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# Spectrum Regulation for Ad-Hoc Wireless Cognitive Radios


David Cohen

Dennis Stewart


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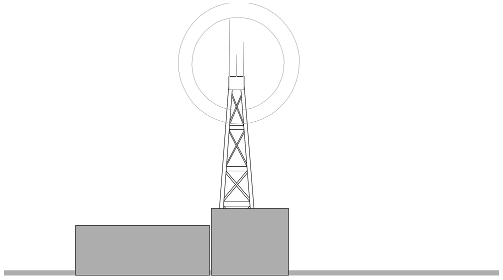
dcohen@umuc.edu

DStewart@alionscience.com

ALION SCIENCE AND TECHNOLOGY

# Paper Topics

- Problem Definition
- Cognitive and Ad Hoc Radio Descriptions
- Regulatory Alternatives including DySpan suggestions
- Recommendations and Suggestions for Future Work

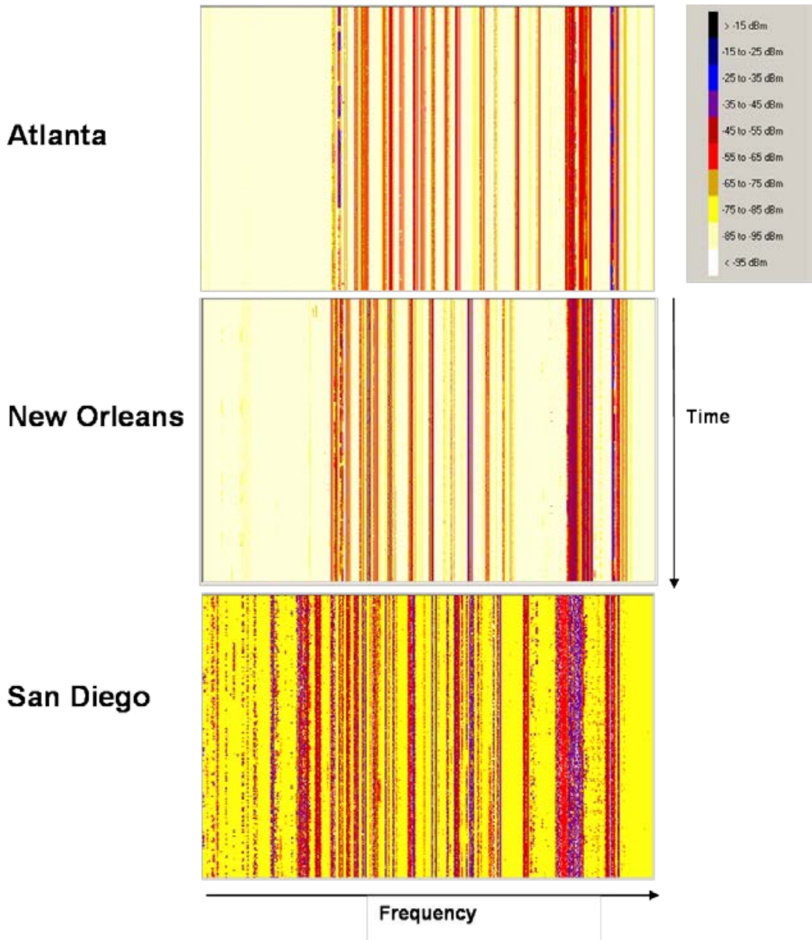
# Cognitive Radio

- Cognitive Radios have the ability to sense the electromagnetic environment and adapt their transmission schemes such that they can compatibly operate around the spectrum usage patterns of incumbent radio systems

- This dynamic adaptive capability can allow Cognitive Radios to operate in spectrum when it is not used by licensed radio systems that have priority access.

- Cognitive Radio may also operate in unlicensed spectrum

# Spectrum Use in Practice Source:FCC




- Some spectrum has highly variable use when viewed in terms of time and geography
- Some spectrum is intensively used

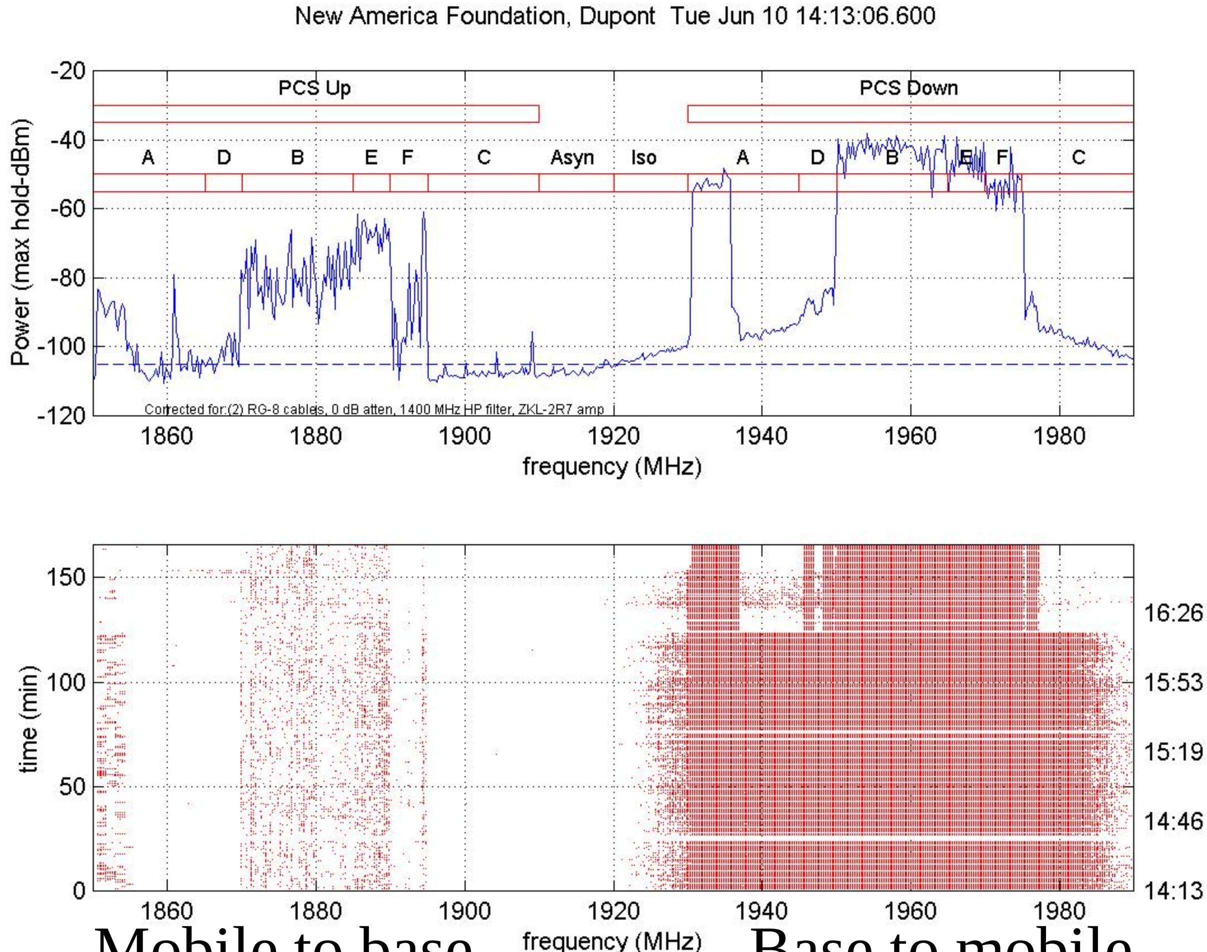
Time, Frequency, and Spatial Variations provide Opportunities for more Intense Spectrum Usage

# Cognitive Radio in Urban Environments

- Urban environments include operations such as cellular and land mobile which have spectrum priority
- Cognitive radio must work around these existing operations which are "non-cooperative"

# Shared Spectrum Company, June, 2003
# Dupont Circle, D.C.

http://vilimpoc.org/research/sda




Mobile to base

Base to mobile

# The Cognitive Radio Dilemma

How can you regulate a radio when you can't know what frequency it will be on, what mode it will be operating in, and how it will morph itself in frequency, bandwidth, power or waveform? "You've got to trust the processes in the radio--you can't really measure the output."

Source: Preston Marshall, XG program manager at the Defense Advanced Research Projects Agency (DARPA), Avionics Magazine, March 2005, http://www.avionicsmagazine.com/cgi/av/show_mag.cgi?pub=av&mon=0305&file=policycontrolledradio.htm

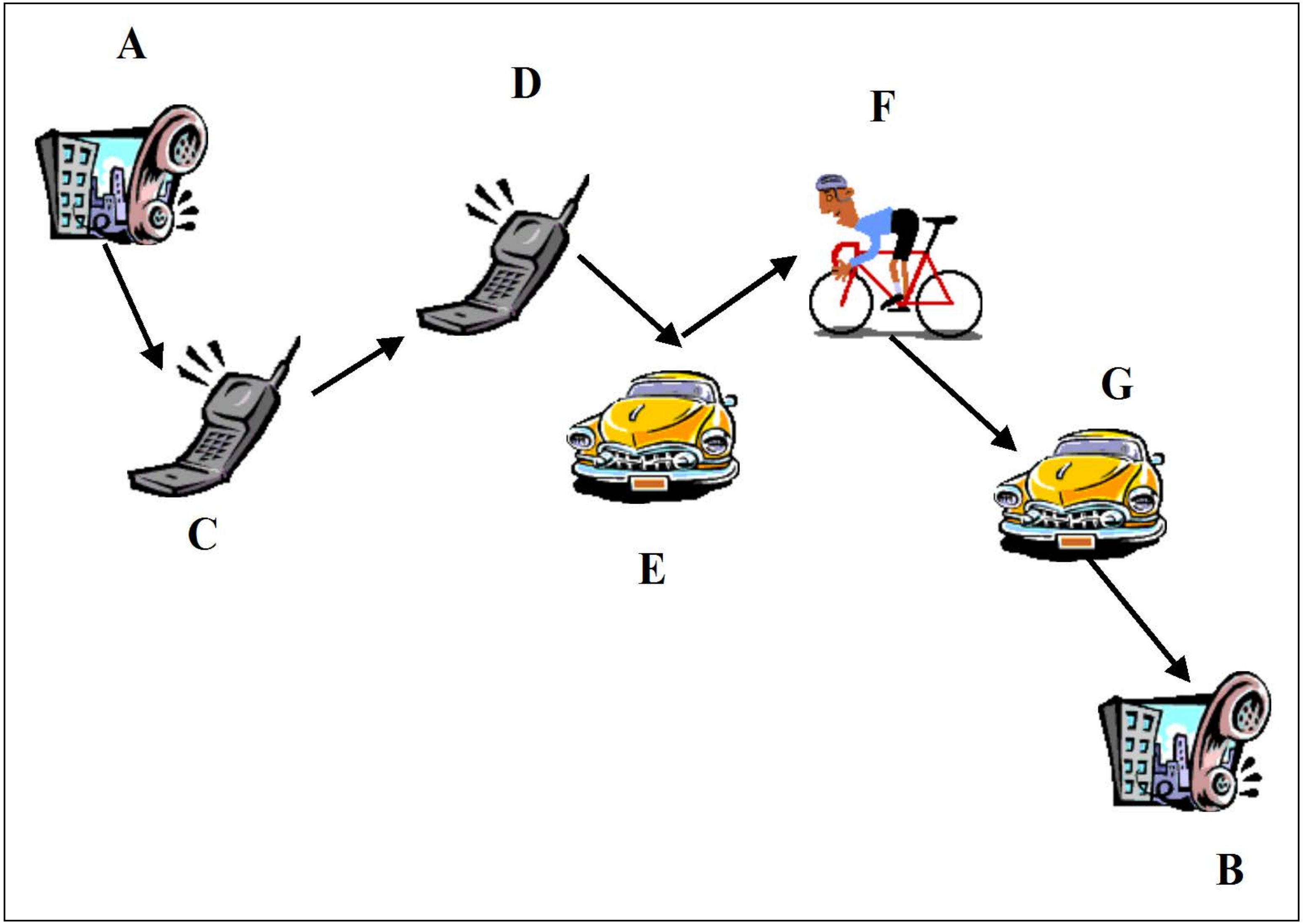
# Cognitive Radio Implementation Methods

1. "listens" to large segments of spectrum
2. Has “statistical”model of primary users including location, power level, bandwidth, time of usage, inactive periods
3. Knowledge of Regulations for sharing the available spectrum (time, frequency, space)
4. Is able to decide optimal transmission (bandwidth, latency, QoS, emission  waveform and modulation) based on primary users’ behavior

# Cognitive Radio Implementation Methods

5. Can determine a “threshold” that corresponds to channel being empty
6. Time scale of the spectrum occupancy varies  from msecs. to hours
7. Requires algorithm for dynamic frequency selection including  choice of next channel of operation

# Ad Hoc Packet Relay Network



# Ad hoc peer to peer networks (DySpan)

- There is a need when utilizing Ad Hoc peer to peer networks to initially broadcast on a common channel for discovery of network topology.
- Once the network topology is known peer to peer channels can be used to accomplish the data communication

# Regulatory Conceptual Overview

- Regulations for cognitive radio should specify constraints for coexistence between competing systems but not specify the implementation techniques

## Spectrum Regulations

Thou Shall:

1. Cause no harm
   a. Listen before transmit
   b. Defer to primary users
2. Use the minimum power and bandwidth necessary
3. Release spectrum when no longer needed

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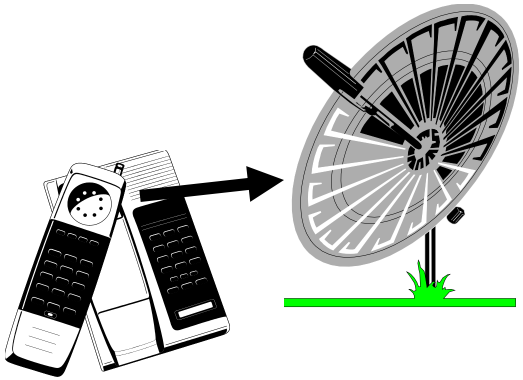
# Current Cognitive Radio Regulatory Implementation 5 GHz Unlicensed Sharing with Radars

- **Requires Dynamic Frequency Selection (DFS) and TPC (Transmitter power control)**
  - The WRC-03 conference approved the 5.15–5.35 GHz, 5.47–5.725 GHz for unlicensed use on a global basis.
  - Domestically, the NTIA Manual recommends military services determine if there are nearby Government radars (Government radar is primary in the band)
  - FCC Sharing Criteria (C.F.R. § 15.407)



# Regulatory Alternatives

(1) During the time the cognitive radio is transmitting and not listening and if a primary system commences transmission interference may occur during the channel abandonment interval. It is an agreed regulatory assumption that this interference is not harmful to the primary user

# Regulatory Alternatives

(2) Machine Readable Policies- Need for regulatory community acceptance of the principle that mobile transceivers may download dynamic spectrum access policies in an agreed standard machine readable format

# Regulatory Alternatives

(3) Cognitive radios shall have no protection from interference

(4) Flexibility in Service Definitions

(5) Security required to insure integrity and reliability of data

(6) More unlicensed spectrum

(7) Unlicensed Sharing of unused TV channels

# Regulatory Alternatives

(8) Multiple Specification of Minimum Signal Levels for the DFS detection threshold

(9) Avoid Worst Case Analyses

(10) Utilize Experimental Allocations

(11) Tiered Spectrum Access Rights

(12) Use of Heteromorphic Waveforms

# Regulatory Alternatives
# Duration of a Transmission

- Currently, there is no regulation limiting the duration of a transmission from a cognitive radio before it must listen to the channel.
- “Right now technology is in the 100 millisecond range but DARPA has asked contractors to go down to 10 milliseconds” [Avionics, March 2005]

# Regulatory Alternatives Location Knowledge

- Utilizing GPS or other technologies each node in a cognitive ad hoc radio systems should know its geographical location

# Regulatory Suggestions of DySpan Conference

- Each secondary user's spectrum channel choice should be rule based (possibly included in the radio regulations)
- Users sense local operations such as neighbor primary operations and each user independently adapts their operation based on these rules.
- The rules will have to be simple if included in the radio regulations.

# Regulatory Suggestions from DySpan

- Network nodes need to make coordinated choice of channel operation from the myriad of possibilities with convergence to a choice of channels in under 2 seconds. [Raytheon simulation using MATLAB]

# Regulatory Suggestions of DySpan Conference

- There is a tradeoff between sensing and sending payload data. Limit sensing and coordination time to a few percent overhead.
- The amount of overhead may depend significantly whether the network is a defined infrastructure (base station +nodes) or ad hoc peer to peer in form. Ad hoc networks require more time to form the network and assign frequencies

# Examples of Rule Based Assignment for Cognitive Radio Zheng & Cao [DySpan 2006]

- Users always select idle channels. Choose channels that during a period of length X showed no activity
- To promote fairness if the number of idle channels is insufficient user grabs channels from a “richer” secondary user.
- A user is richer if it uses more channels than a poorer user

# Recommendations

- DoD after completion of proof of concept take the US lead in the spectrum management community for support of cognitive radio
- NTIA and FCC after proof of concept support domestic and international adoption of cognitive radio regulation
- Support IEEE P1900.x Standards Project on Next Generation Radio and Spectrum Management

# Suggestions for Future Work

- Defining Interference.
  - Should policies define permitted limits for transient interference to account for imperfections in the algorithms and protocols for accessing the spectrum?
  - What are the achievable sensitivity levels (i.e., margin of error) for sensing the environment?
  - What are the achievable sensitivity levels (i.e., margin of error) when using propagation prediction?
- Defining environments. Which environments can cognitive spectrum access systems operate (e.g., dense voice traffic, radar, etc.)?

# Suggestions for Future Work

- Require Studies on Channel Assignment Methods for cognitive radio especially in ad hoc radio environments
- Limitations to include in studies:
  - Limited information exchanges (low overhead)
  - Assignment algorithms must be real time
  - Algorithms must be of low complexity and low communication overhead
- Current assignment methods assume perfect collaboration among users. Investigate impact of troublesome and selfish users

# Suggestions for Future Work

- Examine spectrum channel assignment algorithms for specific military and public safety environments that may include a central control node
- Evaluate the advantage for spectrum capacity if a control channel is available

# Add ons

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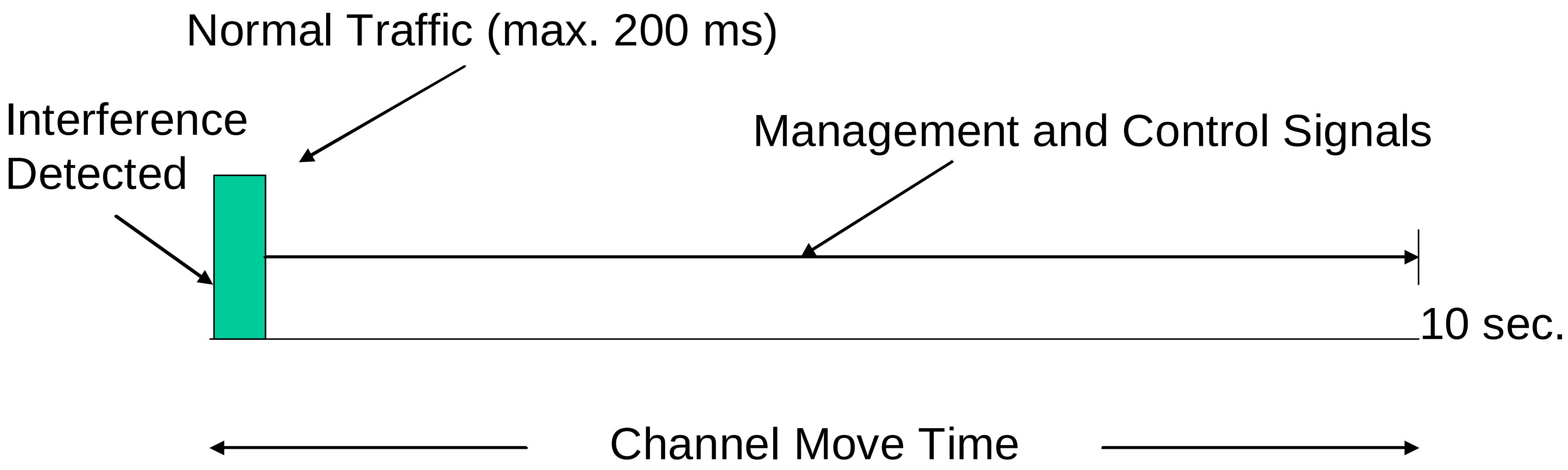
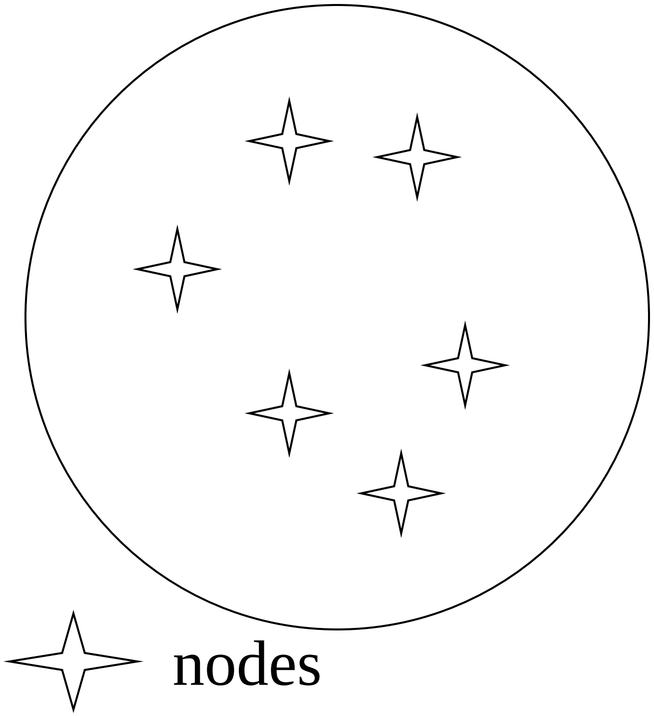
# Cognitive Radio Definition

- A radio or system that senses, and is aware of its operational environment and can be trained to dynamically and autonomously adjust its operating parameters accordingly
- *Source: Working Party 8A ITU-R*

# FCC C.F.R. § 15.407 Sharing 5 GHz *interpretation for* Recommendation ITU–R M. 1652 Annex 1



# Nearest Neighbors




Circle is node neighborhood

- For Ad Hoc Networks to work well requires each node to be connected to 6-8 neighbors (under study)
- Spectrum required depends on no. of connected notes, throughput and frequency reuse distance

# Ad Hoc Network Media Access

- A randomized contention based protocol is good for low loads, due to its low delay.
- An allocation (TDMA slots, CDMA codes) based protocol is desirable for high loads, as it avoids the breakdown induced by too many collisions.
- Keep power to a minimum to avoid interference with other nodes. In cellular there is centralized power control but in an ad hoc network each node has to control its own power to extend battery life.

# Operation in Urban Environments

- “War fighting is very dependent on coalition allies. We went into Iraq, but we had to work with Kuwait. In operating in Iraq, we wouldn’t want to take out Kuwait’s cell phone and television systems. If we’re not going to be good neighbors, people aren’t going to cooperate with us.”
- Quote from Preston Marshall, XG Program Manager in Signal Magazine, December 2003

# Suggestions for Future Work

## Support IEEE P1900.x Standards Project on Next Generation Radio and Spectrum Management

- IEEE P1900.1

  *Standard Dictionary of Terms, Definitions and Concepts for Spectrum Management, Policy Defined Radio, Cognitive Radio and Software Defined Radio*

- IEEE P1900.2

  *Recommended Practice for Interference and Coexistence Analysis*

- IEEE P1900.3

  *Recommended Practice for Conformance Evaluation of Software Defined Radio (SDR) Software Modules using Formal Concepts and Methods Analysis*

# Automatic Frequency Assignment

- U.S. forces operating overseas, must assure that their radio operations at particular frequencies do not interfere with local communications.
- Today (2005) a manpower intensive process is used to assign frequencies to all the radios involved in a mission.
- One goal is to develop intelligent radios that have all national frequency spectrum protocols stored in memory (microchips). This will facilitate automatic, seamless operation without the need for lengthy frequency allocation negotiations

# Ad Hoc Network Characteristics

- An **ad hoc** network is a collection of mobile communications devices (nodes)
- No fixed infrastructure
- No pre-determined organization of available links.
- Not all nodes can directly communicate with each other, so nodes are required to relay packets on behalf of other nodes in order to deliver data across the network.

# ITU- upcoming meetings

- *Fall **2006 Plenipotentiary Conference** (Istanbul)**2007** Mar. 5-16,*
- *2007 **Conference** Preparatory Meeting (Geneva)Jul. 9, 2007*
- *Deadline for WRC-07 Proposals Oct. 1-5, 2007*
- *Radio Assembly (Geneva)Oct. 8-Nov. 2, 2007 **WRC-07** (Geneva)*