

*Cognitive Radio  
24<sup>th</sup> August 2009*

*Mansoor Shafi  
Mansoor.Shafi@telecom.co.nz*



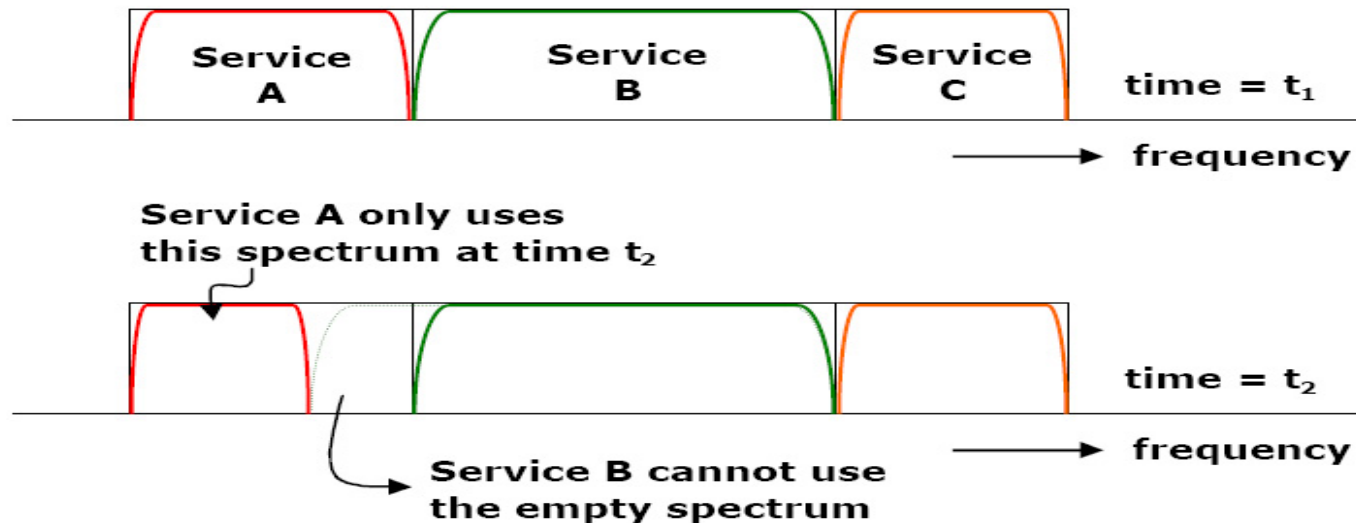
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# *What Is The Place for Cognitive Radio?*

*Mansoor Shafi  
Principal Advisor Wireless  
Telecom New Zealand Ltd*

# The Case for Cognitive Radio

- The Present regime is Command & Control.
- Divide Spectrum into applications
  - Radio Regulations
- Hands off for other applications even when the Spectrum is under utilised



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# *How do we do it New Zealand?*

- Local Implementation of the Radio Regulations
  - Management Rights
  - Licence rights
  - General User Licences
  - etc

## *We have a mixture of:*

- Command & Control
- Service & Technology neutrality
  - Effectively whatever you like approach.

# *But the Services & Technology neutral approach has problems*



Transmitters and Receivers cannot be adjacent.



## TDD UL

- At  $t=t_1$   
FDD Tx adjacent emission falls into TDD Mob Rx
- At  $t=t_2$   
FDD Base Tx interferes with TDD Base Rx
- TDD Mob Tx interferes with FDD Mob Rx

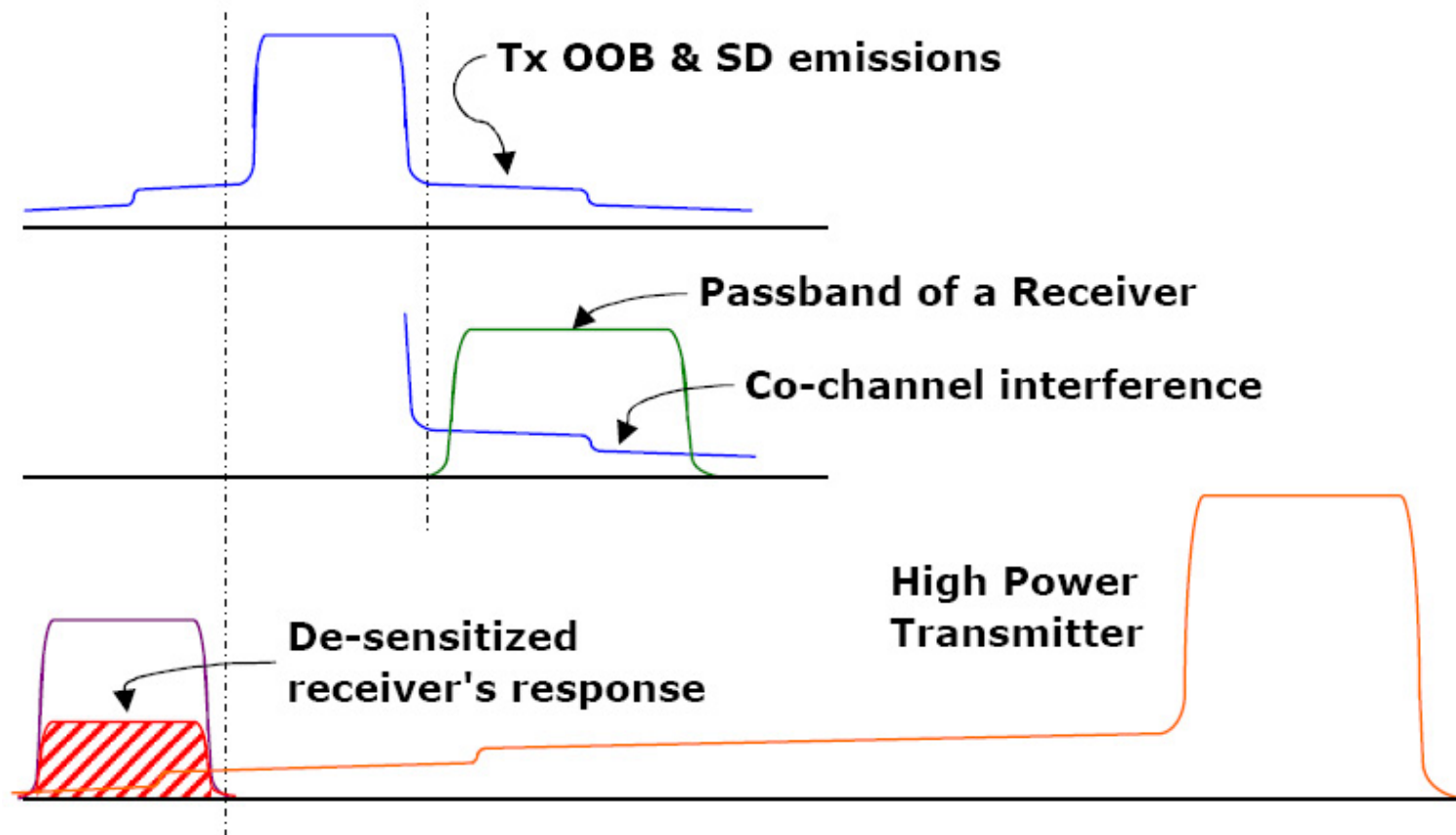
- We have experienced (A) in NZ, the time for (B) has yet to come.

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## *Whether it is PU or CR, handling of Interference is Crucial*

Interference may arise from:

- Tx out of band emissions falling into a Rx band
- Tx spurious domain emission falling into a Rx band
- Intermodulation (2A – B) products
- Receiver de-sensitisation due to a strong out of band interferer:
  - A 200 kW TV transmitter in an adjacent mobile receive band



These Interfering Scenarios are a facet of radio engineering and can still arise in CR systems.

*If you are blind then the presence or absence of light is not an issue ...*



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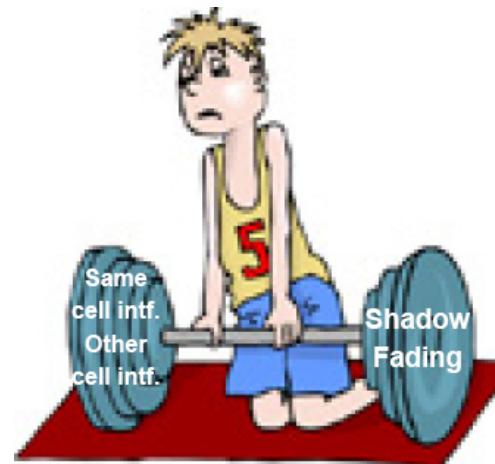
# *How Does Interference Impact Radio Systems?*

- If one is deaf, then even kW's of Interfering EIRP will not have an impact
- If one is very sensitive, then even a low power interferer is damaging

- Point to Point Radio systems have robust fade margins and are more tolerant of interference

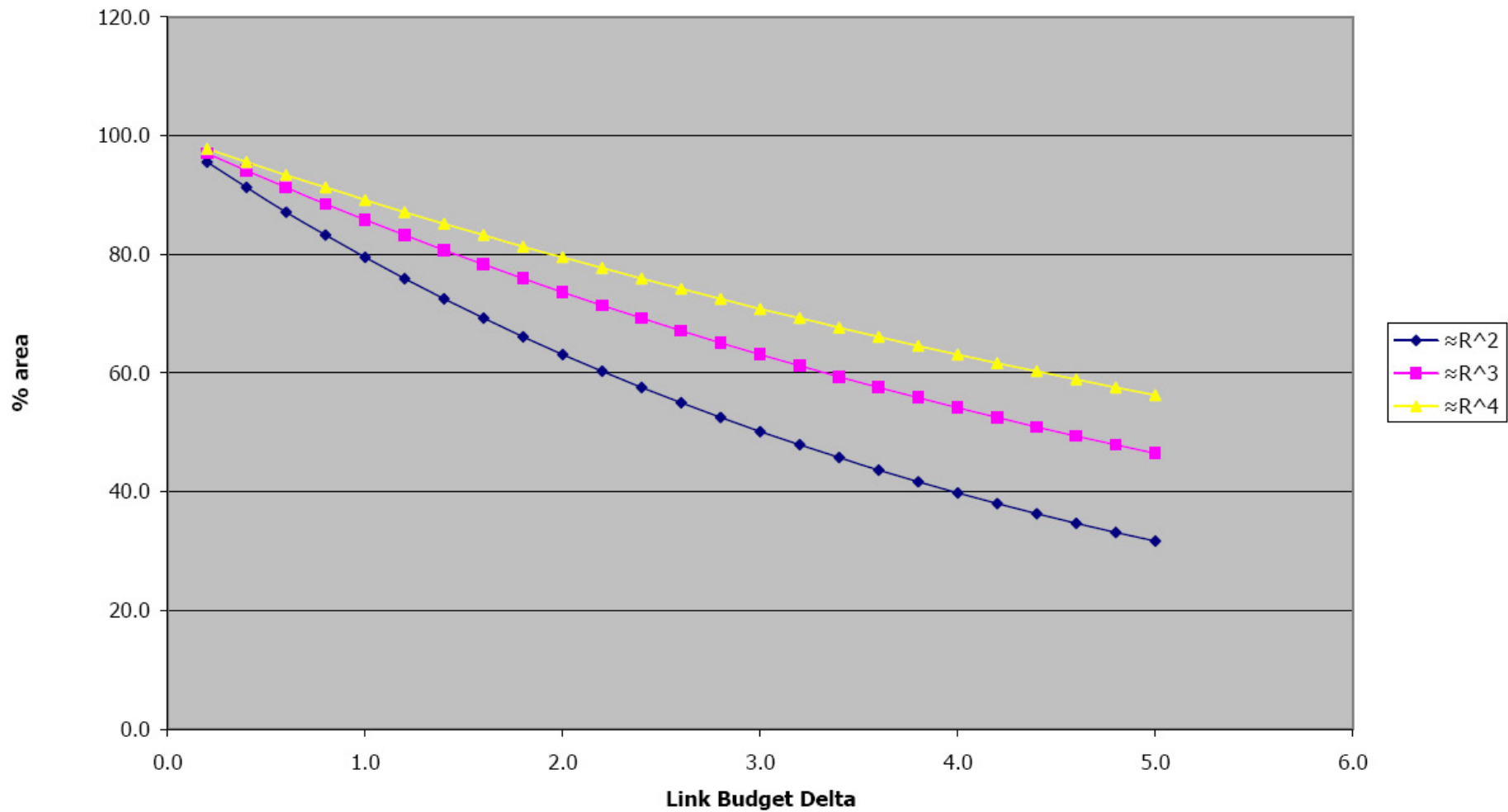


- Cellular radio systems are very sensitive to interference & cannot tolerate any other system interference



**CRs should not be introduced in Cellular bands!**

### Resultant coverage area with Link budget Penalisation



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# CR Network Paradigms

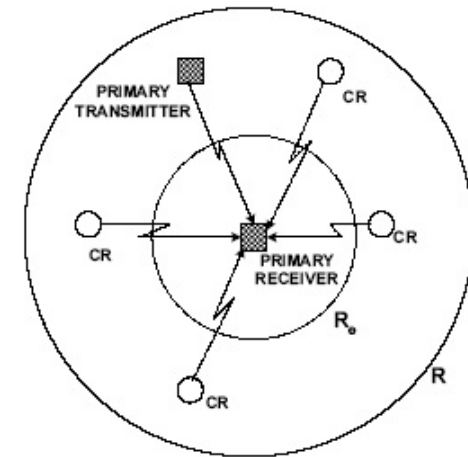
There are three main Paradigms:

- Underlay
  - CR knows the channel state information (CSI) to the Primary
  - CR transmits simultaneously as long as interference is below acceptable limit
  - Tx power of CR is limited by the interference constraint
- Overlay
  - CR knows the CSI to the primary and also knows the codebooks and message of Primary
  - CR transmits simultaneously and to offset interference to Primary, relays Part of Primary message
  - CR can transmit at any power

# CR Network Paradigms

- Interweave
  - CR knows the spectral holes in time & frequency
  - Simultaneous transmission is only done in case of false transmission
  - CR Tx power is limited by the range of spectrum hole sensing

**But - a real spectrum hole in frequency is hard to find, there may still be adjacent channel interference issues!**

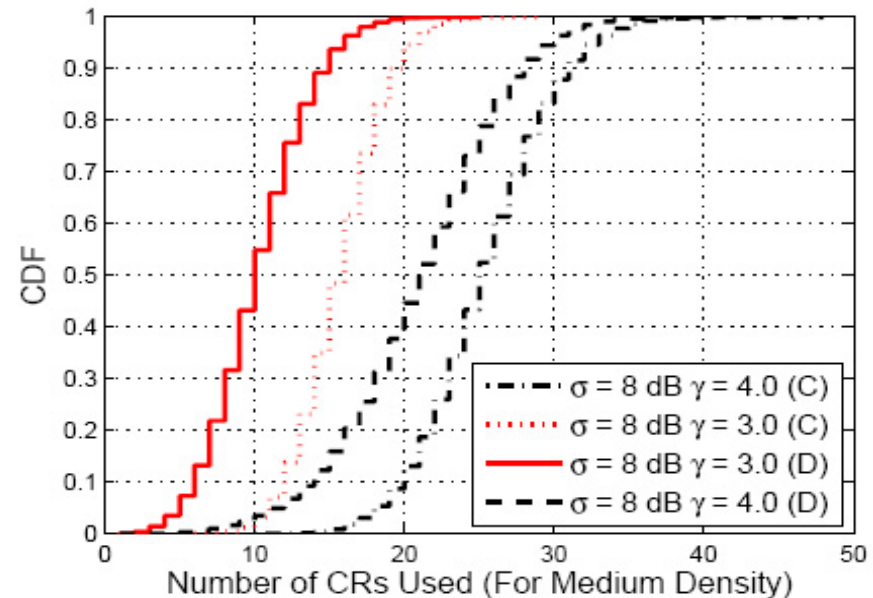


\* Fig. 1. System model ( $R_0$  not shown)

PU – Primary (licensed) User  
CR – Cognitive Radio  
(or secondary users [SUs])

# Some Early Simulation Results

- SNR of Primary at Cell edge is allowed to degrade by a small amount
- Numbers of CRs that can be sustained is found



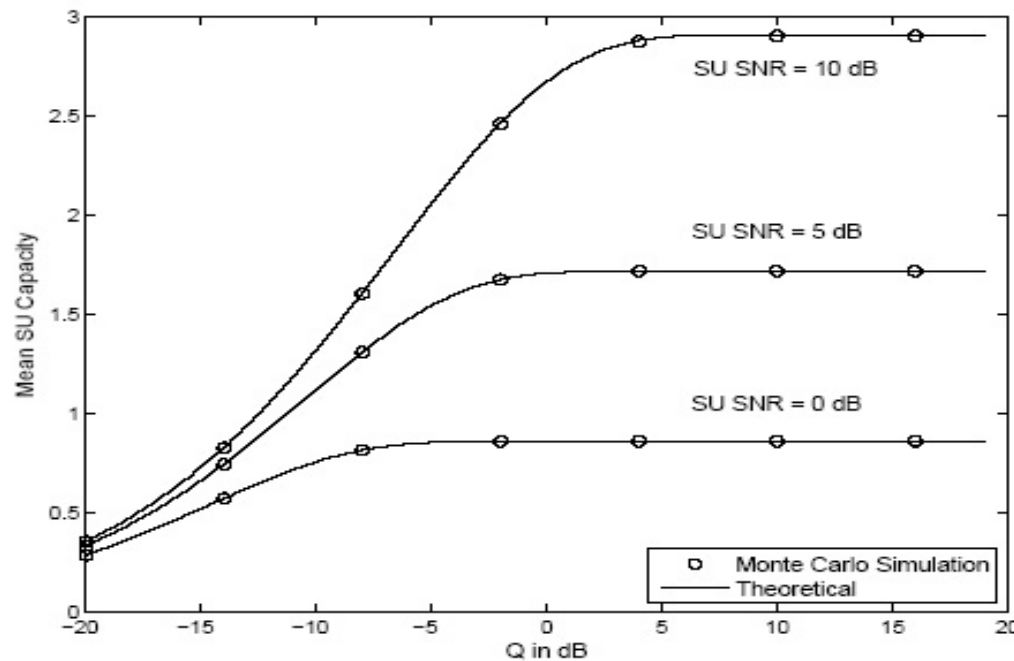
\* Fig. 5. CDF of the number of CRs obtained using REM based approaches for various  $\gamma$  values. D and C denote decentralized and centralized approaches.

CDF – cumulative distribution function, REM – radio environment map  
 $\sigma$  - standard deviation of shadow fading variable,  $\gamma$  - path loss exponent

\* Interference and Deployment Issues for Cognitive Radio Systems in Shadowing Environments  
Authors: Muhammad Fainan Hanif, Mansoor Shafi, Peter J. Smith, Pawel A. Dmochowski  
Conf. Proc. ICC 2009

## In another Study,

- If the peak interference to noise power ratio at the Primary User receiver is  $Q$ , and the maximum power that the CR can transmit is at  $P_m$ , then

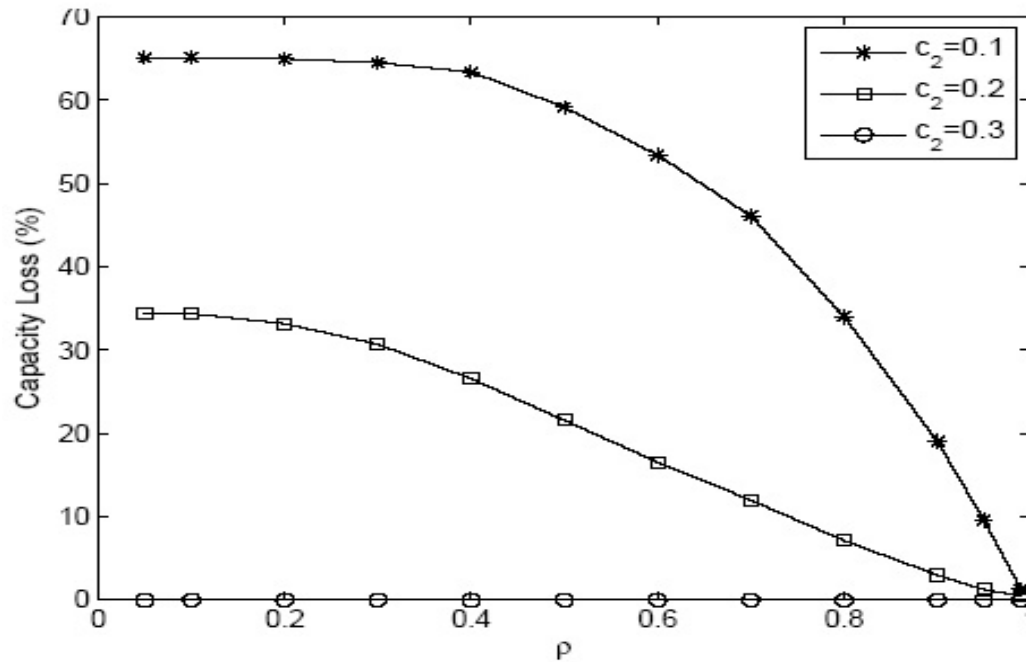


SU – Secondary User (i.e. Cognitive Radio)  
Q – peak interference power at Primary User (PU) receiver  
SNR - Signal to Noise Ratio  
Mean SU Capacity in units of bits/s/Hz

\* Fig. 2. The SU mean capacity versus  $Q$  for different SU SNRs.

\* Channel Capacity Limits of Cognitive Radio with Imperfect Channel Knowledge  
Authors: Himal A. Suraweera, Peter J. Smith, Mansoor Shafi, Michael Faulkner  
Conf. Proceedings G Com 2009

If the channel gains are not perfectly known, the primary may impose a lower peak interference constraint - thereby resulting in a capacity loss to the Cognitive Radio



\* Fig. 3. Percentage capacity loss against  $\rho$ .

$\rho$  – correlation coefficient (of channel)  
 $C_2$  – a proportionality factor so that the acceptable interference,  $Q$ , is  $C_2$  times the PU SNR, and  $C_2 < 1$

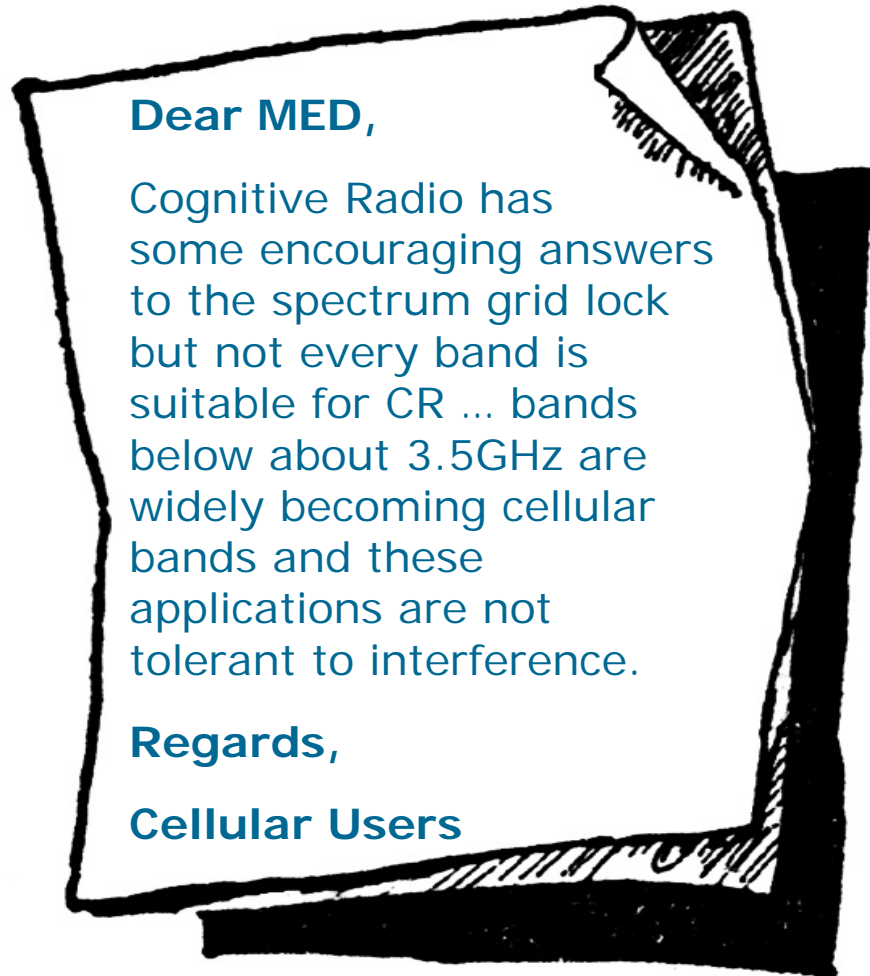
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The results of these preliminary Studies are encouraging but assume that:

- PR systems can accept as loss of performance due to a degraded cell edge SNR
- or*
- a reduced Coverage area

Clearly this depends upon the application.

As noted before, Cellular radio is heavily encumbered by its own issues and may be unable to absorb additional CR interference.



Even if a spectrum hole is found, interference issues that are currently present due to opposing Tx/Rx directions, adjacent channel, etc may still be present and need careful attention.

*Thank you  
for your  
attention.*



**Questions?**