Spectrum Project Overview

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SPECTRUM Project Meeting
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Project Motivation

- What everyone agrees on:
  - Spectrum use is inefficient
  - FCC licensing has yielded false scarcity

Proposed New Methods

- **Open Access (Commons)**
  - [Noam, Benkler, Shepard, Reed …]
  - Agile wideband radios will dynamically share a commons
- **Spectrum Property Rights**
  - [Coase … Hazlett, Faulhaber+Farber]
  - Owners can buy/sell/trade spectrum
  - Flexible use, flexible technology, flexible divisibility, transferability

Open Access
(the triumph of technology)

- Spread Spectrum and UWB for sharing and interference mitigation
- Agile software-defined radios to *avoid* interference
- Licensed spectrum will be unnecessary
- **Q: What are limits of technology?**

Spectrum Property Rights
(The triumph of economics)

- Current allocations are inefficient.
- A spectrum market will (by the force of economics) yield an efficient solution
- **Q: What should the rights be?**

Property Rights Proposals

[Faulhaber & Farber]

- **Fee-simple ownership**
  - People can buy/sell/lease specific frequencies in specific locations with the right to exclusive use
- **Fee-simple ownership with non-interference easement**
  - People can buy/sell/lease specific frequencies in specific locations with the right to emit anytime without interference
    - Others (non owners) can transmit as long as they don't meaningfully interfere
    - Examples: UWB, agile radios that can vacate fast

Spectrum Clearinghouse/Spot Market
[Noam]

- **Packets are sent with access tokens**
  - Token specifies channel
- **Token prices?**
  - would depend on congestion
  - determined by an automated clearinghouse
  - Assured access available in futures mkt

Open Access
[Shepard, Reed, Benkler]

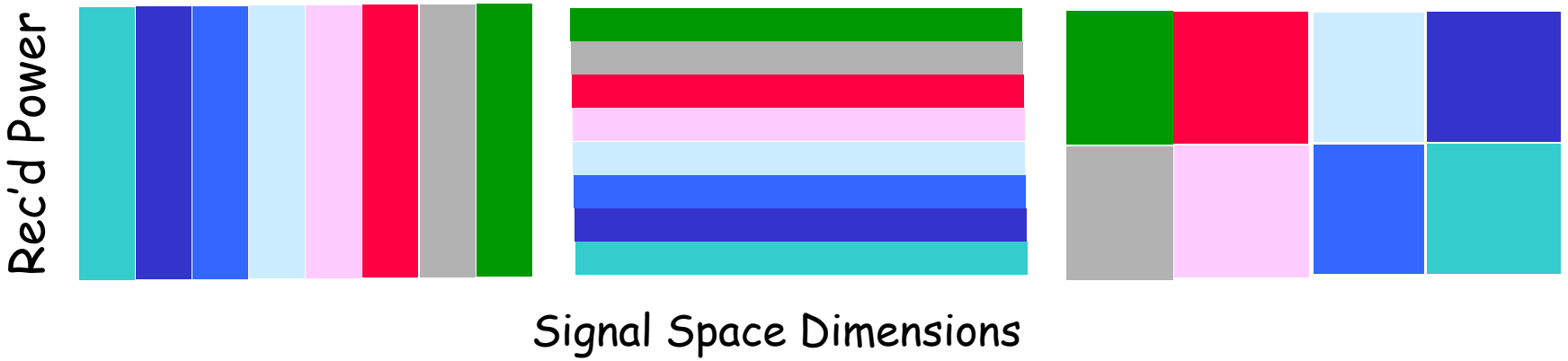
- **Systems of end-user devices**
- **Technology Panacea**
  - Spread spectrum, UWB
  - Short range communications
  - Ad hoc multi-hop mesh networks
- Evidence: success of 802.11 vs. 3G
- Minor technical rules for transceivers
  - power, spreading

Open Access

Technical arguments against

- **Partially developed theory**
  - ad hoc network capacity, with/without mobility
  - IT relay and interference channel
- **Infant technology**
  - UWB, antenna arrays
  - Transmitter agility
- **Technology not separable from user assumptions**
  - Capabilities of technology vary with cooperation

Capacity Allocation
1 Receiver, 8 Transmitters

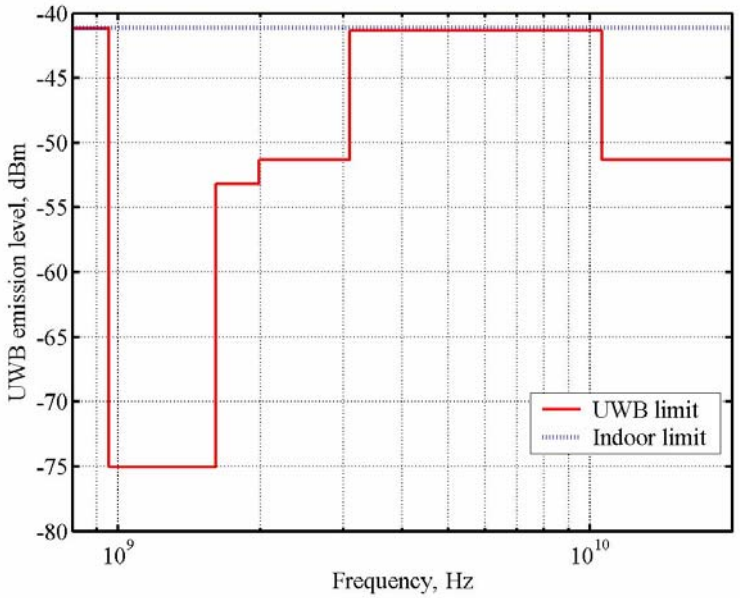


- Above policies have same capacity
  - Spreading makes no difference
  - Agility makes no difference
  - Strong (unreasonable?) assumptions on technology
  - May depend on cooperation

Property Rights vs Commons

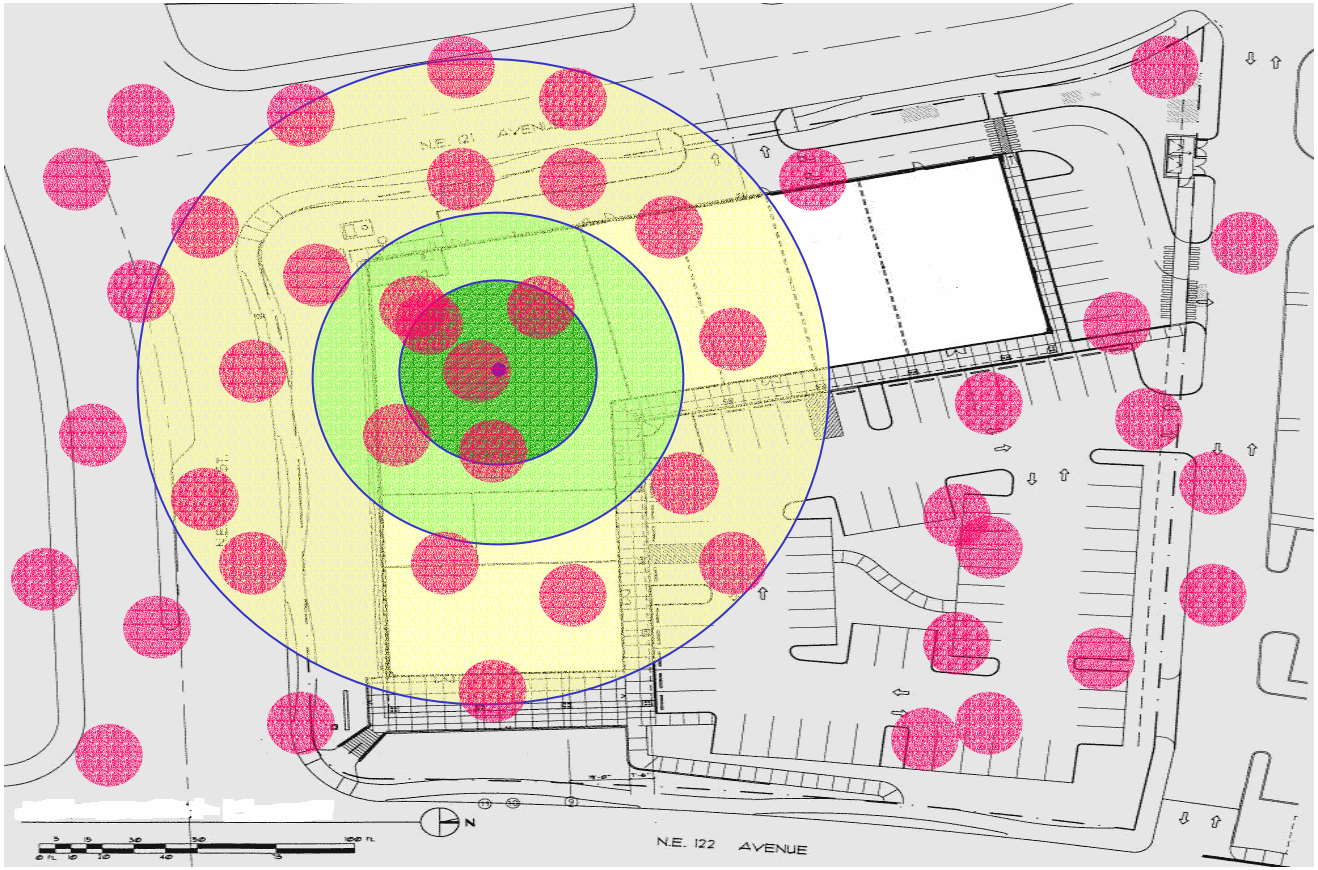
- **Transaction Costs**
  - Direct costs of buyers and sellers
    - High for property rights. Zero for commons.
  - Indirect costs of dispute resolution
    - Low for property rights? High for commons?
- **Scarcity**
  - If spectrum is scarce:
    - commons ⇒ tragedy of the commons
    - Property rights will efficiently allocate resources
  - If spectrum is not scarce,
    - Commons OK without costs of property rights mgmt

Is Spectrum Scarce?
Some UWB Observations



- UWB Mask: -41 dBm/Mhz (3-10 GHz)
  - 10^{-4} mW/MHz
  - 2 μW for 20 MHz

WiFi Coverage
(UWB Inteference)



- UWB Interference
  - Effects are cumulative, but does it matter?

WiFi Coverage

- Traditional user at dist R
- 20 MHz BW,
- 20 mW xmit Power
- Channel
  - $P_R(r) = K/r^4$

- N UWB sources: $E[N]=\lambda\pi R^2$
- Interference (per user): $E[I]=K/R^2r_0^2$
- Total Interference: $I_T=E[N]E[I\}=2\lambda\pi K/r_0^2$

WiFi Coverage

- Traditional user at dist R
- 20 MHz BW,
- 20 mW xmit Power
- P_0= 20 mW/2 μW =10^4

- SIR_{dB} = 32 -20log(R/r_0)-10log(λ)
- R/r_0 =100, λ=1/m^2: **SIR=-8 dB (Ouch!)**
- R/r_0 =10, λ=0.1/m^2: **SIR= 22 dB (OK!)**

Spectrum Scarcity?

- Usable NLOS spectrum = 10 GHz
  - Advances in Moore's Law
    - $\Rightarrow$ devices will use all 10 GHz
- Capacity increases with infrastructure
  - Reducing R increases capacity
- Capacity increases with technology?
- Analogy of the day:
  - Oil has been scarce for 100 years, but
  - Technology advances keep yielding new supplies

Spectrum Project
Technical Approaches

- Approaches/methods/solutions depend strongly on radio technology
- Technical Approaches in this project:
  - Eric Friedman
    - Fair Sharing via information theory models + cooperation
  - Predrag Spasojevic
    - Achievable Rates via Complex Coding + Cooperation
  - Chris Rose
    - Interference Adaptive Transmitters
  - Narayan Mandayam
    - Cooperation via pricing for wideband, energy constrained wireless nodes
  - D. Raychaudhuri
    - Network protocols for cooperation
  - Roy Yates
    - Coarse measurements