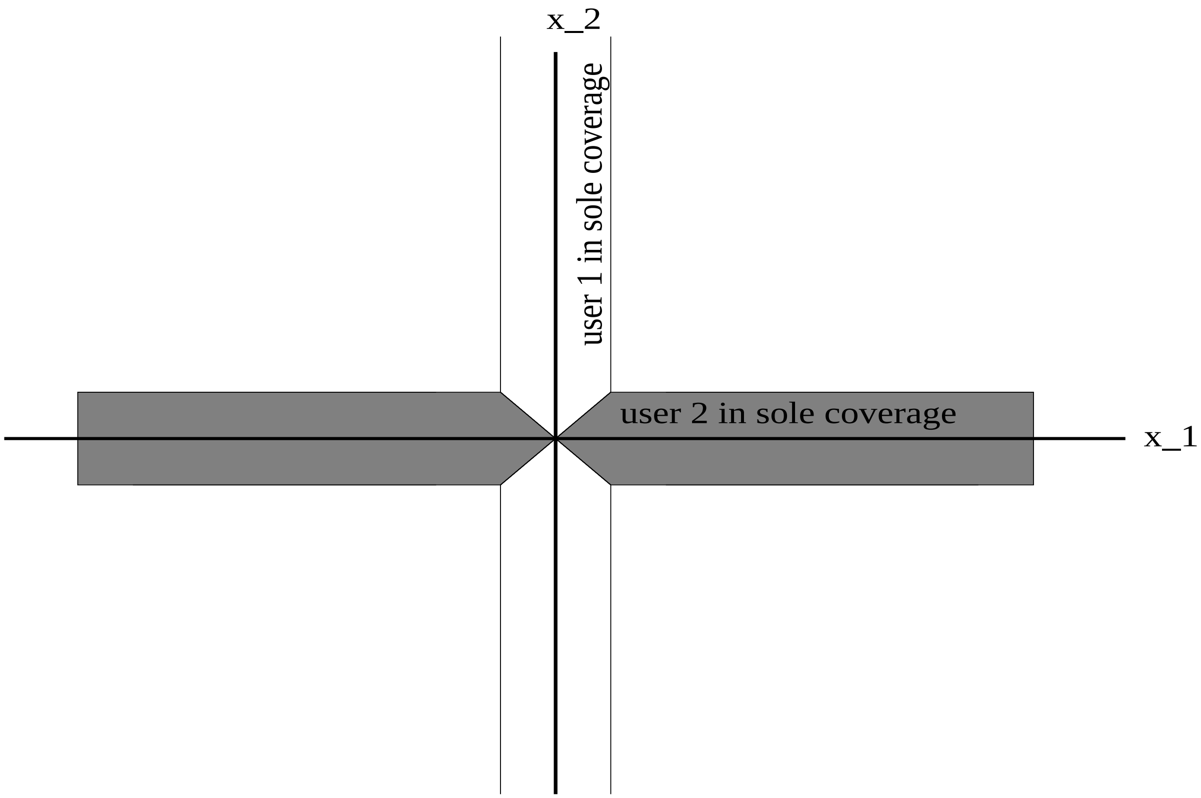
Eul(er) it and – A Conundrum!

$$P_1(\mathbf{x}_1,\mathbf{x}_2)G(\mathbf{x}_1)+P_2(\mathbf{x}_1,\mathbf{x}_2)G(\mathbf{x}_2) = \frac{G(\mathbf{x}_1)}{\lambda_1} - WN_0 \quad (6)$$

$$P_1(\mathbf{x}_1,\mathbf{x}_2)G(\mathbf{x}_1)+P_2(\mathbf{x}_1,\mathbf{x}_2)G(\mathbf{x}_2) = \frac{G(\mathbf{x}_2)}{\lambda_2} - WN_0 \quad (7)$$

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 $\rightarrow$ 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