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A Harmful Interference Model for White Space Radios

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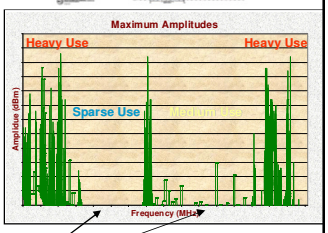
The Idea

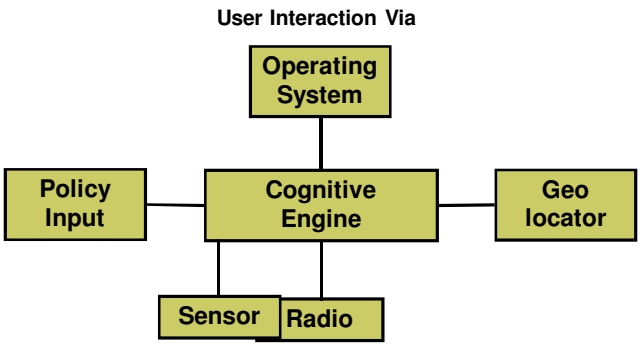
- The spectrum is fully allocated.

- Urban measurements:
  - > 75% never used
  - > 90% unused on average
  - Rural areas - even more



- Cognitive Radio:
  - Avoid Licensed users
  - Communicate in "white spaces"

Cognitive vs. Traditional Radios



A CR does more than a traditional radio

Cognitive Radio Review: Channel Avoidance Strategies

- Locate Unlicensed Device, check Database
- Detect Licensed Devices
- Licensed Device Beacons

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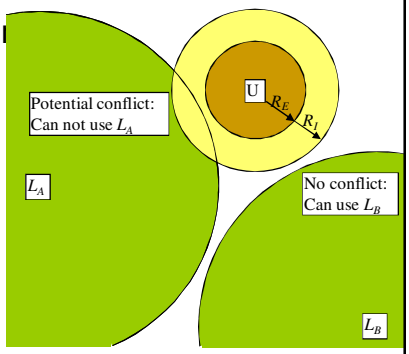
Locate Licensed Device, Database

- Positioning can be sloppy
  - As long as can bound error
  - 100km OK in rural areas



- Proactive Database

Internet?

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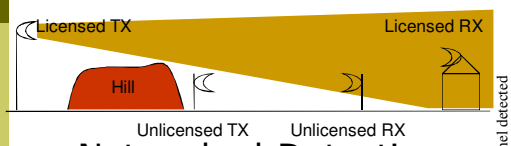
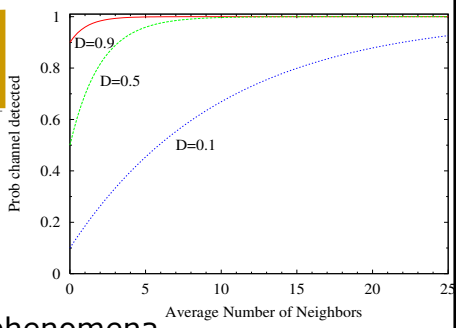
Detect Licensed Devices

- Hidden Terminal Problem





- Networked Detection
  - Much more reliable
- Receiver Detection
  - Interference is receiver phenomena
  - Requires help from the receiver

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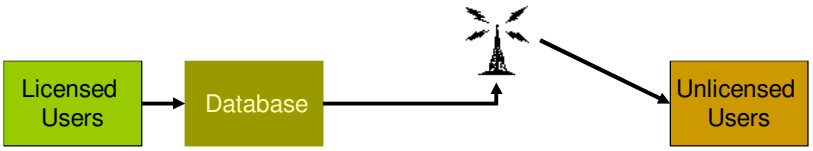
Licensed Device Beacons

- Per transmitter/receiver is laborious
- Area Beacons:
  - Combine best of Database and Beacons



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Avoidance Summary

Method	Accurately:		Requires:				Appropriate for:		Cost Burden on:		
	Avoids Interference	Exploits Whitespace	Constant Monitoring	Positioning	Standard	BW	High Power	Low Power	Unlic.	Lic. Trans.	Lic. Rec.
Database	X	X		X	X		X			X	
Detecting Transmitters	X		X				X		X		
Transmitter Beacons	X		X		X		X	X	X	X	
Area Beacons	X	X		X	X	X	X	X		X	
Unlicensed Signaling	X		X			X	X	X	X		
Receiver Beacons	X	X	X		X		X	X	X		X

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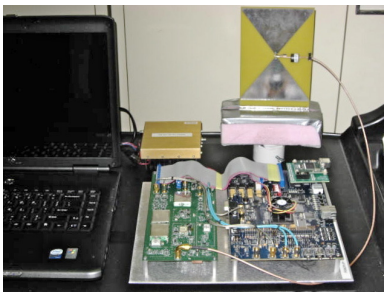
The Problem

- Technically functional radio



Detects primary users

Correctly picks channel

- You can't turn just it on!

The "real world" challenges of CR

Licensed Service Providers	FCC 04-186 NPRM Unlicensed Operation in the TV Broadcast Bands	CR Device Manufacturers
 These rules will degrade my service! Any unlicensed use can interfere	**Regulator**  This will create more problems then it will solve	 How do we test our equipment? Should I invest R&D in this market?
	CR Operators What are the risks with this technology	

NSF, Brown, et al. (2004) Spectrum Management for Spectrum Plenty

A Harmful Interference Framework: The Idea

- Define interference up front:
  - How it is measured
  - By who
  - What levels constitute “harmful”
  - What to do if it is harmful
- Define so that:
  - Licensed users have sufficient protection
  - Unlicensed users/manufacturers have assurances
  - Regulators solve problem once a priori

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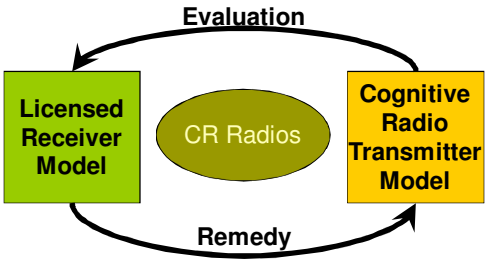
Measurement Scenario



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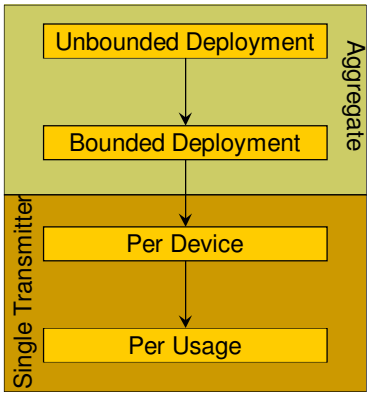
Unlicensed Transmitter Model



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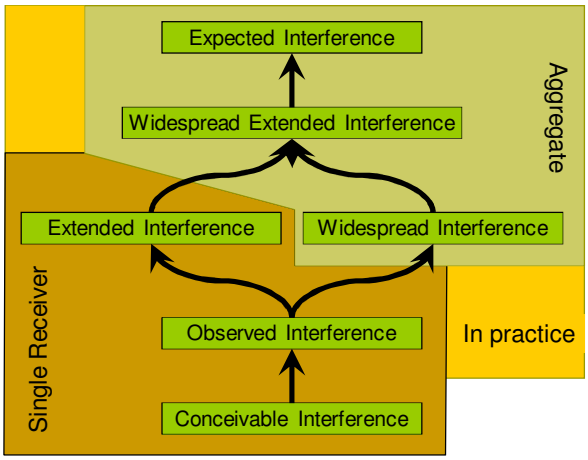
Licensed Receiver Model



More Detail on this Later

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Evaluation

- Who evaluates
  - Licensee
  - Licensed Receiver User
  - Unlicensed Device Manufacturer
  - Unlicensed User
  - Regulator
- How Evaluates
  - What conditions
  - What parameters

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Remedy

- If harmful interference is found:
  - Turnoff offending transmitter(s)
  - Change Unlicensed Rules
    - Operation parameters (Software Defined Radios)
    - Definition of harmful interference
    - Allowed/Prohibited Usages
  - Change Licensed Rules

Remedy should be incorporated into rules

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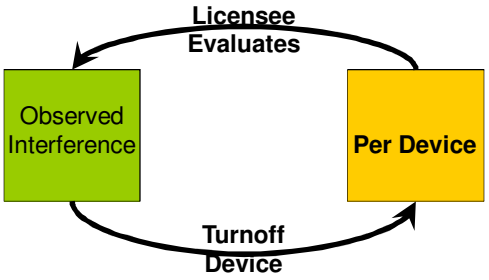
Example 1: Simplest Model



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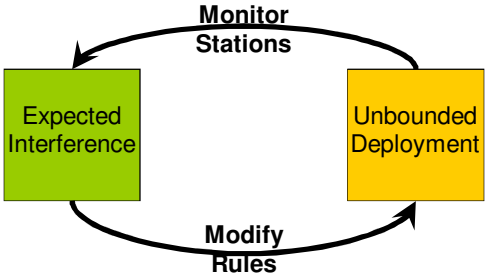
Example 2: Broadcast TV



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Example 2: Broadcast TV Monitor Stations

- Monitor TV outages at stations in coverage area

Case	TV Signal	Cable Signal	Line Power
Normal	Good	Good	Good
Interference Outage	Bad	Good	Good
Cable Outage	Good	Bad	Good
Broadcast Outage	Bad	Bad	Good
Power Outage	X	X	Bad

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Broadcasters: These rules will degrade my service!

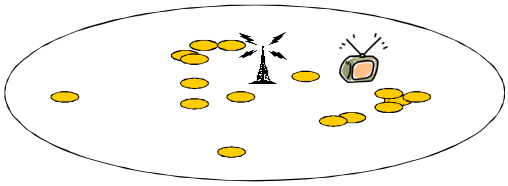
- What does TV suffer already?
  - DBS is 99.8% "extremely reliable"
  - TV is 90% at grade B contour
  - Utility power is 99.9%

- Already many Wireless Microphones

Can we achieve an expected
1 in 10,000 TV outage
in an unlimited unlicensed deployment?

Brown, "An Analysis of Licensed Channel Avoidance Strategies for Unlicensed Devices," *IEEE DySPAN* 2005

Radio Interference Model



$$F = r_{\min}^2 PCEG_{UL} G_L M N_{UL} / A$$

F = fraction of licensed devices suffering outage on average
r_{min} = worst case min separation between unlicensed and licensed devices
P = power control factor (< 1)
C = channel avoidance factor (< 1)
G = antenna gain factors (< 1)
M = model constants (~ 3)
N_{UL} = number of unlicensed devices
A = area of system

Helps Regulator

Sets"Cognitive" Requirement

Brown, "A Harmful Interference Model for Unlicensed Device Operation in Licensed Service Bands," *J. of Communication*, 2006

Channel Avoidance Reliability

- Set 1000 unlicensed devices/km^2
- For < 1 in 10,000 TV interference require
  - Low Power CR: 90% reliable
  - High Power CR: 99.99% reliable
    - These are reasonable.

But not to the broadcasters!

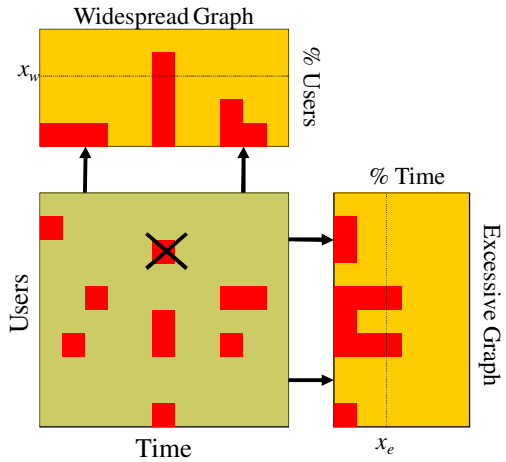
•Brown, "Enabling and Evaluating Unlicensed Operation in the TV Broadcast Bands," reply comments to FCC Docket No. 04-186, 2005.
•Kolodzy et al., "Technical Reply Comments," to Docket No. 04-18, 2005.
•Brown, "A Model for Analyzing Unlicensed Device Operation in Licensed Broadcast Service Bands," reply to NTIA Docket No. 06051 21 29-61 29-01, 2006.

Harmful Interference Model

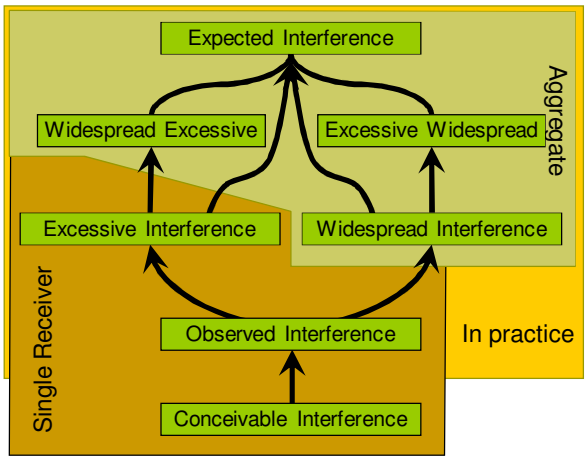
- Broadcasters: Conceivable Interference

Big Gap

- Expected Interference



Harmful Interference Taxonomy



Provides a common framework for HI

Berger, et al., "IEEE Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems," IEEE Standard, P1900.2-2008.

Example 3: Wireless Microphones

- In TV bands
- Hard-to-detect

- 500,000 sold
- Cognitive Radios will harm them!

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Example 3: Wireless Microphones

- No database exists
- No one is going to invest in beacons
- Detection is the only strategy

What can the CR do?
What can the "Licensed" devices do?

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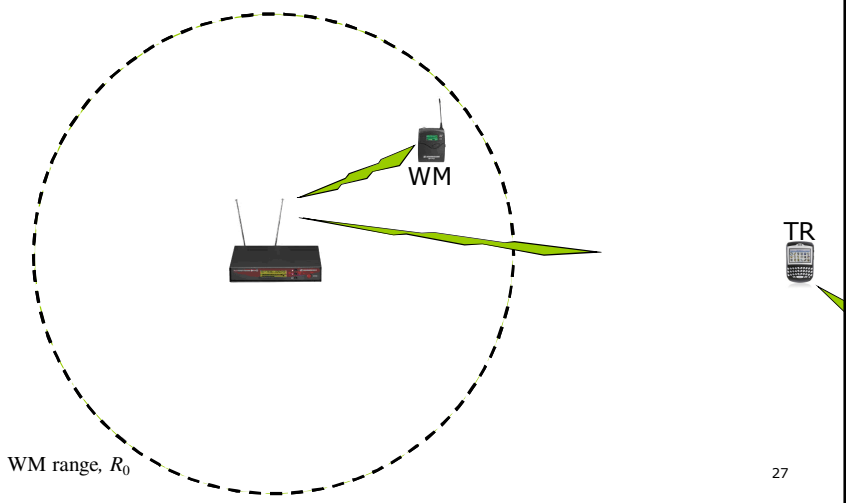
ingle Interferer Model:

Traditional Radio Interference



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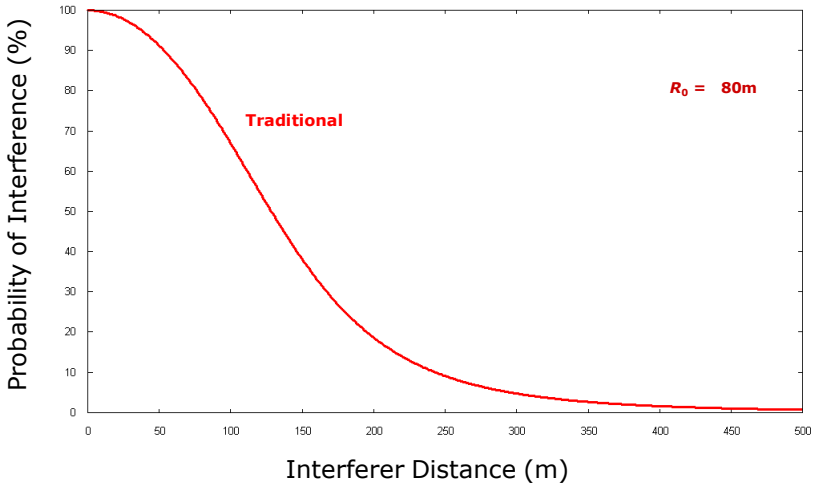
ingle Interferer Model:

Traditional Radio Interference



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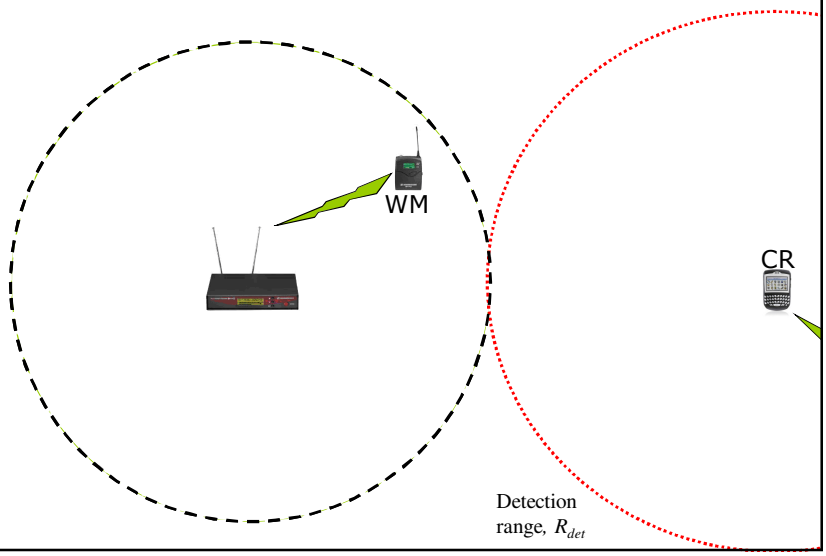
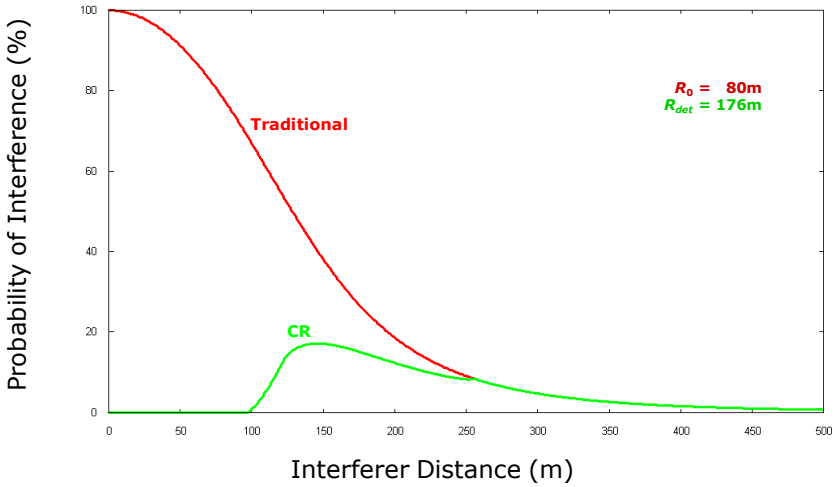
ingle Interferer Model:

Cognitive Radio Interference



ingle Interferer Model:

Cognitive Radio Interference



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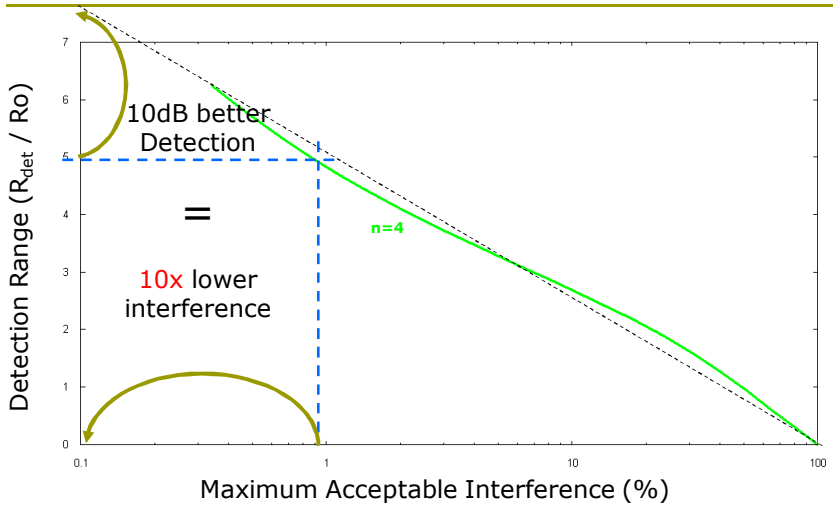
ingle Interferer Model:

Optimum Detection Range



For < 1% interference, detection range ≈ 5 times Ro

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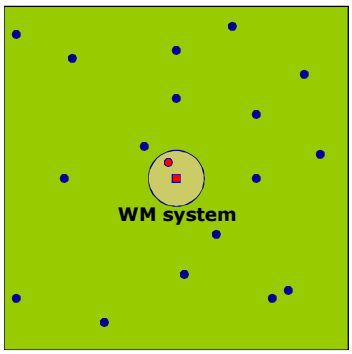
Multiple CR Model:

Multiple Cognitive Radios

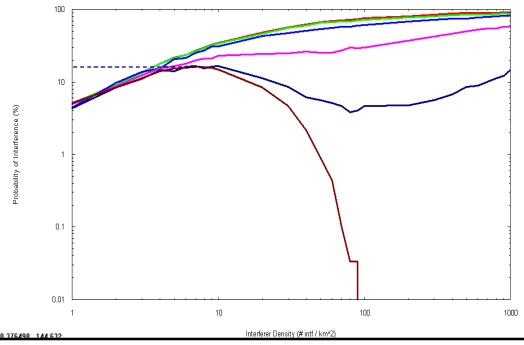
- So far:
  - Single Interferer
  - Worst-case location
- Now:
  - Multiple interferers
  - Spread randomly over area
  - Function of density

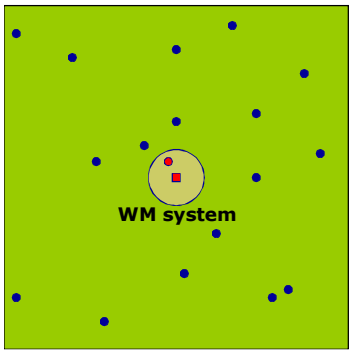


Multiple CR Model:

Cooperative Spectrum Sensing

- No Cooperation
- Partial Cooperation
- Full Cooperation





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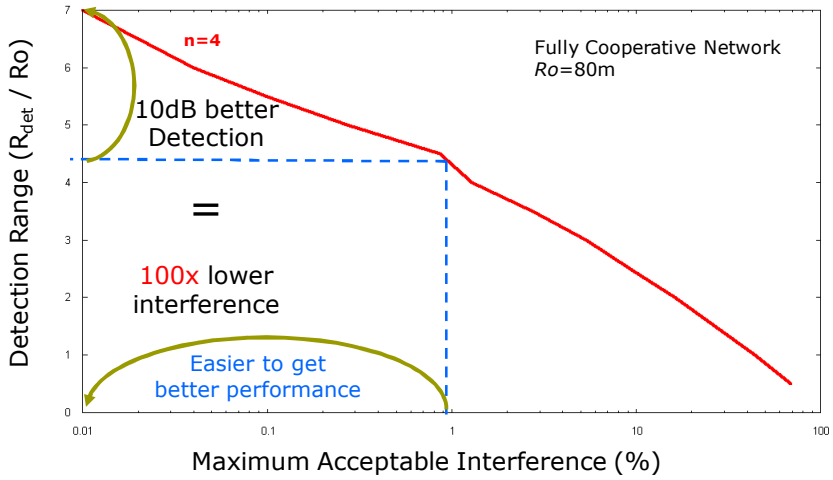
Multiple CR Model:

Detection Range of CR Devices

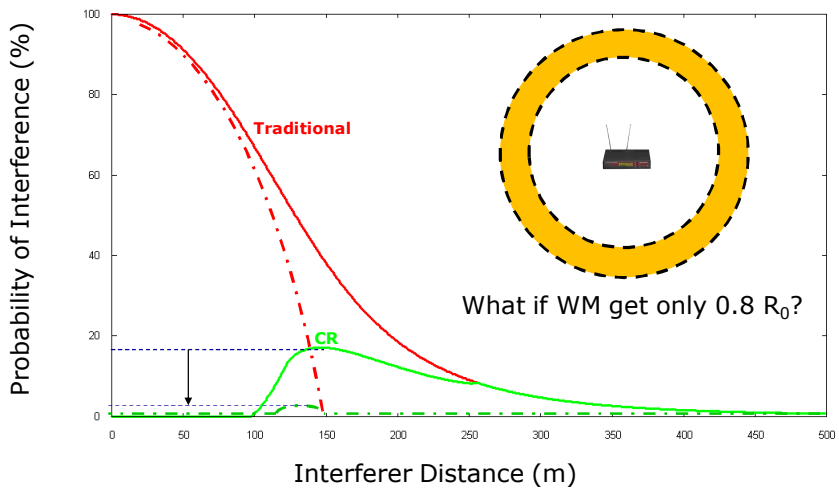


For interference < 1%, $R_{det} \approx 4.5\ Ro$, similar to single interferer analysis 34

Dhillon, Brown, "Models for Analyzing Cognitive Radio Interference to Wireless Microphones in TV Bands," *IEEE DySpAN* 2008.

ingle Interferer Model:

What if the Licensed user changes?



It's a two-way street.

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Conclusions

- Harmful Interference model should be considered up front
- Affords better protection to both incumbent and white spaces radio
- Many choices are possible.

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