ET Doc. No. 03-108

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Remarks of
Jonathan S. Adelstein
Commissioner, Federal Communications Commission

Workshop on Cognitive Radio Technologies
Office of Engineering and Technology
Federal Communications Commission
Washington, DC

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Federal Communications Commission
Office of the Secretary

May 19, 2003
[As prepared for delivery]

Let me welcome you again to the Workshop on Cognitive Radio Technologies. Thank you for taking the time to participate in today's discussion. I appreciate the folks in OET inviting me to help kick-off the event and the work of Jim Schlicting and Mike Marcus in organizing the workshop. While I've only been at the Commission for six months, I've been really impressed with the professionalism and expertise of the OET staff – even though Julie and Bruce couldn't help me fix the remote control on my office TV the other day! Seriously, it's been a real pleasure to work with Ed Thomas and his staff on the many key technical issues we've already addressed this year.

As I've tried to make clear, I'm a big fan of wireless services. I'm fascinated by spectrum-based technologies, which are increasingly the real drivers of innovation in telecom. Today we're exploring the amazing possibilities that cognitive radio technologies have to offer.

Use of spectrum touches our lives in a lot of ways. Whether calling for help with a flat tire, staying in touch with our family, or helping with a problem at work, spectrum is the medium we can use on the go to make our lives safer and more productive. The incredible progress we've made in wireless is also enhancing the security and prosperity of our Nation.

The cognitive radio technologies that are today's focus offer the potential for even more innovation that can spur our nation's productivity and our citizens' safety.

Of the many challenges Congress has charged the Commission with, spectrum management is a top priority. I've set out an approach for spectrum policy in what I have called a "Framework for Innovation." In dealing with spectrum, I believe the Commission has a responsibility to establish ground rules for issues such as interference and availability, but applying the rules with a light touch. In this area, fortunately, we can rely heavily on technology, with engineering and innovation driving increased performance, increased capacity, and more and better services for consumers.

New cognitive radio technologies can potentially play a key role in shaping our spectrum use in the future. These technologies can lead to the advent of smarter unlicensed devices that make greater use of spectrum than possible today – without interfering with licensed users. Cognitive radios may also provide licensees with innovative ways to use their current spectrum more efficiently, and to lease their spectrum on the secondary market. I saw some of these very

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technologies demonstrated last week at the summit at NTIA, and am just amazed by their potential.

In the broader framework, cognitive radio technologies offer the promise of helping us leave the world of command-and-control behind and create an environment where a framework for innovation can leverage their potential benefits. The potential of these technologies to "do more with less" can help us make room to accommodate both more users and the newest service offerings.

Cognitive radio technologies can also help address two critical points identified in the recent Spectrum Policy Task Force Report with which I strongly agree. First is the goal of "increasing the public benefits derived from the use of radio spectrum," and, second, the concern that "increasing demand for spectrum-based services and devices are straining [our] longstanding and outmoded spectrum policies."

I commend Chairman Powell for his leadership in this area, and applaud the hard work of Dr. Paul Kolodzy, Lauren Van Wazer, and the Task Force staff for helping identify spectrum management areas ripe for reform. This follow-on workshop is an excellent example of how I think we should define and pursue our key spectrum policy goals.

With the right framework in place, we will continue to see exciting innovations increase performance and capacity. These will offer consumers more and better services, no matter where they live. The right kind of spectrum management policy promotes these developments by pushing boundaries to accommodate new technologies and services. As policy makers, we always need to consider the latest technologies in managing the spectrum. Of course, that's a big part of why we're here today.

Again, welcome to today's workshop. Please help us think through these critical public policy issues so that we remain "cognitive" of them in the future.

And thank you for joining us this morning.

ET Doc. No. 03-108

GENERAL DYNAMICS

Decision Systems

SDR Technology Implementation for the Cognitive Radio

Bruce Fette PhD

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General Dynamics Decision Systems

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May 16, 2003

Cognitive Radio* is Built on SDR*

- We must start with a Software Defined Radio as a basic platform on which to build a Cognitive Radio
- Cognitive Radio can provide the spectral awareness technology to support FCC initiatives in Spectral Use

*SDR and Cognitive Radio are terms coined by Dr. Joe Mitola - see appendices for references

Definition of SDR

- **From FCC NPRM*: "We view software defined radios as the result of an evolutionary process from purely hardware-based equipment to fully software-based equipment. In this regard, the process can be roughly described in three stages**

  - **1. Hardware driven radios:** Transmit frequencies, modulation type and other radio frequency (RF) parameters are determined by hardware and cannot be changed without hardware changes.
  - **2. Digital radios:** A digital radio performs part of the signal processing or transmission digitally, but is not programmable in the field
  - **3. Software Defined Radios:**. All functions, modes and applications can be configured and reconfigured by software.

*Notice of Proposed Rule Making (NPRM) 8/12/00

Definition of SDR - Continued

- **SDR Forum:**
  - ↗ **4.** SW defines all waveform properties, cryptography and applications, is re-programmable, and may be upgraded in the field with new capabilities
- **Importance of Standards (APIs)**
  - ↗ **5.** HW Interfaces, RF services, Operating Environment, Application to Radio Interfaces

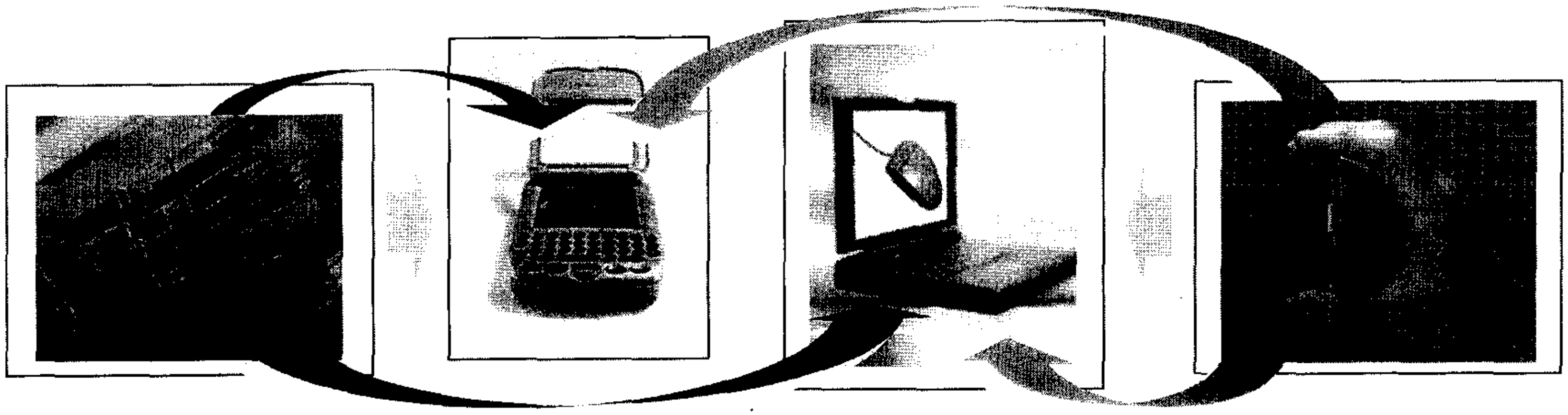
SDR Technology

- **Technology fundamentals:**
  - ↗ Digital Signal Processors (DSPs) provide virtually infinite programmability
  - ↗ All modulation, cryptography, protocols, and source coding (voice, data, imagery) are established using software
  - ↗ Many types of modulation can be accomplished over a broad range of frequencies, thereby an SDR is capable of servicing more than one class of service
  - ↗ Field serviceable, when requirements change, upgrades and modifications are relatively easy to execute

SDR Standardized Architecture Supports Both Current and Future Applications

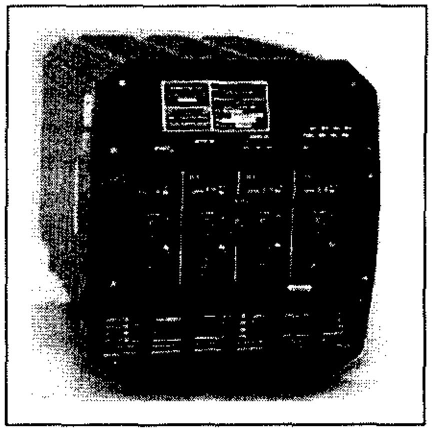
- FDMA, TDMA, CDMA, TDD
- AM, FM, MFSK, MPSK, MQAM, CPM, SSB, DSSS ...
- DES, 3DES, AES, MeXe
- Trunked Radio, APCO-25, GSM, Iridium, 802.11..
- Tone Coded Squelch, CVSD, LPC, VSELP, AMBE, ...

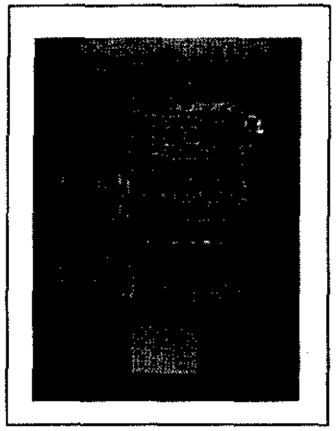
It's just a matter of software!

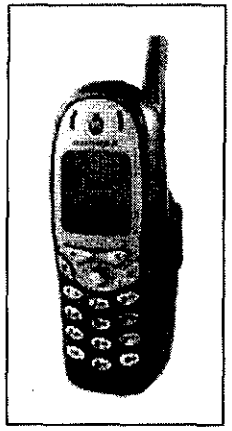


Building the Cognitive Radio using SDR Technology - The SDR Radio is Available Now!

- SDR drives the Cognitive Radio concept that will provide the spectral awareness technology supporting the FCC's Spectral Use initiatives
- SDR is a proven, flexible, COTS technology platform
- SDR Technology is in Production and Available Now

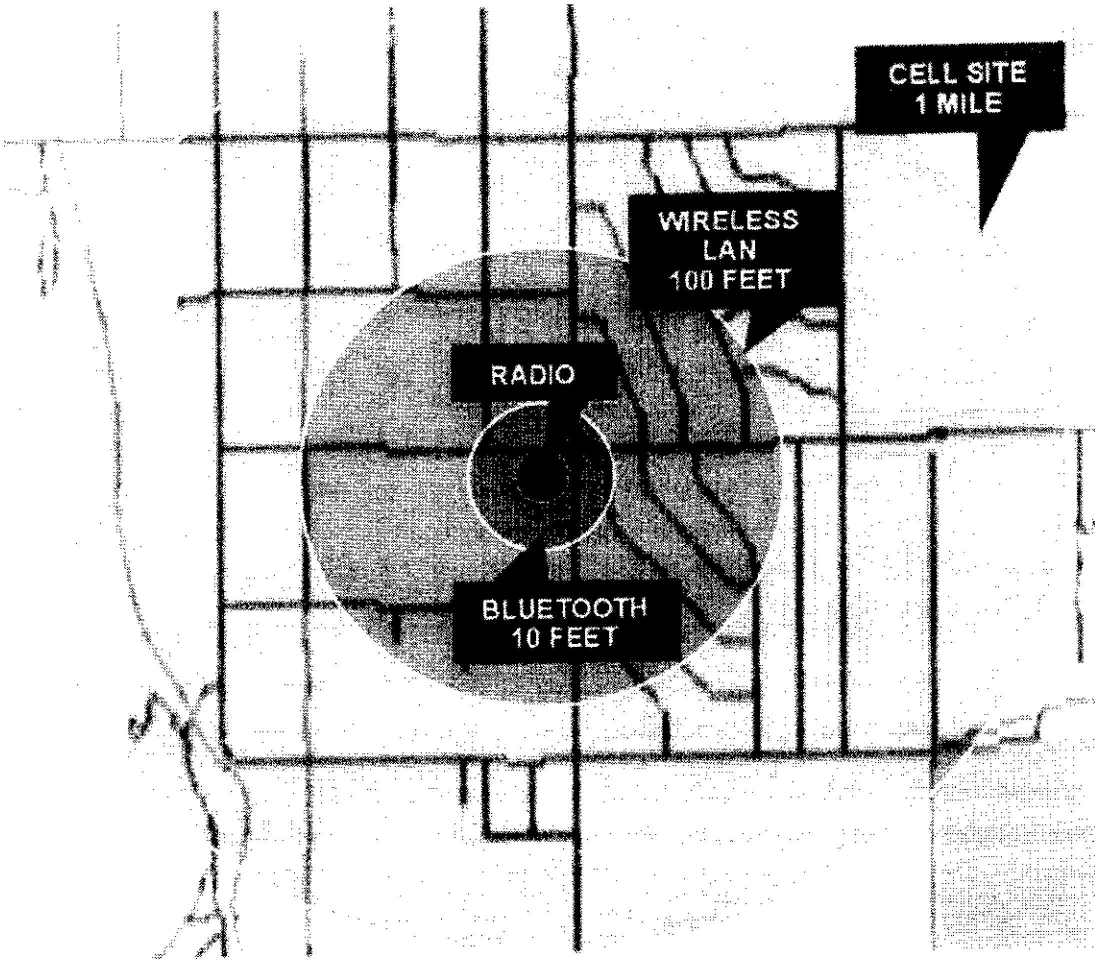






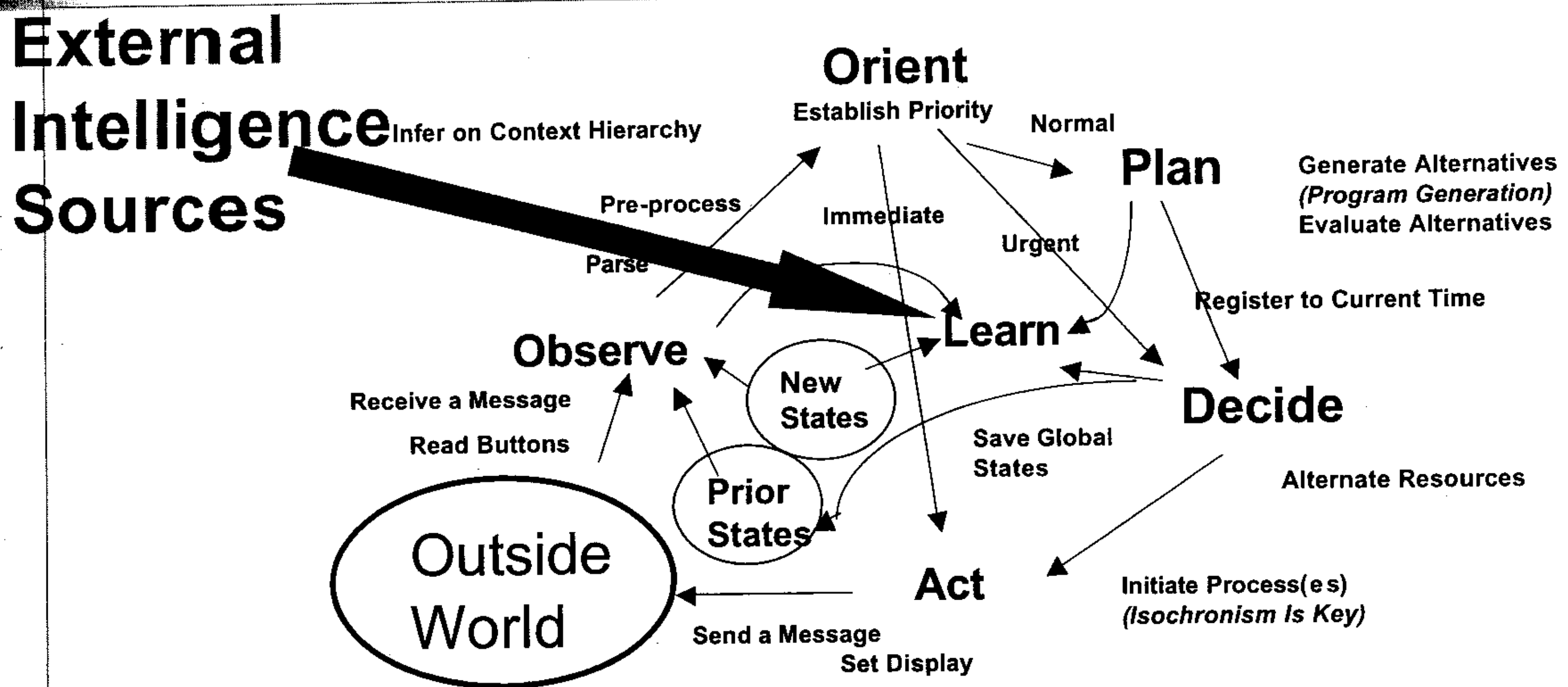
New Announcements Coming Soon

Cognitive Radio Means “Smart” and “Alert”



- It knows where it is
- It knows what services are available, for example, it can identify then use empty spectrum to communicate more efficiently
- It knows what services interest the user, and knows how to find them
- It knows the current degree of needs and future likelihood of needs of its user
- Learns and recognizes usage patterns from the user
- Applies “Model Based Reasoning” about user needs, local content, environmental context

How Does a Cognitive Radio Get So Smart?



The Cognition Cycle

Mitola, "Cognitive Radio for Flexible Mobile Multimedia Communications", IEEE Mobile Multimedia Conference, 1999, pp3-10

Example Spectral Awareness Etiquette That Can Be Implemented on Existing SDR / Cognitive Radio

- **Infrastructure Based Approaches**
  - Possible Infrastructure Reuse - spread economic support base
  - Existing examples of Spectrum sharing Protocols
    - A) Trunked radio
    - B) Cellular spectrum borrowing
    - C) Demand Assigned Multiple Access (DAMA)(demand assigned time sharing)
  - Infrastructure Supports wide Range of Spectrum Management Policies
    - Match Requirements, Priorities, Spectral Mask of Owners

Example Spectral Awareness Etiquette Can Be Implemented on Existing SDR/Cognitive Radio (continued)

- Cognitive Radios can adopt new etiquettes for new standards
  - Possible Demonstrations using existing SDRs
    - ✓ Spectrum rental transactions
    - ✓ Spectral Availability (Borrow) Beacon
    - ✓ Local Spectrum Utilization Database Server (time, freq, code, space, power, modulation)

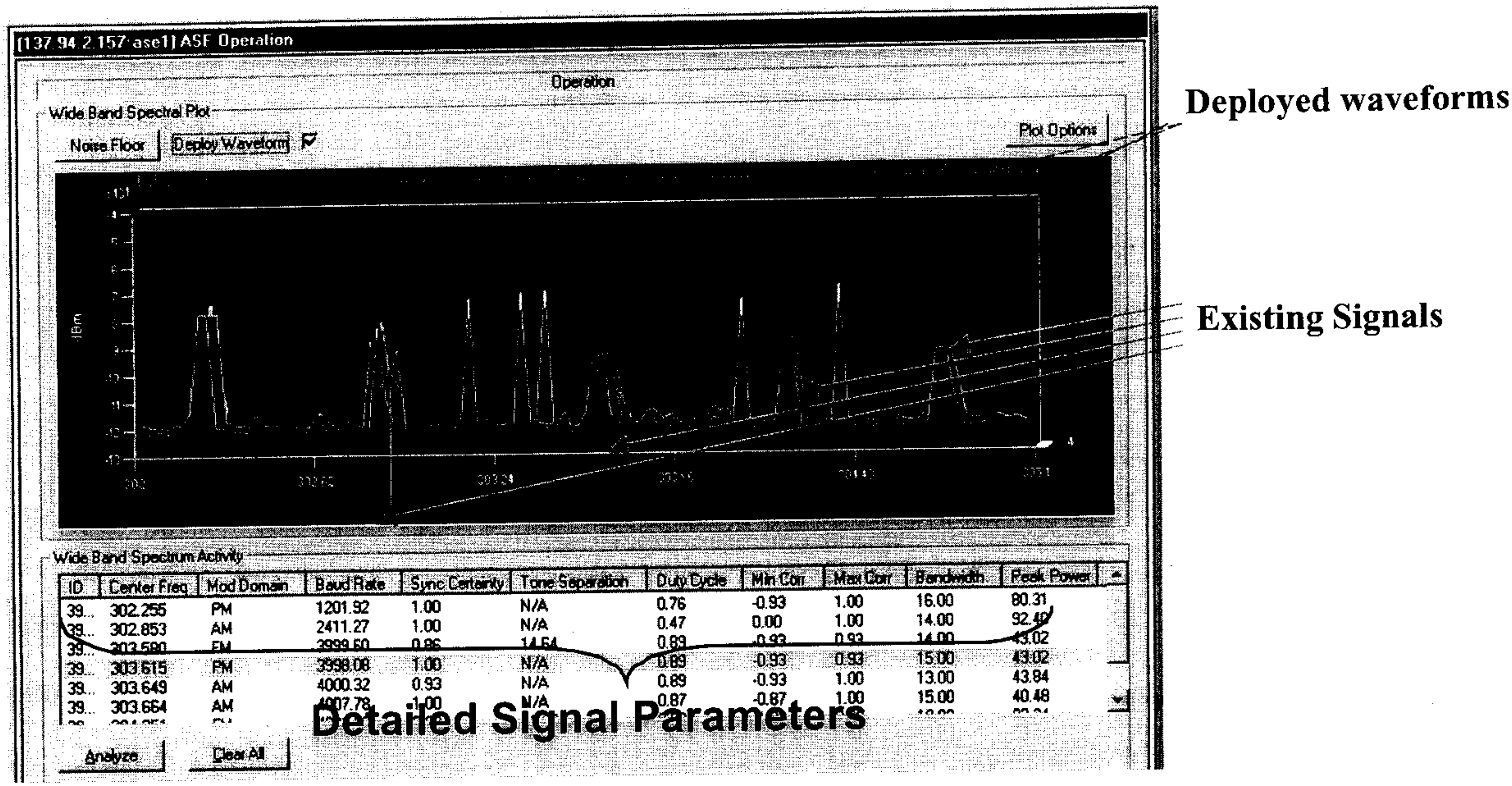
- **Distributed techniques - Possible Demonstrations**
  - Spectral Noise temperature (Kolodzy, 2002)
  - RTS - CTS handshake (handshake includes local spectral activity model at each end of link, as well as BW, packet size, TX PWR for APC). Minimizes hidden node problem
  - Underlay, Overlay, Interweave

Example Spectral Awareness Etiquette Can Be Implemented on Existing SDR/Cognitive Radio (continued)

- Waveform Orthogonality: Time - Freq - Code - Hop/Chirp - Spatial
  - Usually Involves some form of CSMA sensing for high priority user

Adaptive Frequency - find a frequency

SDR Finds Frequency - Time Opportunities
Spectral Awareness Etiquette



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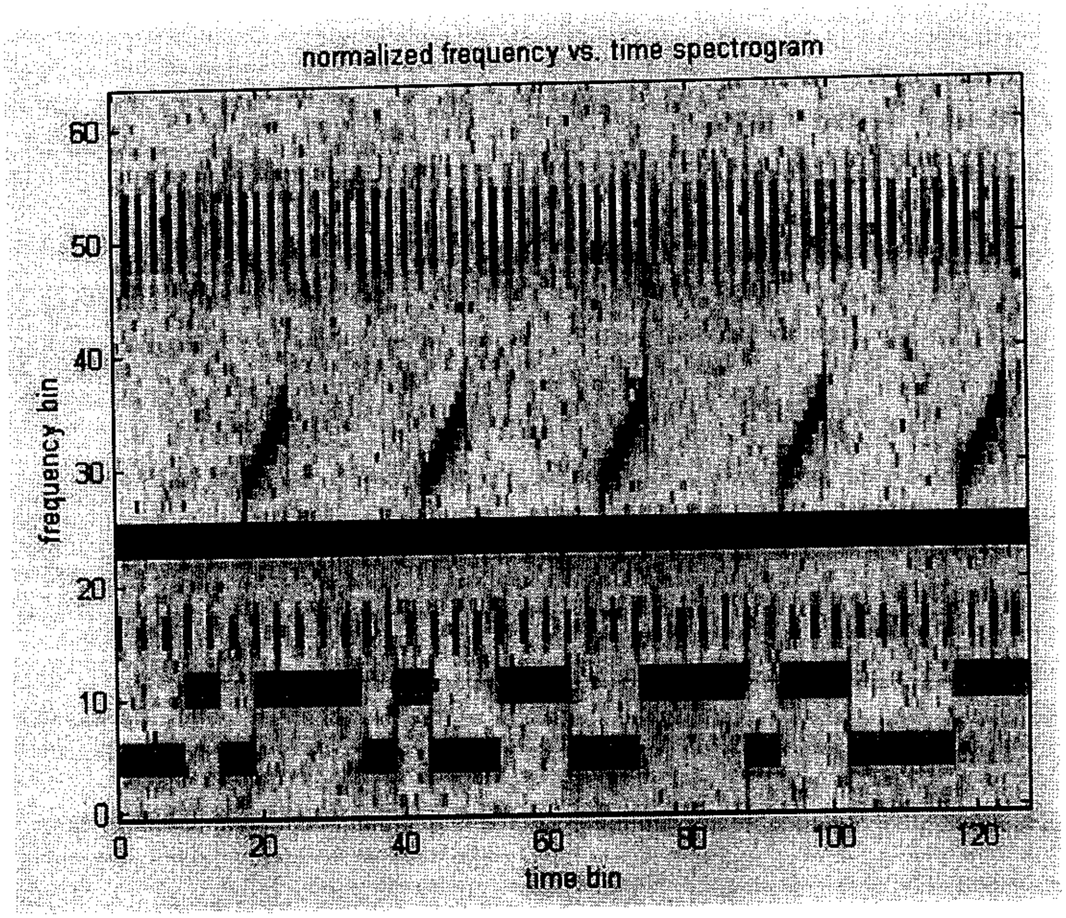
Adaptive Frequency - find a frequency

Adaptive TDMA - find an unused time slot in between a periodic user

Opportunities for Spectral Reuse Amongst Periodic Signals



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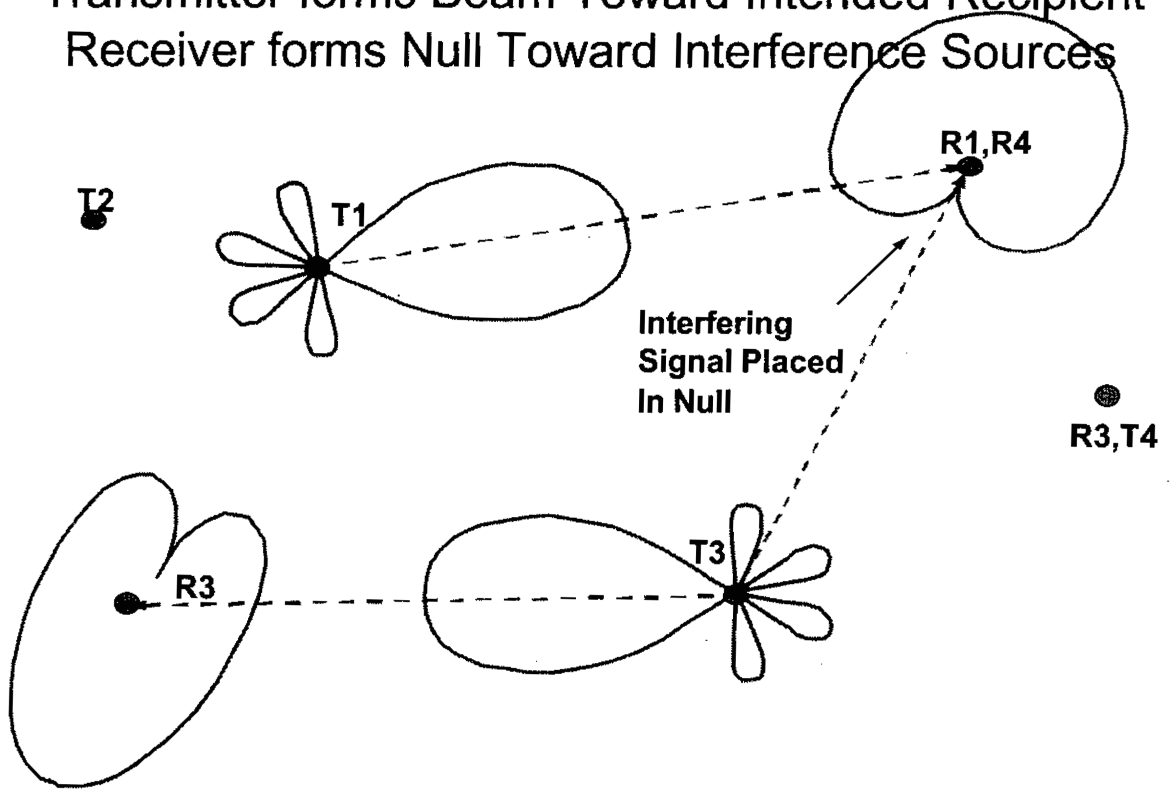
Adaptive Frequency - find a frequency

Adaptive TDMA - find an unused time slot in between a periodic user

Spatial - Beam steering and Null Steering

Time - Frequency - Space
Each Domain has Opportunities for Spectral Reuse

Transmitter forms Beam Toward Intended Recipient
Receiver forms Null Toward Interference Sources



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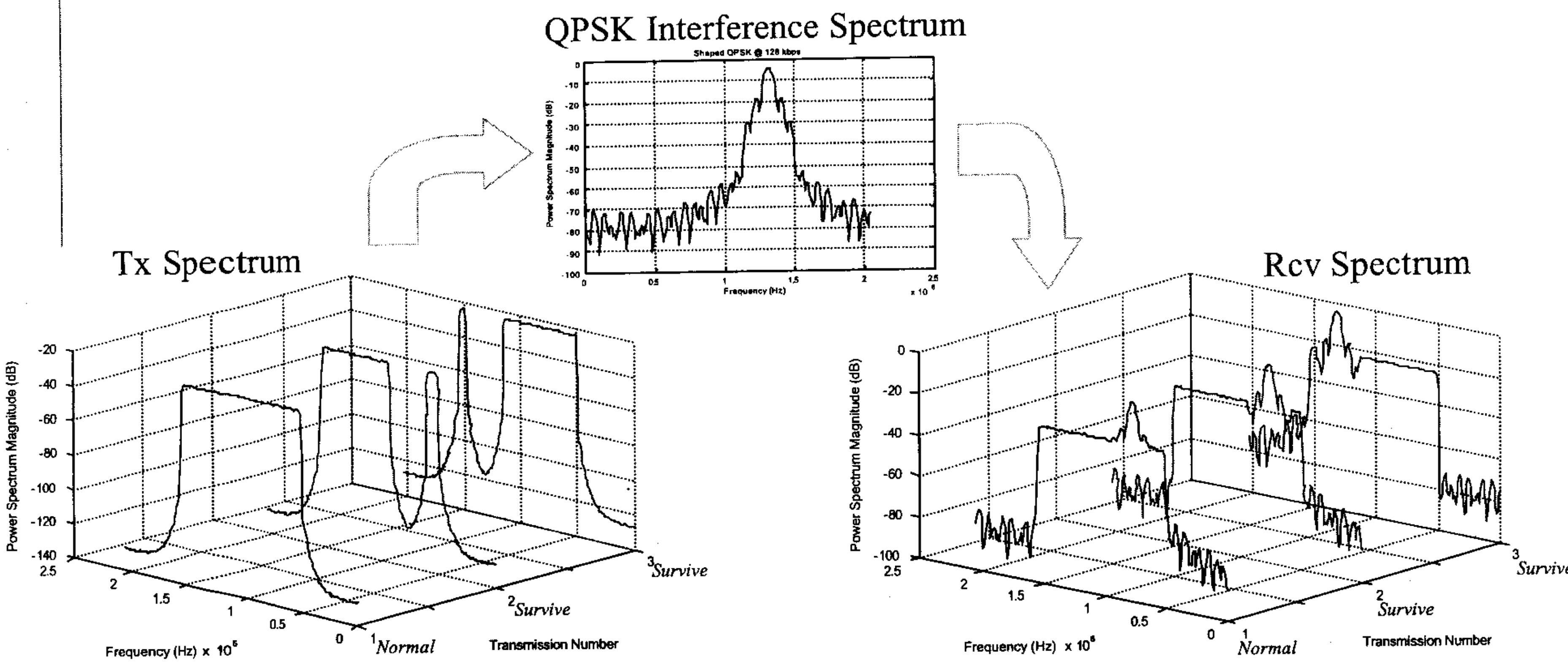
Adaptive Bit Loading onto OFDM carriers based on SNR

OFDM Interference Avoidance



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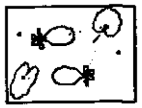
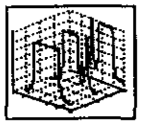


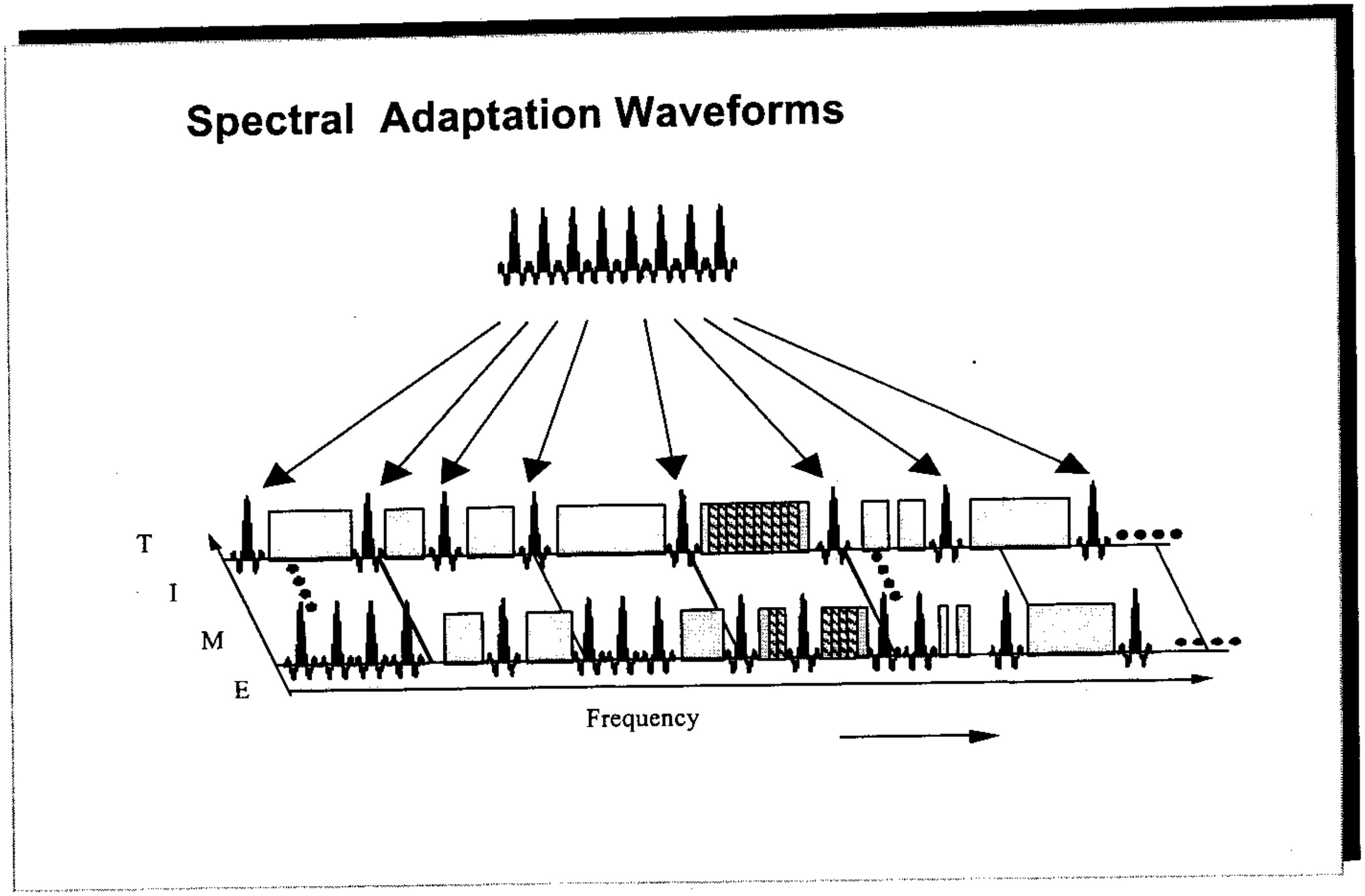
Spatial - Beam steering and Null Steering



Adaptive Bit Loading onto OFDM carriers based on SNR

OFDM techniques where small spectral holes can be filled by one or a few carriers that fit the time - frequency hole

OFDM Carriers Selected for Use That Fall into Available Spectrum



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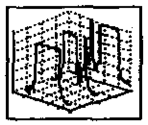

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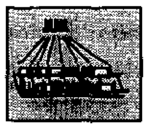

Interference Suppression & MultiUser Decomposition

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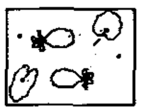

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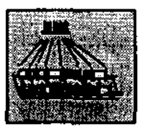
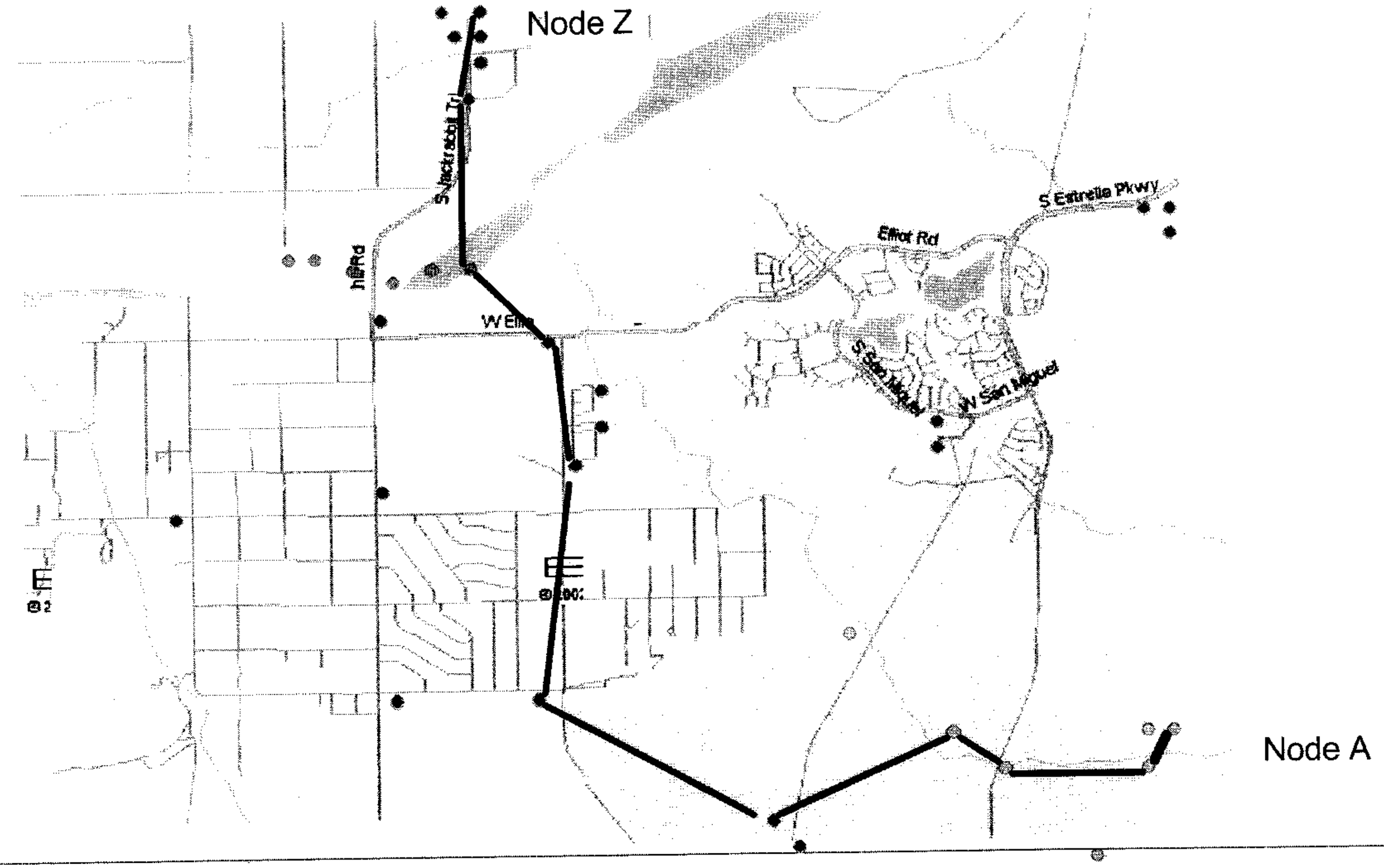


Interference Suppression & MultiUser Decomposition

- Importance of Adaptive Power Control
- AD Hoc Networking (shortest hop routing w APC)

Transmitting from A -> Z : AdHoc Networking



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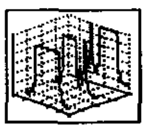
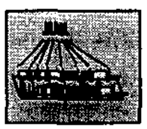


OFDM techniques where small spectral holes can be filled by one or a few carriers that fit the time - frequency hole



Interference Suppression & MultiUser Decomposition

- Importance of Adaptive Power Control
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Timeline: SDR's to have Cognitive Capabilities

2003	2004	2005	2006	2007	2008
▶ DARPA's Demonstrations within 1 year	▶ Commercial viability exploration & commercial analysis under existing agreements	▶ Viability demonstrated for commercial purposes within 2 year			▶ 5 years for etiquettes to be formally standardized ▶ SDR Forum can initiate early work and insert into standards bodies as work matures
2003	2004	2005	2006	2007	2008

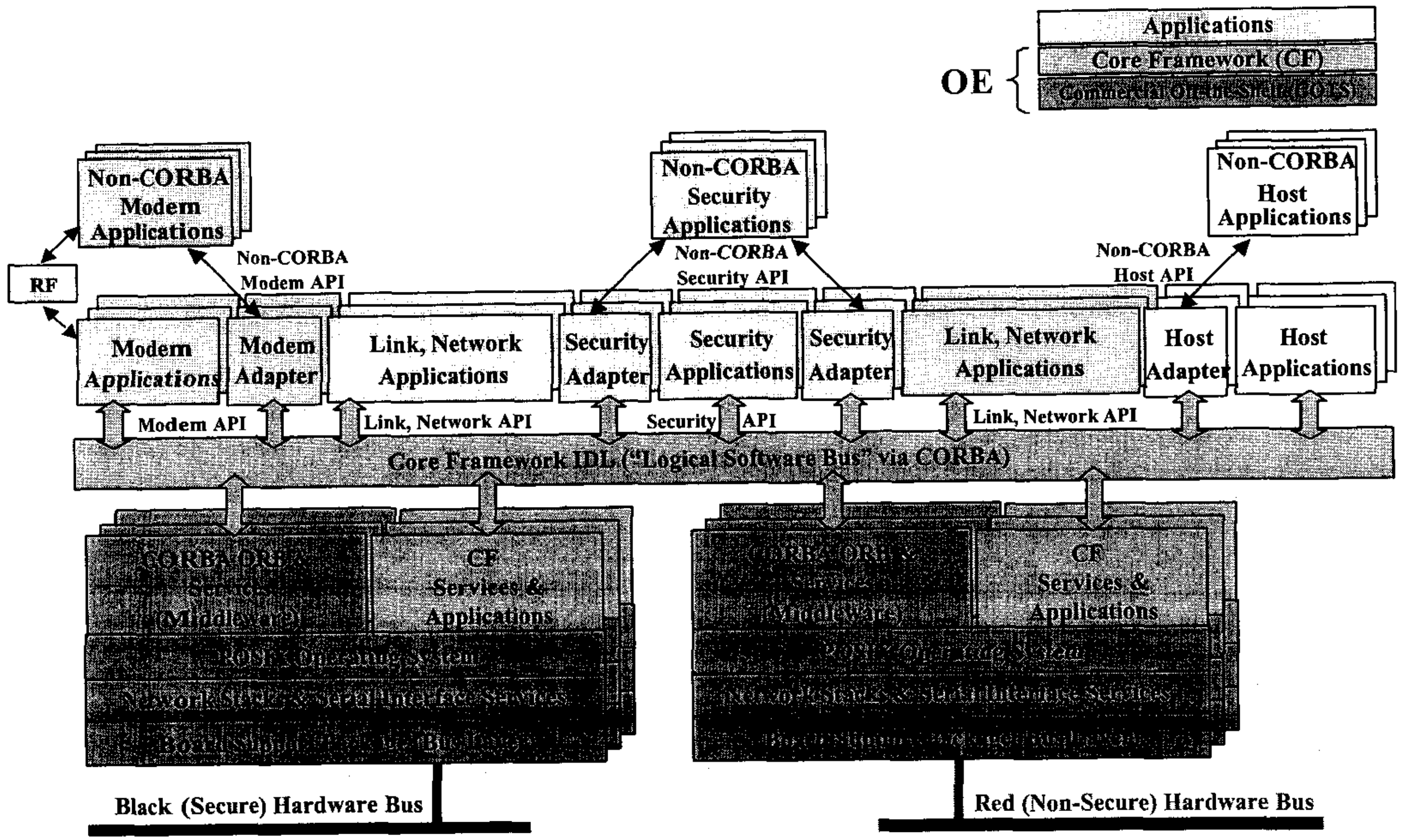
In Conclusion

- SDR Products and Technology are a Reality Today
- SDR Standards are Actively Being Worked today by Standards Bodies and Organizations
- Cognitive Radios have the Ability to Implement Protocols and Policies Beyond Traditional Communications.
- New Realms of Knowledge and Information Transfer are Achievable with Cognitive/SDR Radio as the Underlying Technology Enabler

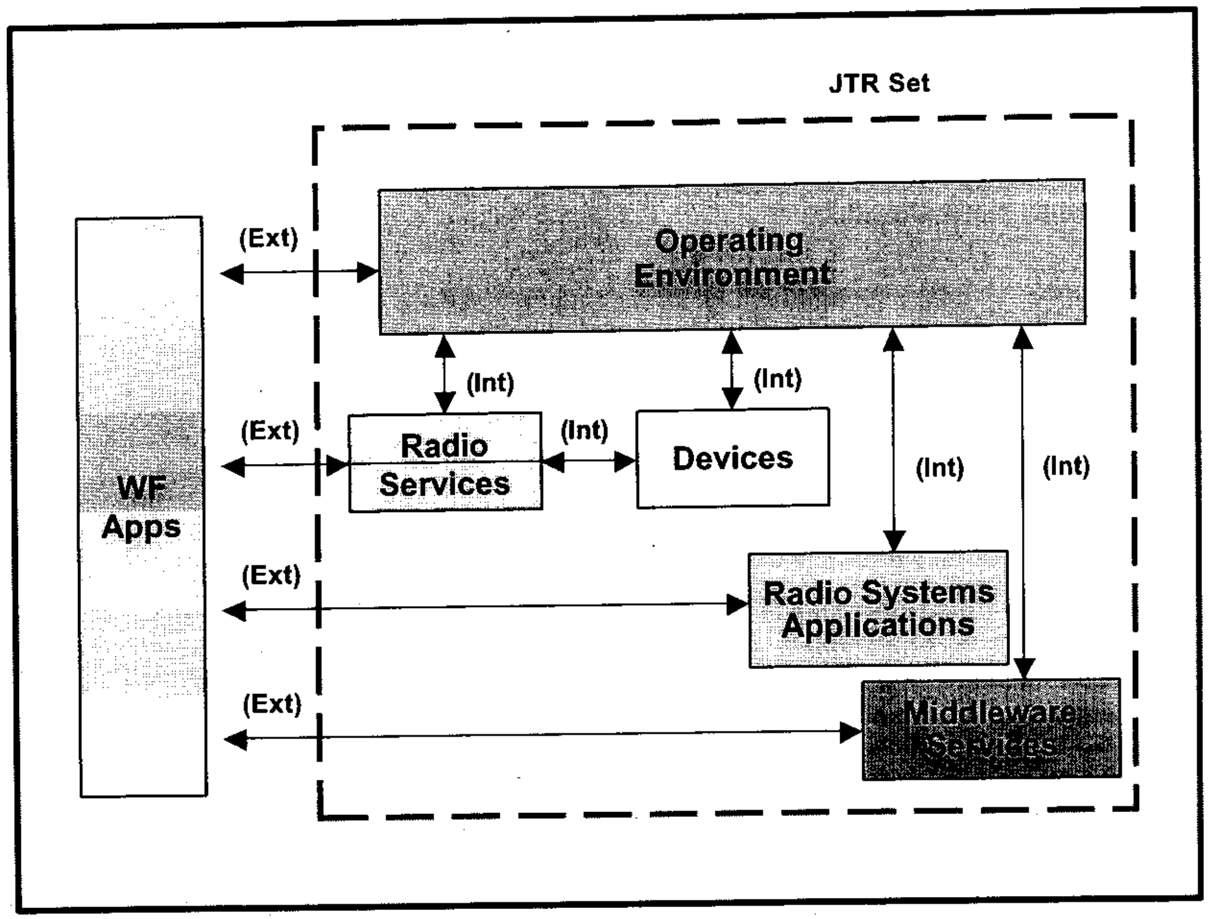
Appendix

- SCA Reference Architecture
- Radio Services for Application Portability
- SDR Forum Standardized Hardware Architecture
- Reference Publications

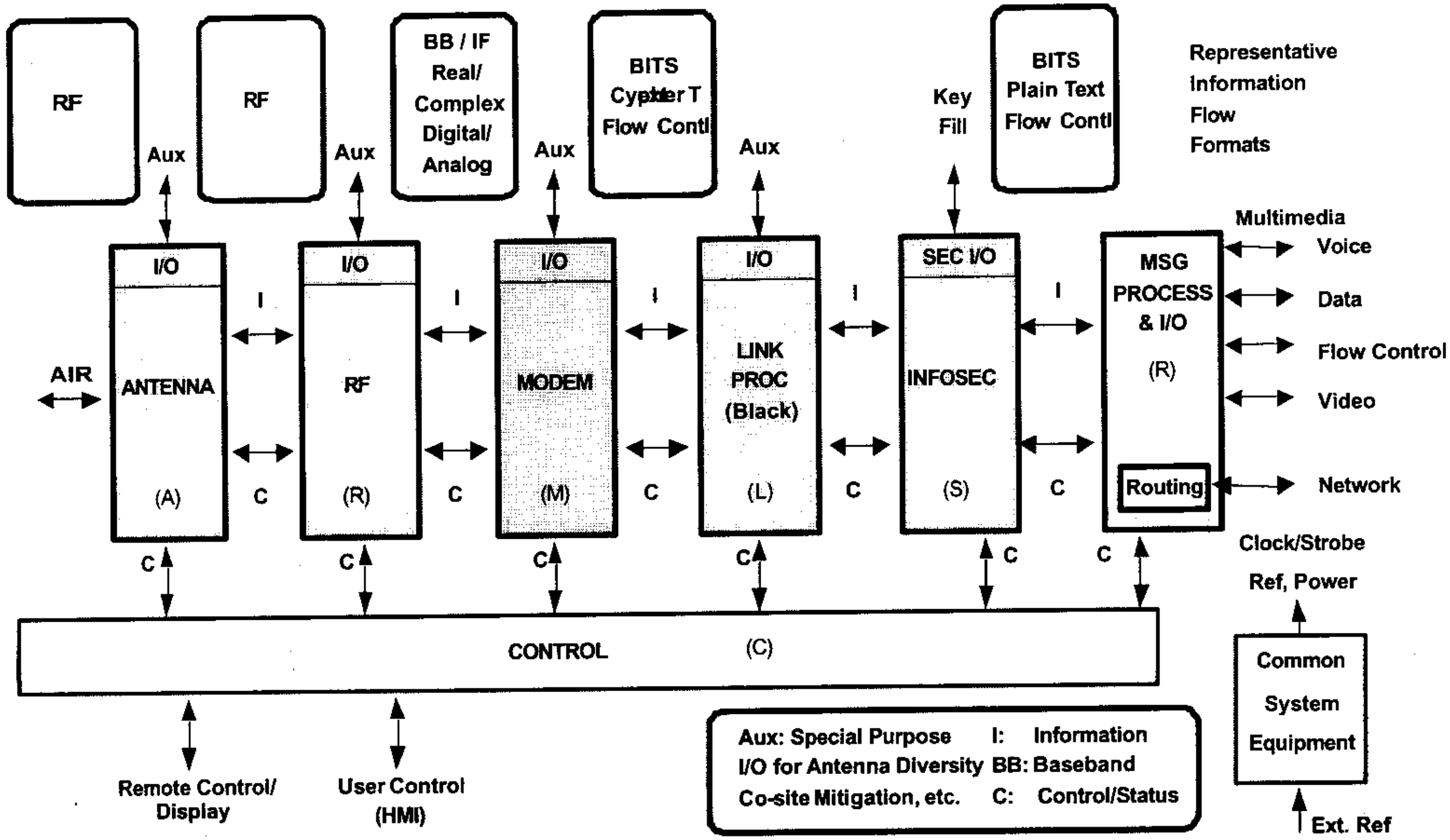
SCA Reference Architecture



Radio Services For Application Portability



SDR Forum* Standardized Hardware Architecture



From Programmable Modular Communications System (PMCS) Guidance Document, 1997

*SDR Forum was established as an Industry Organization to address SDR technology on 1995

Reference Publications

- Mitola, "Cognitive Radio for Flexible Mobile Multimedia Communications", IEEE Mobile Multimedia Conference, 1999, pp3-10
- Mitola, "Future of Signal Processing - Cognitive Radio", Keynote, IEEE ICASSP, May 1999
- Mitola, Maguire, "Cognitive Radio: Making SW Radios More Personal", IEEE Personal Communications, August 1999, pp13-18
- Mitola, "SDR Architecture Refinement for JTRS", Milcom 2000, pp 214-218
- Mitola, "Software Radio Architecture: A Mathematical Perspective", IEEE J on Selected Areas in Comms, April 1999, pp 514-538
- Margulies, Mitola, "Software Defined Radio: A Technical Challenge and a Migration Strategy", 1998, pp551-556

ET Doc. No. 03-108

Frequency Agile Spectrum Access Technologies

Presentation to
FCC Workshop on Cognitive Radios
May 19, 2003

Mark McHenry
Shared Spectrum Company
703-761-2818
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Agenda

- Requirements
- Spectrum occupancy characteristics
  - Significant amount of "low hanging fruit"
- Spectrum access methods
  - Listen-Before Talk
    - "TDMA" spectrum
    - Broadcast spectrum
  - Probe
  - Geo-location/database

Frequency Agile Radio Requirements

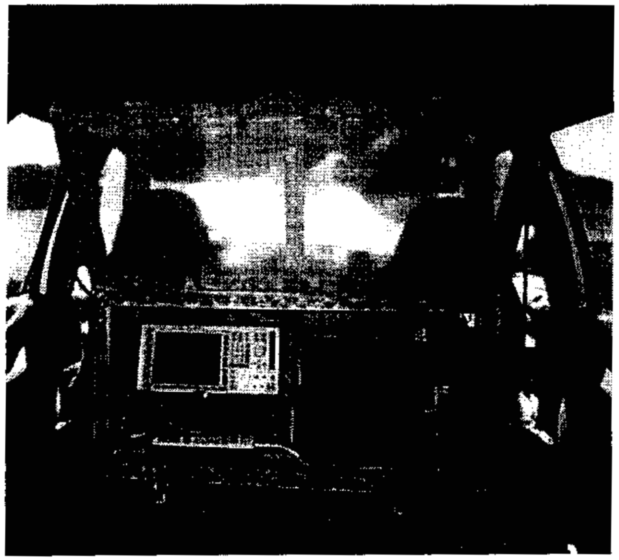
- Create insignificant interference
  - Secondary operation with minimal requirement for coordination with primary system licensees
  - Unlicensed with equipment certifications on a system basis to assure avoidance of interference
- Operate in multiple bands
  - Assured capacity
- Offer cost/capacity/link range/deployment benefits
  - Access more (5 X?) spectrum than any current system
  - Operate in VHF/UHF TV band
  - Rapid spectrum agreements for itinerate use

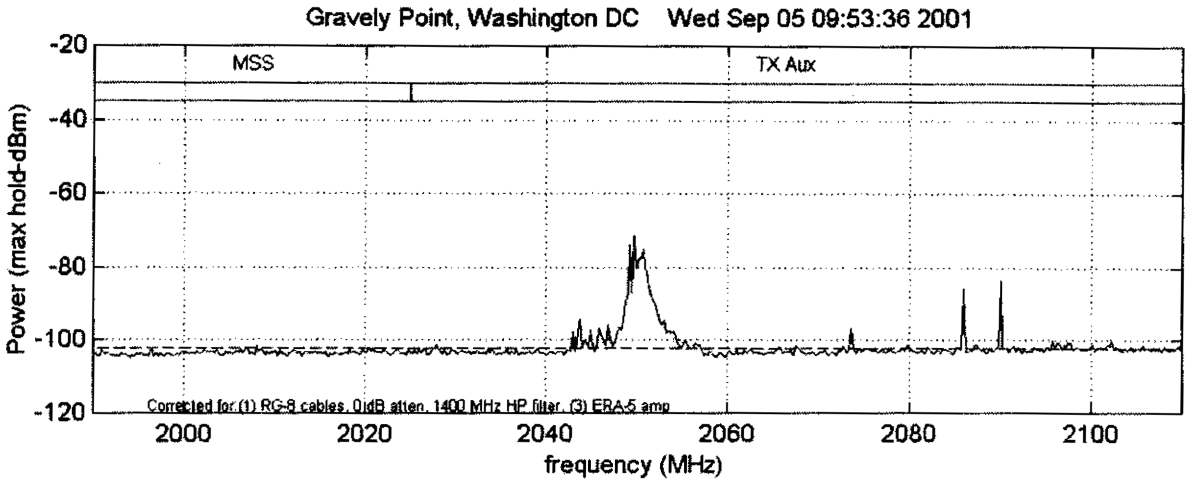
Spectrum Occupancy Is Low

- "In many bands, spectrum access is a more significant problem than physical scarcity of spectrum, in large part due to legacy command-and-control regulation that limits the ability of potential spectrum users to obtain such access."[1]
- Shared Spectrum's measurements indicate
  - Many bands have no detectable occupancy
  - Some bands have low occupancy
  - Some bands have high occupancy

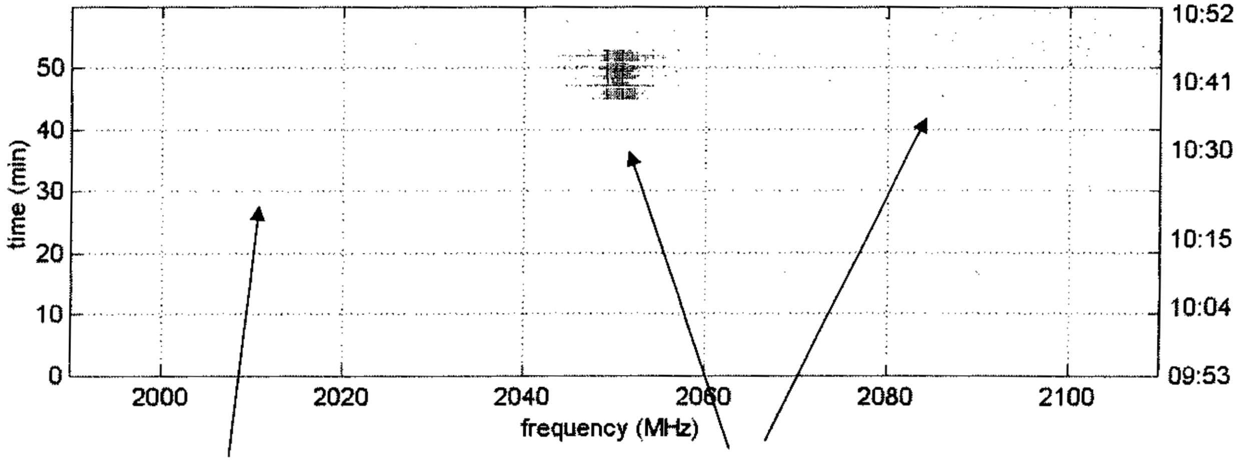
Note 1: FCC Spectrum Policy Task Force Report, page 3

Typical Spectrum Occupancy Measurement





FCC should conduct and publish spectrum occupancy measurements to identify low occupancy bands



No signals

Medium and short duration signals

Initially Harvest the Low Hanging Fruit

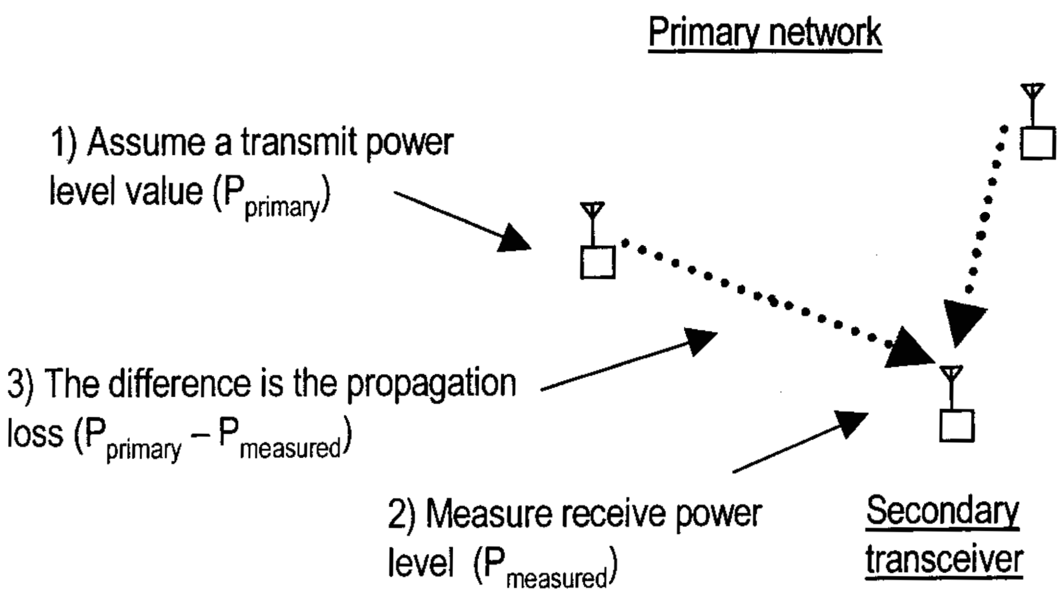
- Measurements show a large quantity of long duration, large area spectrum holes
- "Simple" spectrum access methods are sufficient
  - Minimal coordination between transceivers
  - Moderate computational costs
- Later evolve algorithms to handle more complex situations
  - Short duration, small spectrum holes
  - Optimize frequency assignments for increased capacity

Agenda

- Requirements
- Spectrum occupancy characteristics
  - Significant amount of “low hanging fruit”
- Spectrum access methods
  - Listen-Before Talk
    - “TDMA” spectrum
    - Broadcast spectrum
  - Probe
  - Geo-location/database

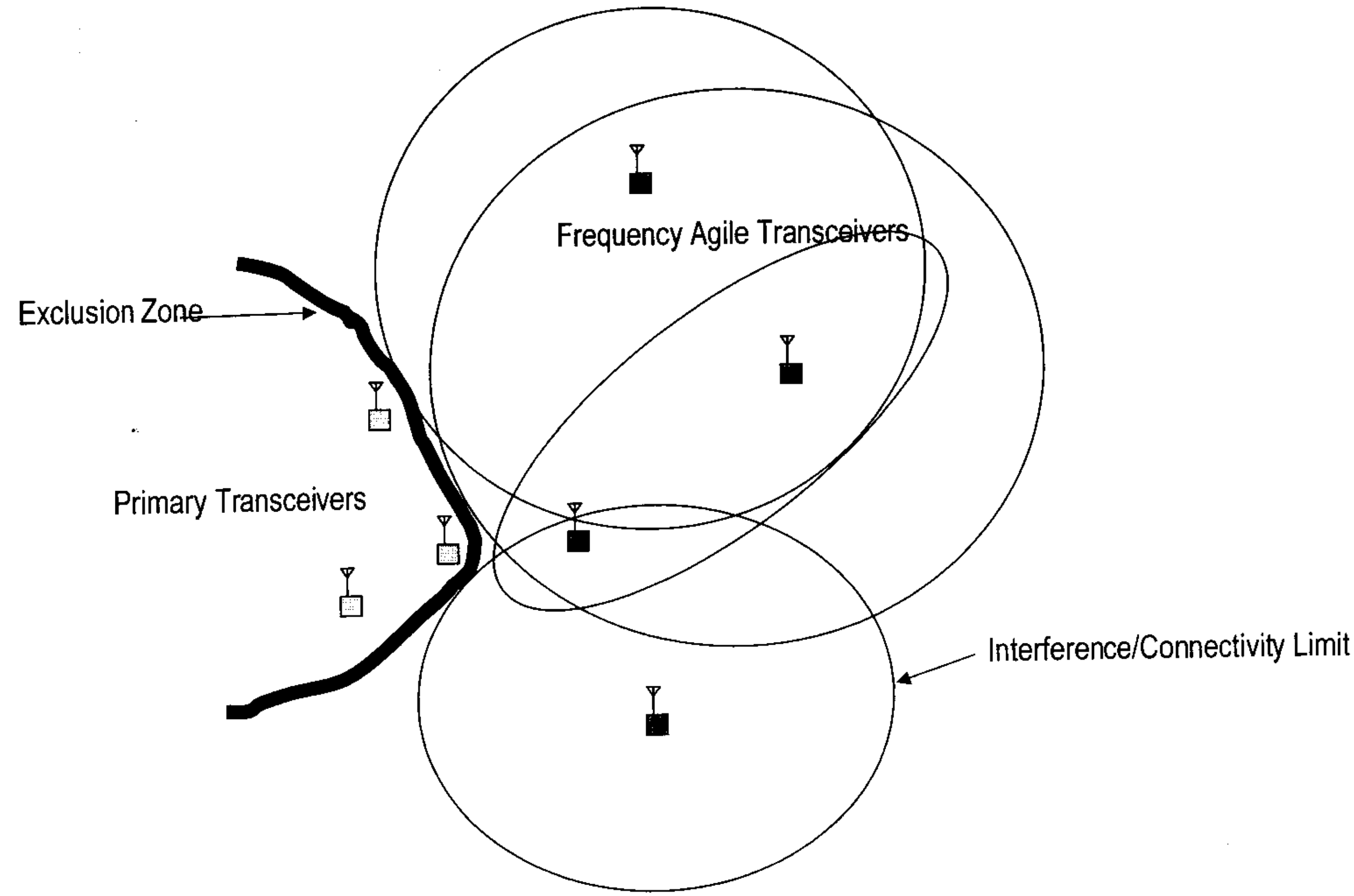
Adaptive, Receive-Only Spectrum Access Method

$$P_{max\ TX} = P_{allowable\ interference} + P_{primary} - P_{measured}$$



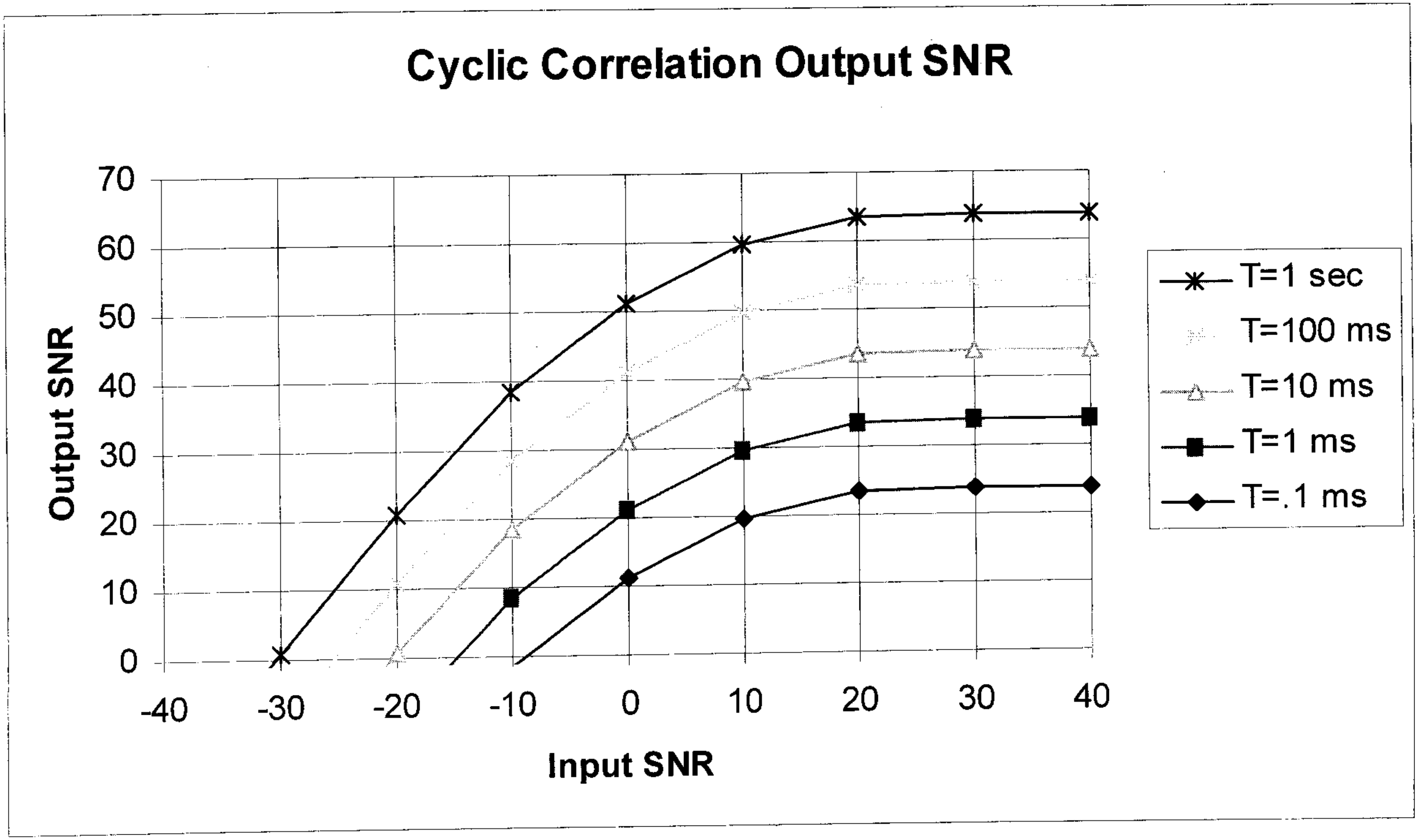
- $P_{max\ TX} = 10*\log10(k * T * B) + P_{Primary} - P_{measured}$ - Margin
  - Margin = 10 to 20 dB, required for cummulative effects, rapid propagation changes, false alarm minimization
  - T – Interference Noise Temperature, in K
  - B = signal bandwidth, in Hz

Frequency Agile Coverage "Morphs" To Fit Primary Users

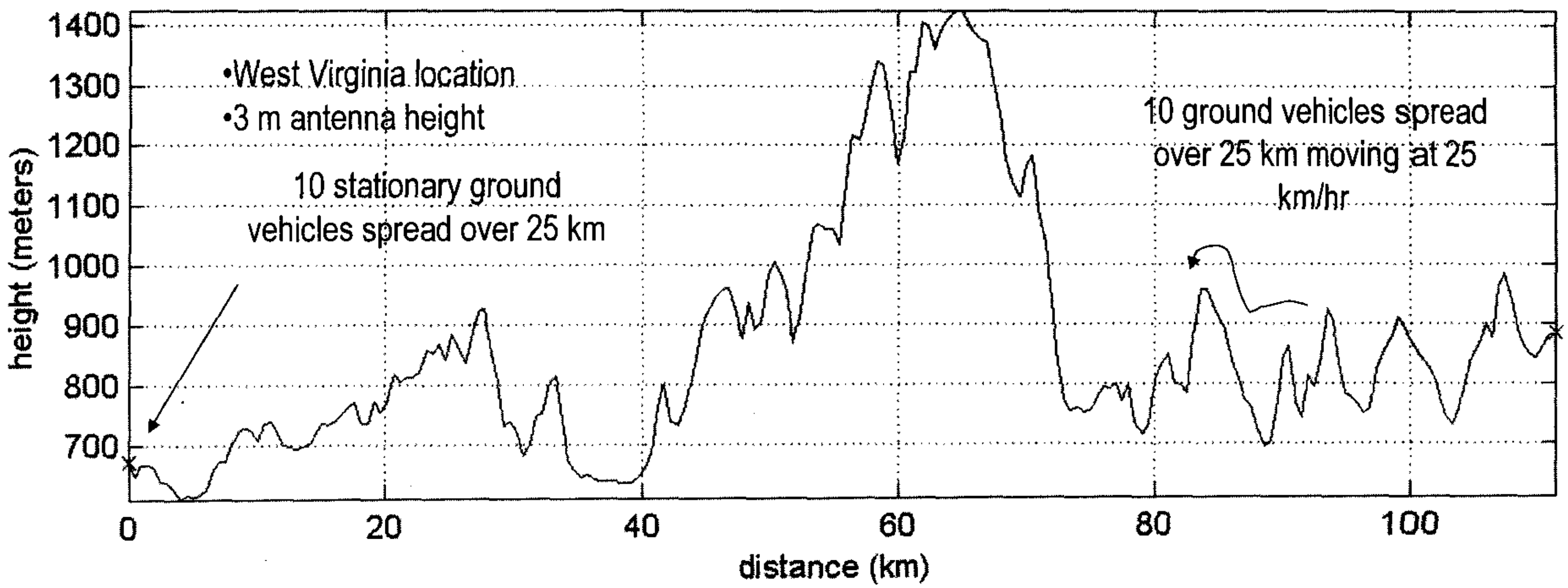


Hidden-node problem overcome by each Frequency Agile transceiver listening to all Primary users within range

High Sensitivity Receiver Performance

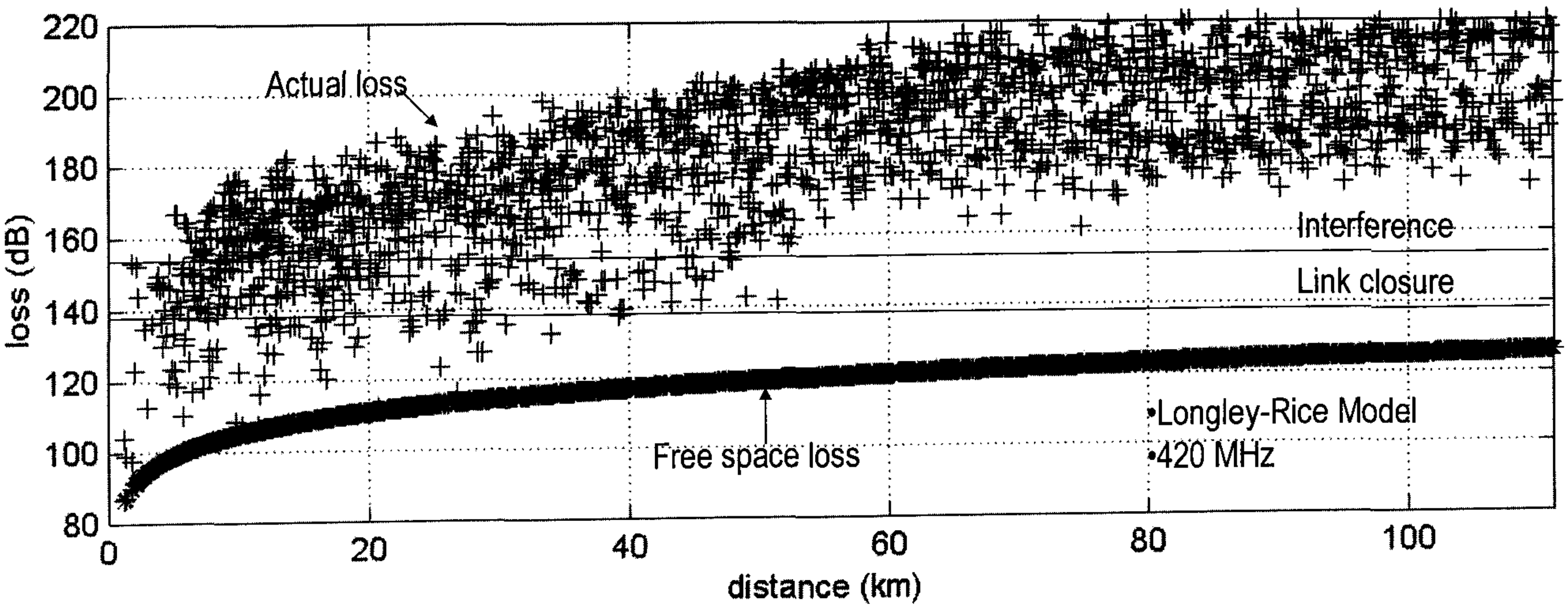


Simulation Example

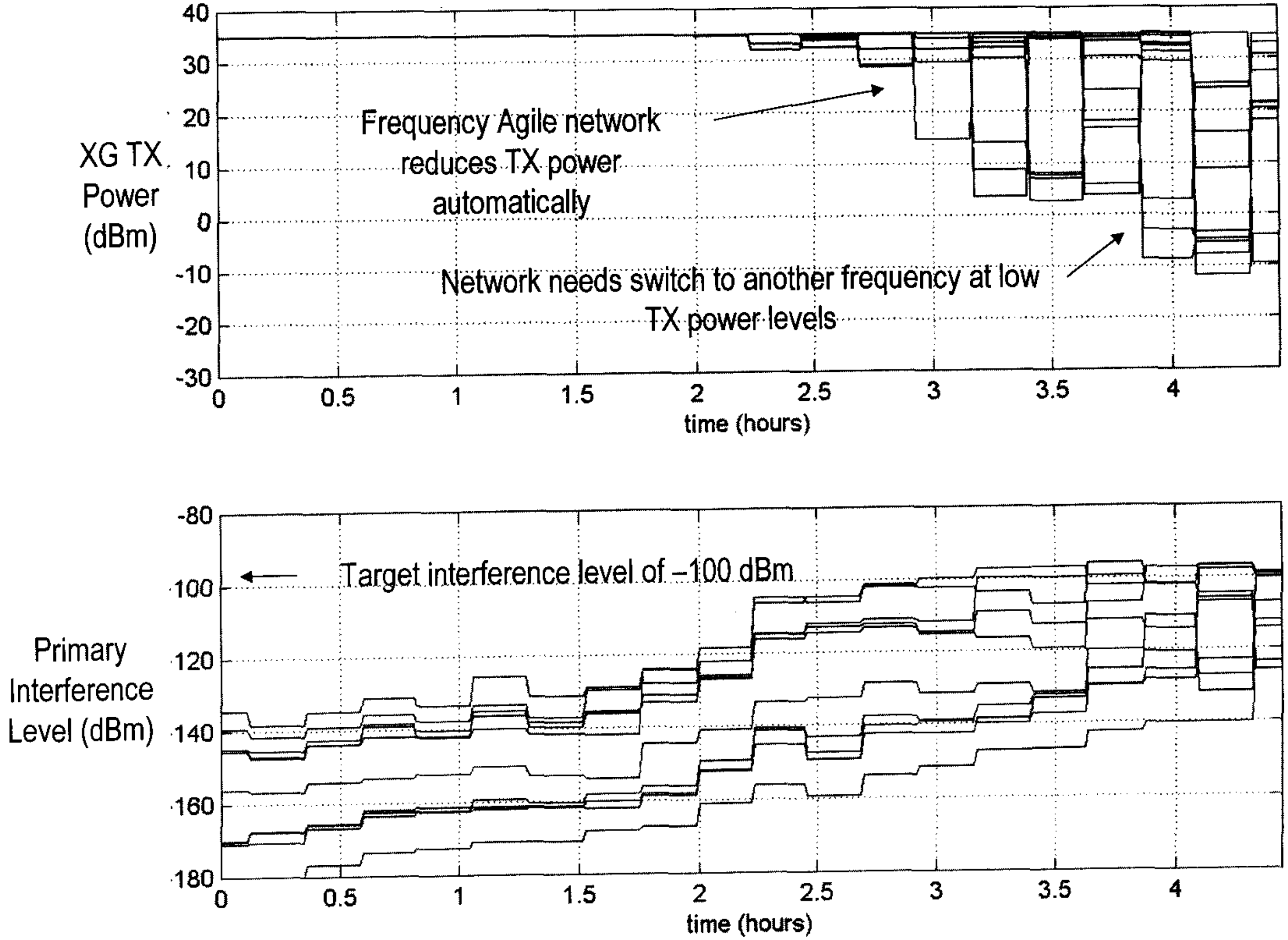


- Primary users are stationary
- XG users are mobile
- Omni-directional antennas
- 420 MHz signal frequency

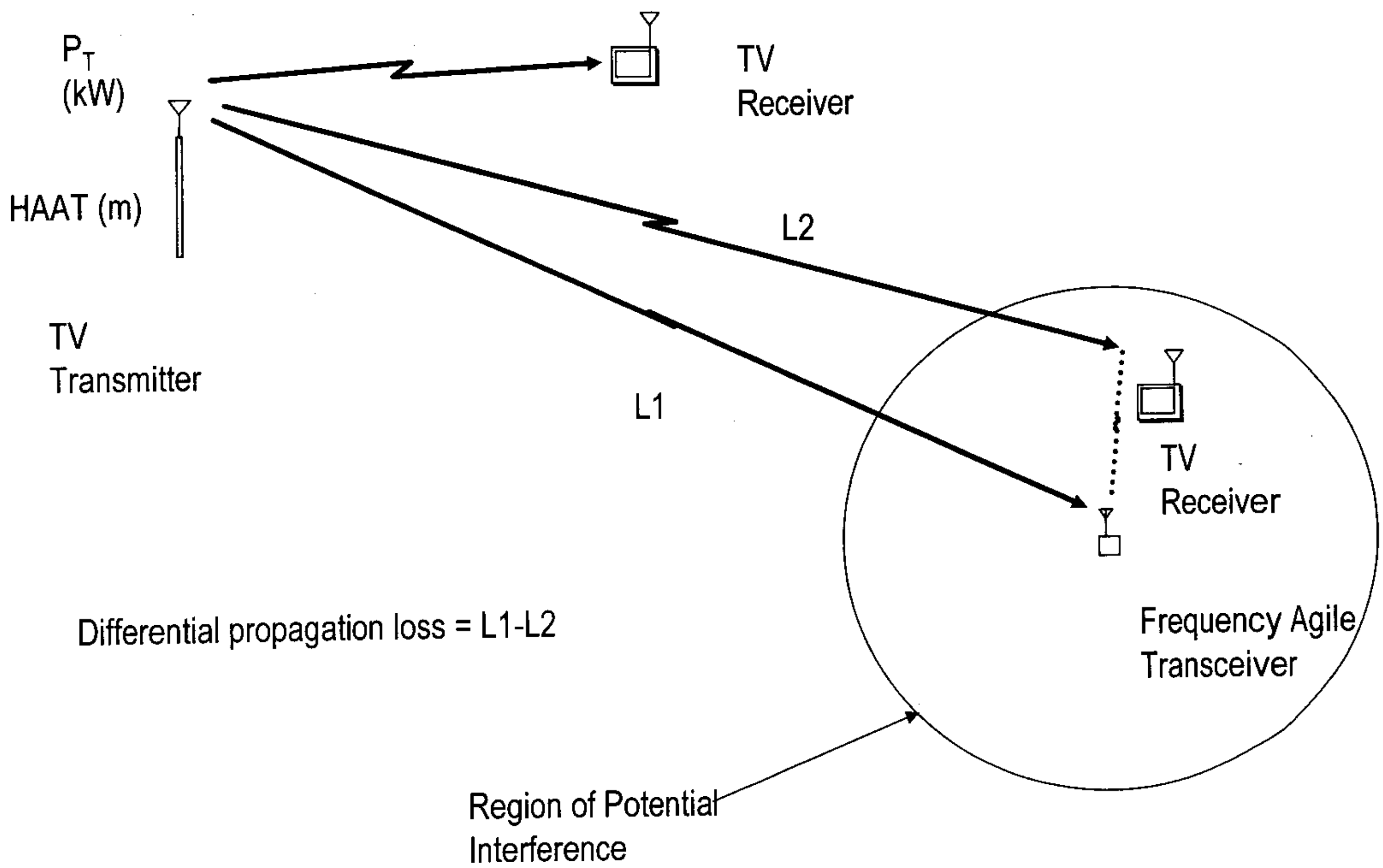
Propagation Losses



TX Power and Interference



Listen-Only Method in the Broadcast Bands



Transmit Power Rule

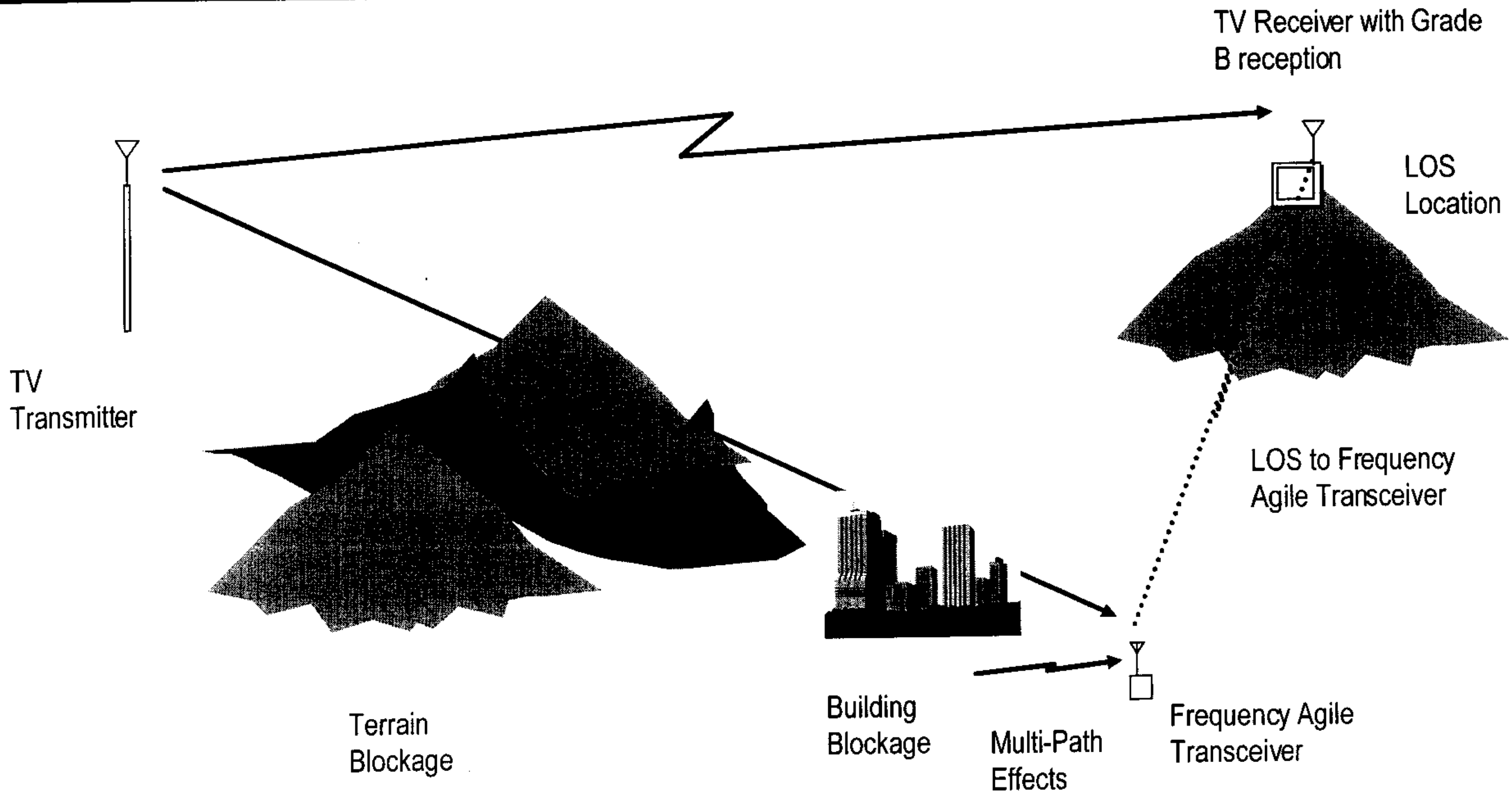
$P_{max\ TX}$ = Po if Primary signal is not detected

= Transmission prohibited if Primary signal is detected

where, $P_{max\ TX}$ = Frequency Agile transmitter power level, in dBm

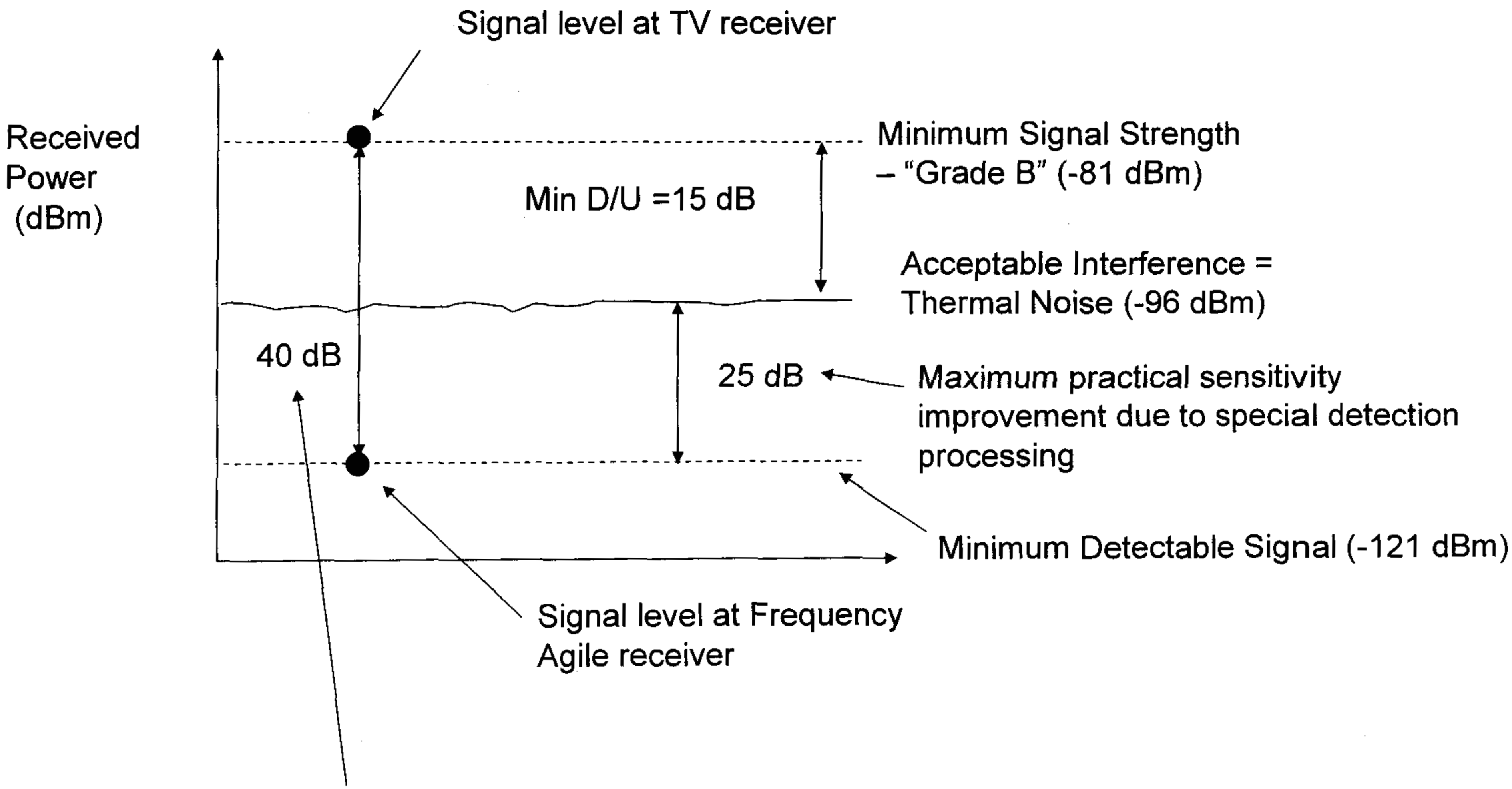
Po = specified power value, in dBm

Minimal Interference



- Joint probability of three conditions
  - Agile Receiver doesn't detect TV signal
  - Primary user receives TV signal
  - D/U < 15 dB

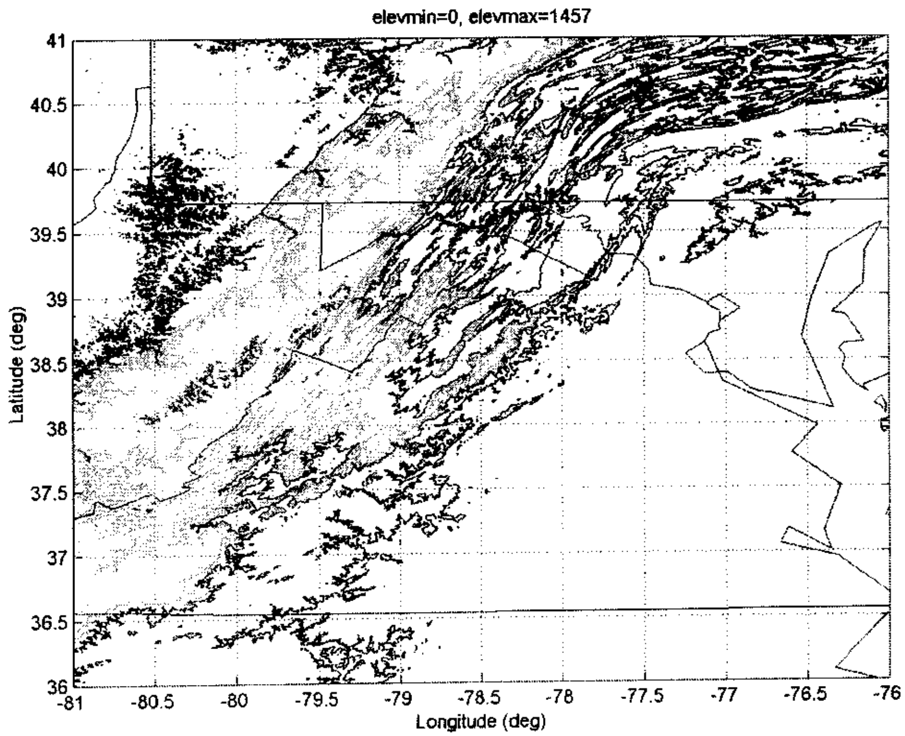
Maximum Differential Propagation Value

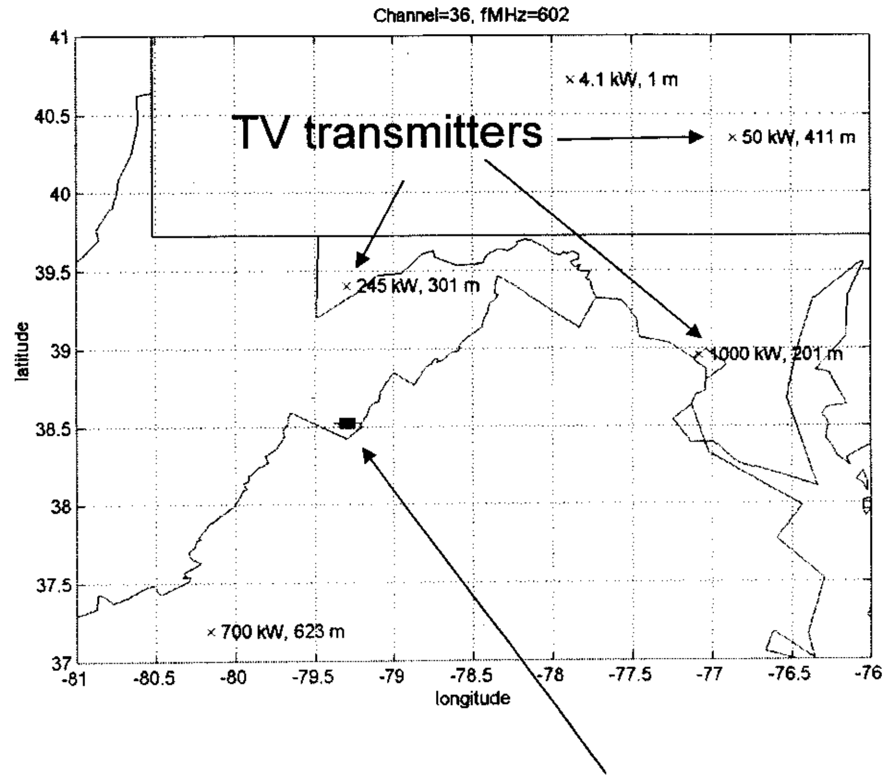


Maximum differential propagation value = 40 dB

Simulation of Differential Propagation

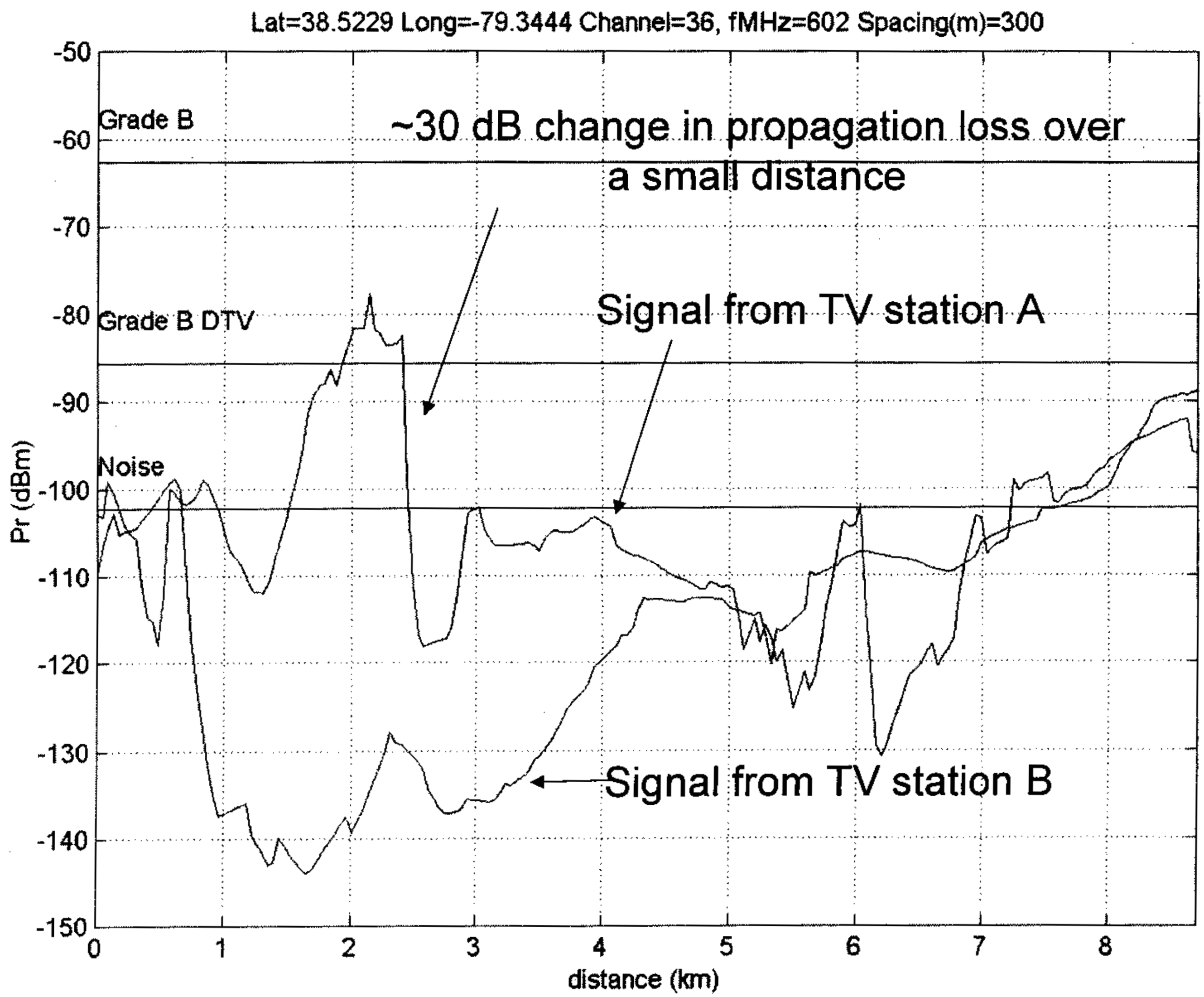
Scenario – Mid-Atlantic Region
Elevation contours





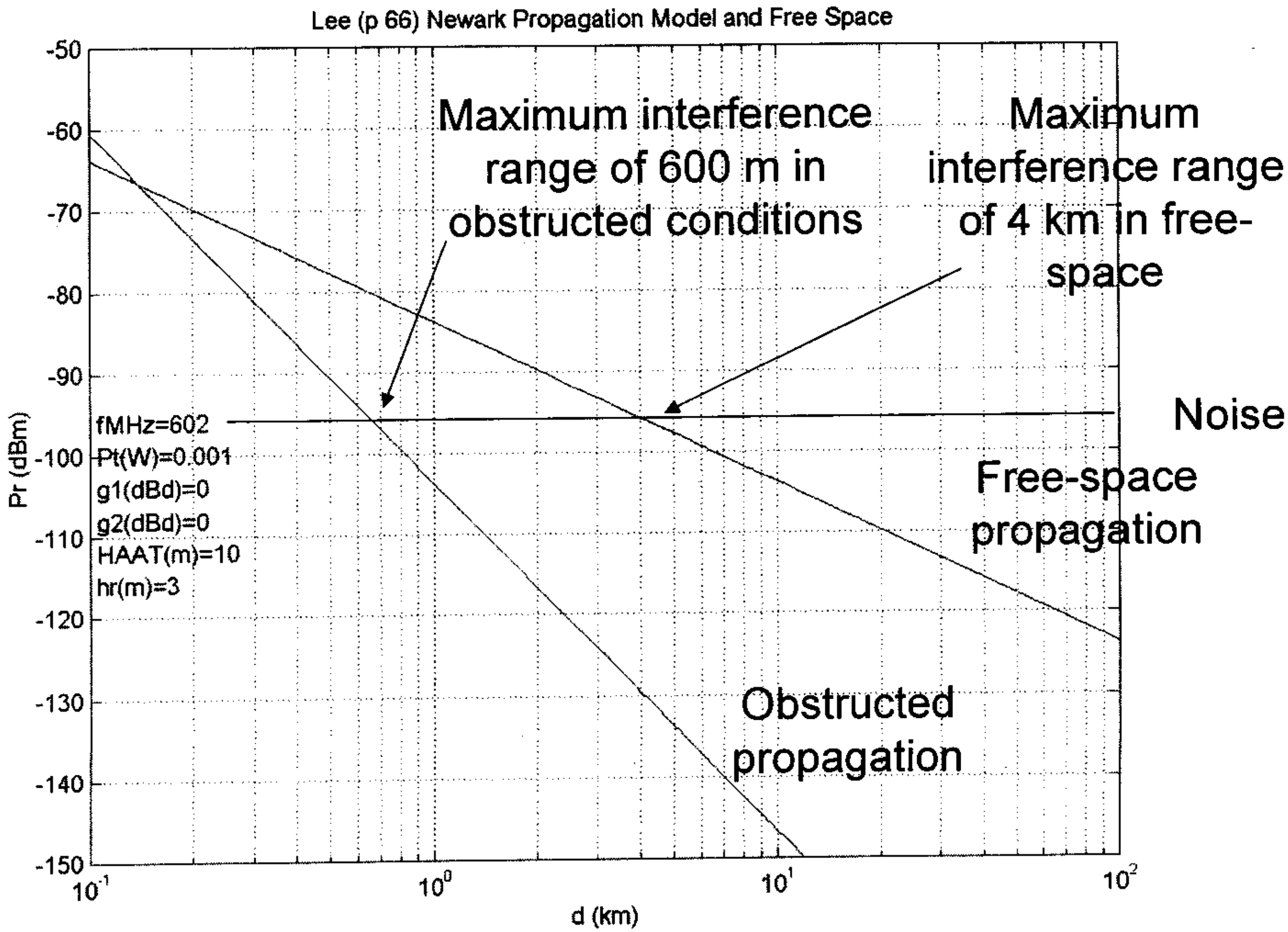
Test reception points along a ~ 8 km path

Large Change in Propagation Loss over a Short Distance is Rare

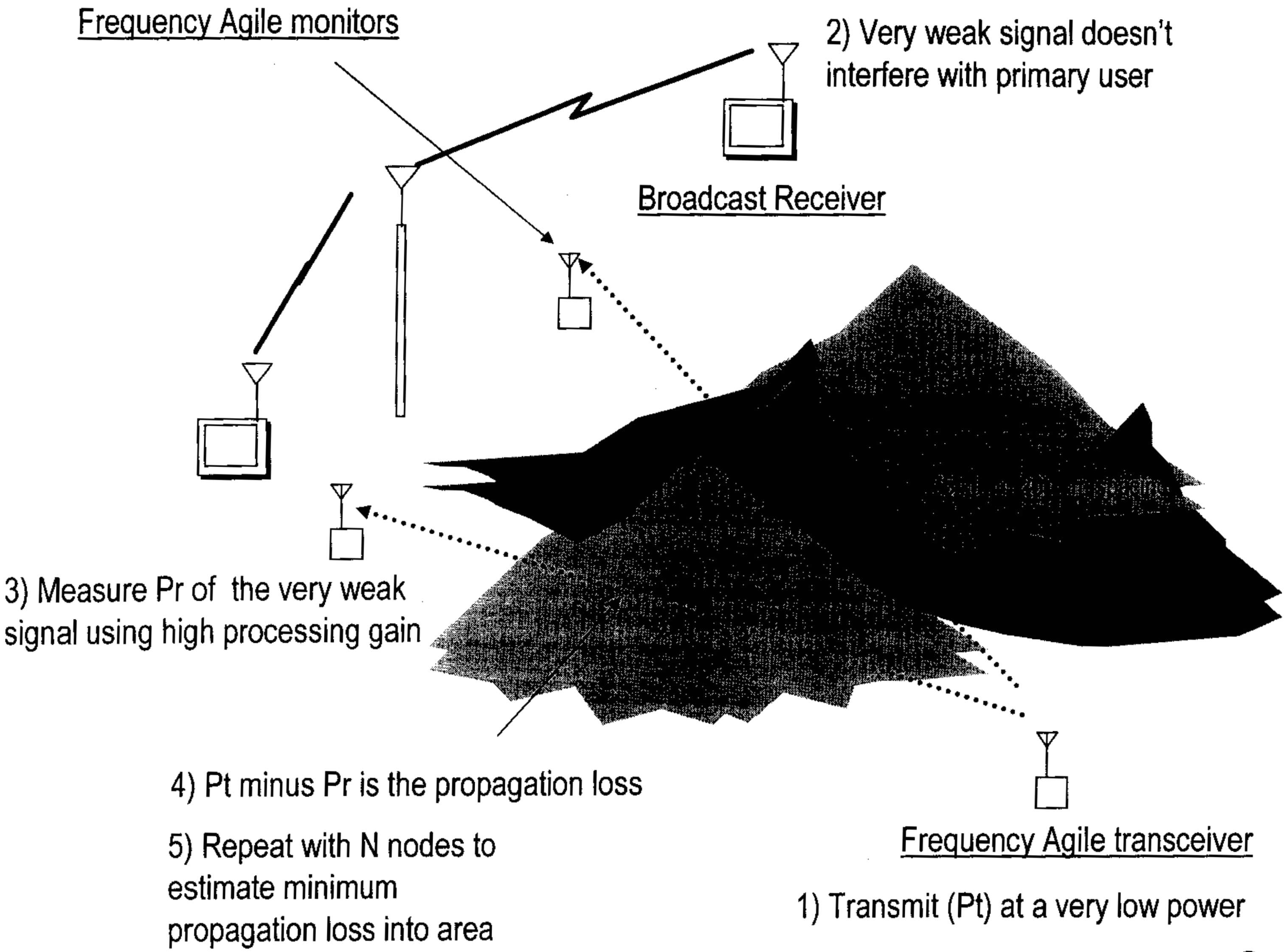


Low Power Transmitters Have a Small Interference Range

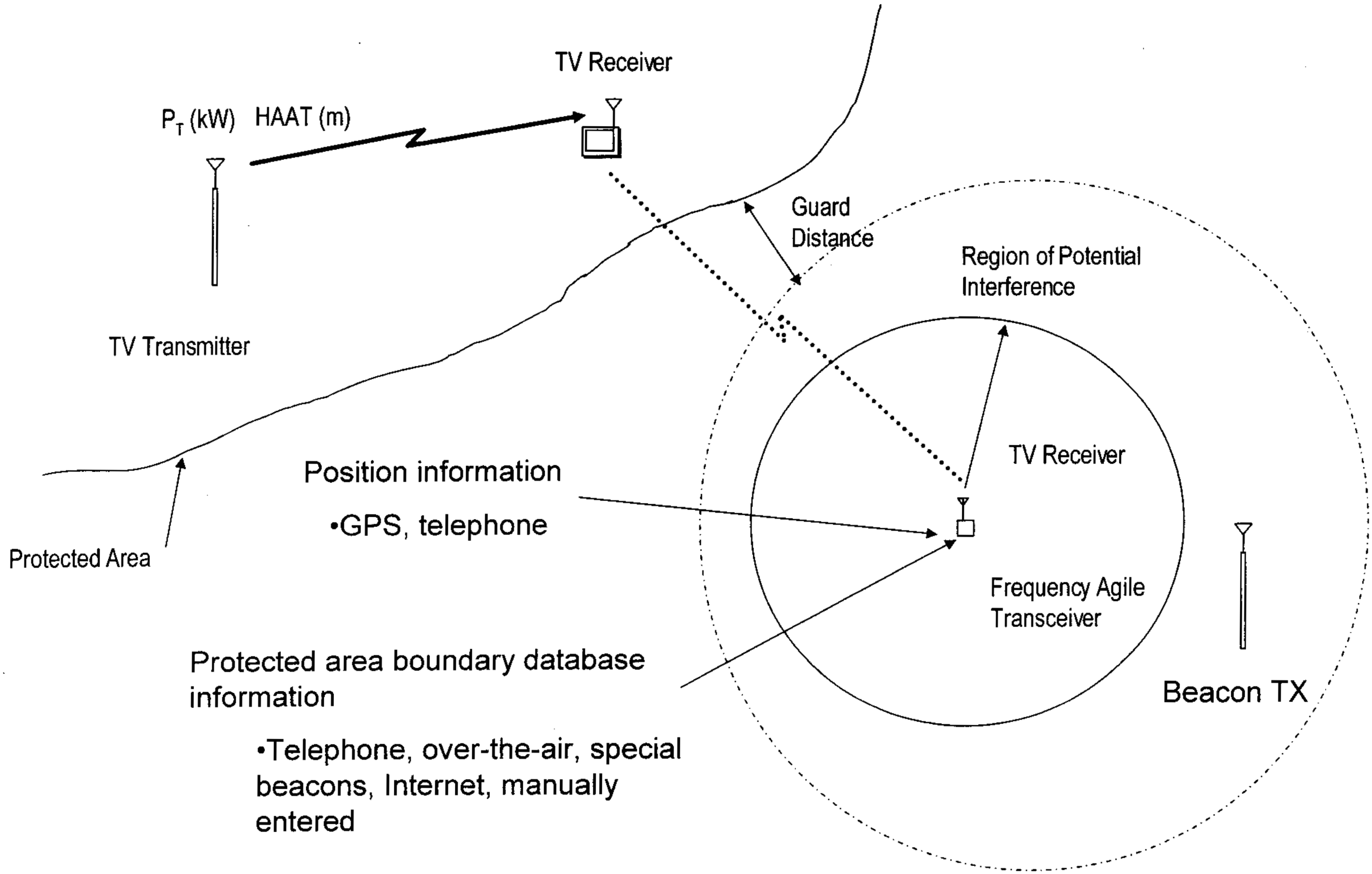
1 mW transmit power



Spectrum Probing Method



Geo-Location Method



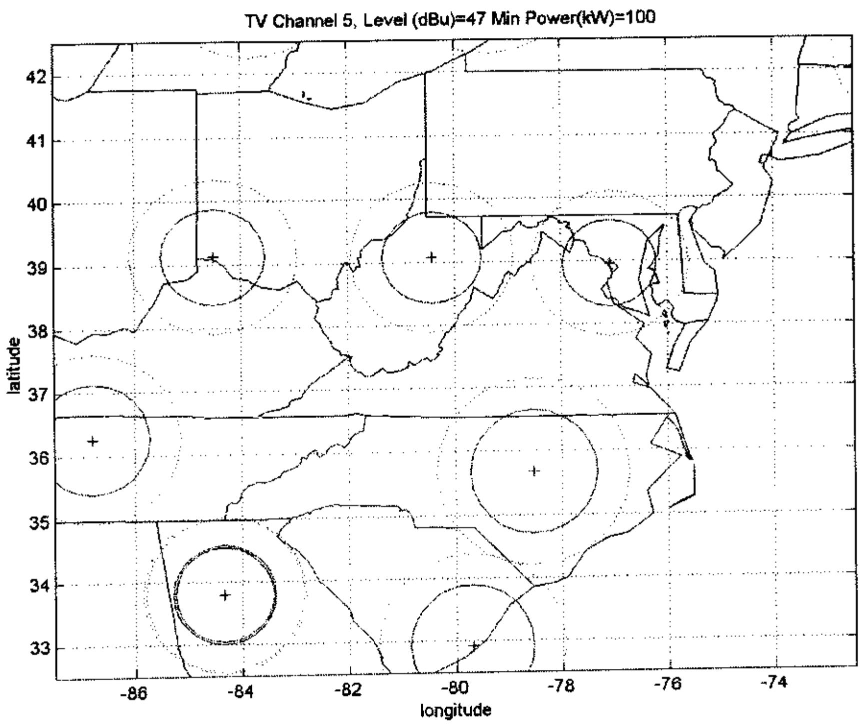
Position information

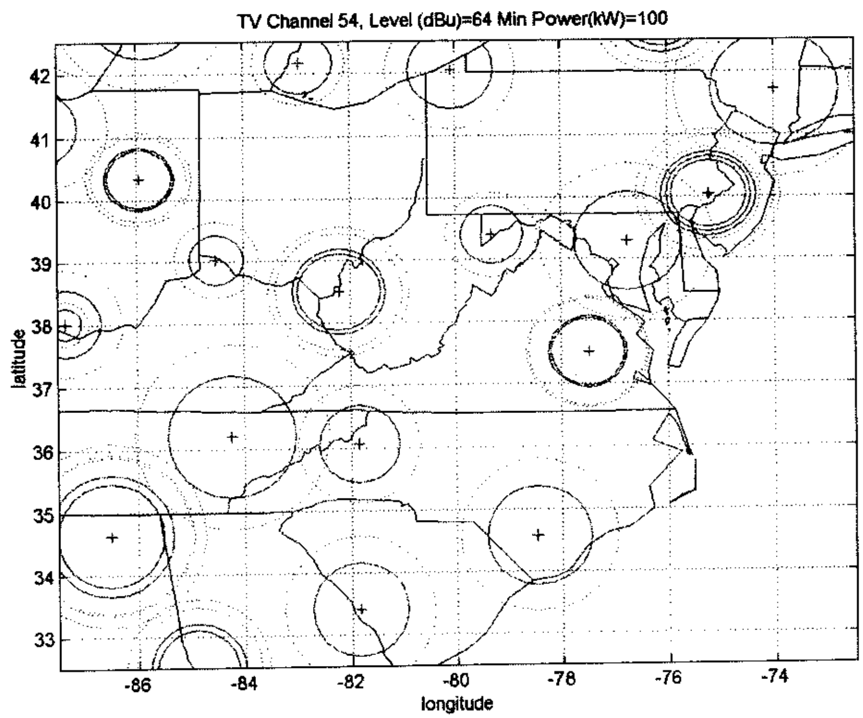
•GPS, telephone

Protected area boundary database information

•Telephone, over-the-air, special beacons, Internet, manually entered

Significant "White Space" Between TV Coverage Areas

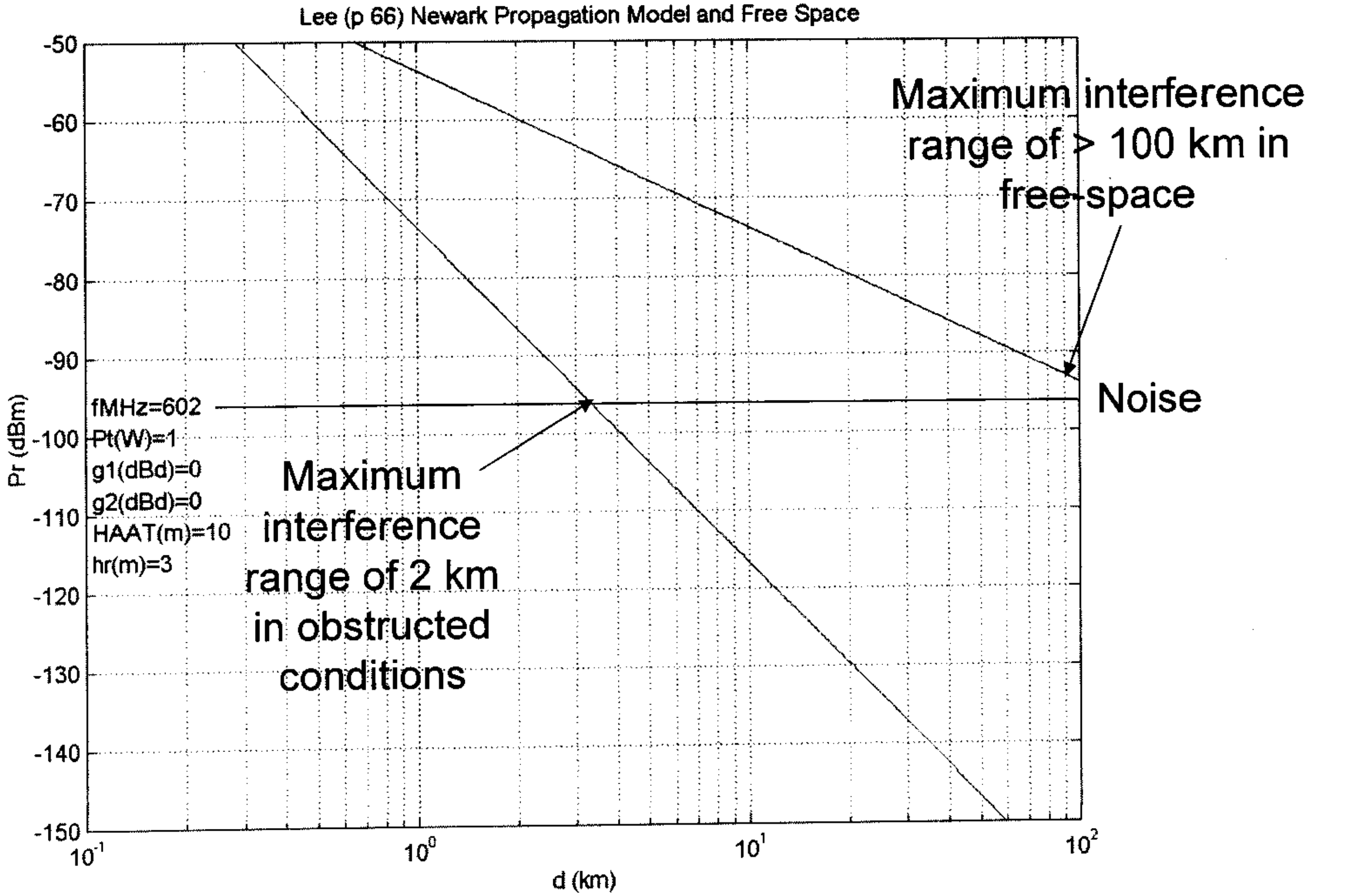




Grade B 50% and 90% contours
Channel 5 and channel 54

How Large A Guard Distance?

1 W transmit power



Large guard distances reduce spectrum harvest

TV bands: 100 km is too large >> Limit TX power to mW's

Other bands: Max TX power ?

Summary

- Multiple, robust spectrum access methods
  - Listen-Before Talk
    - "TD MA" spectrum
    - Bro adcast spectrum
  - Geo-location/database
- FCC should conduct and publish spectrum occupancy measurements
  - Many spectrum holes are large and have long duration
- FCC should allow experimental interactive operations
  - All access methods including Probe
  - TV and other bands