Cognitive radio challenges

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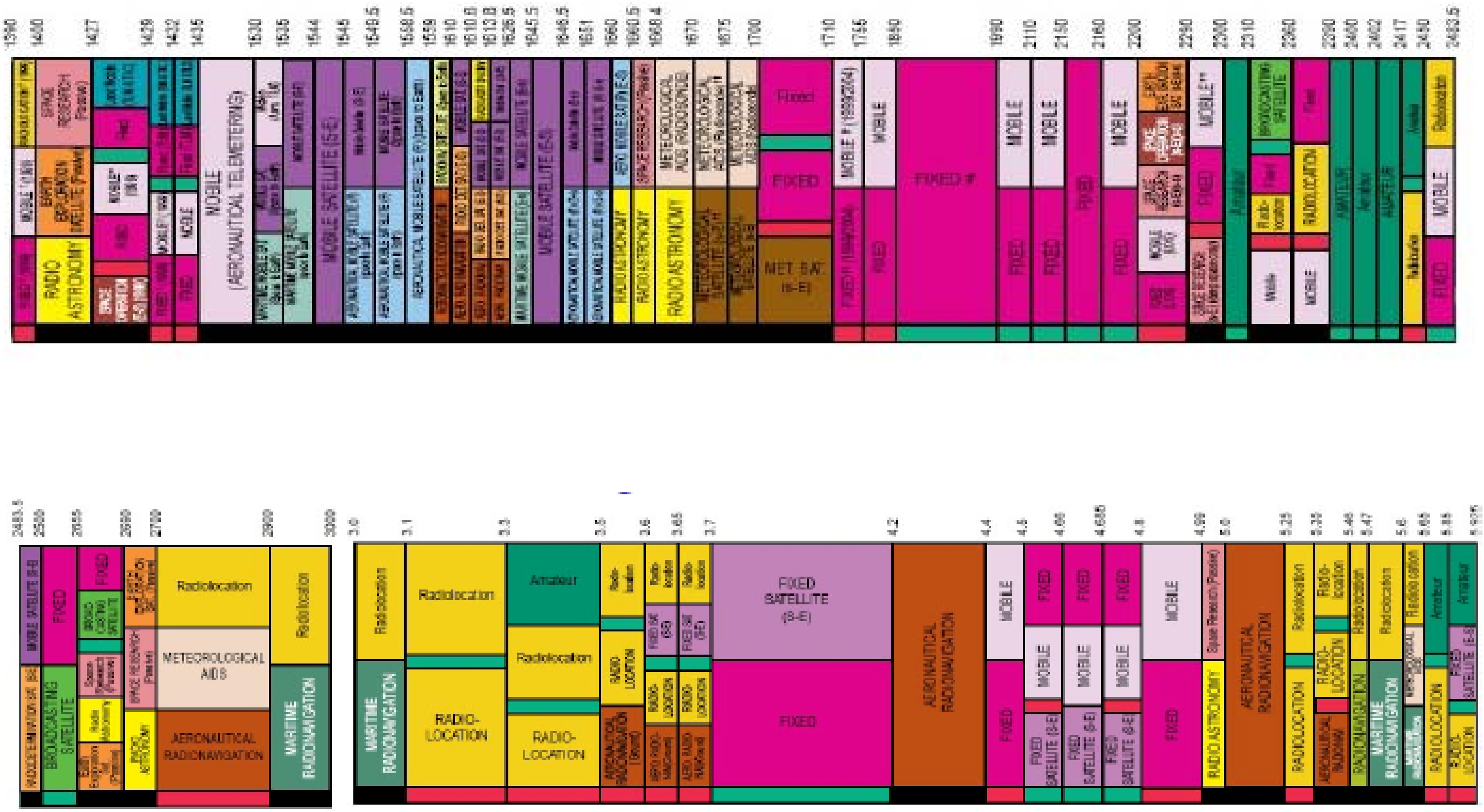
Cognitive Radio Concept

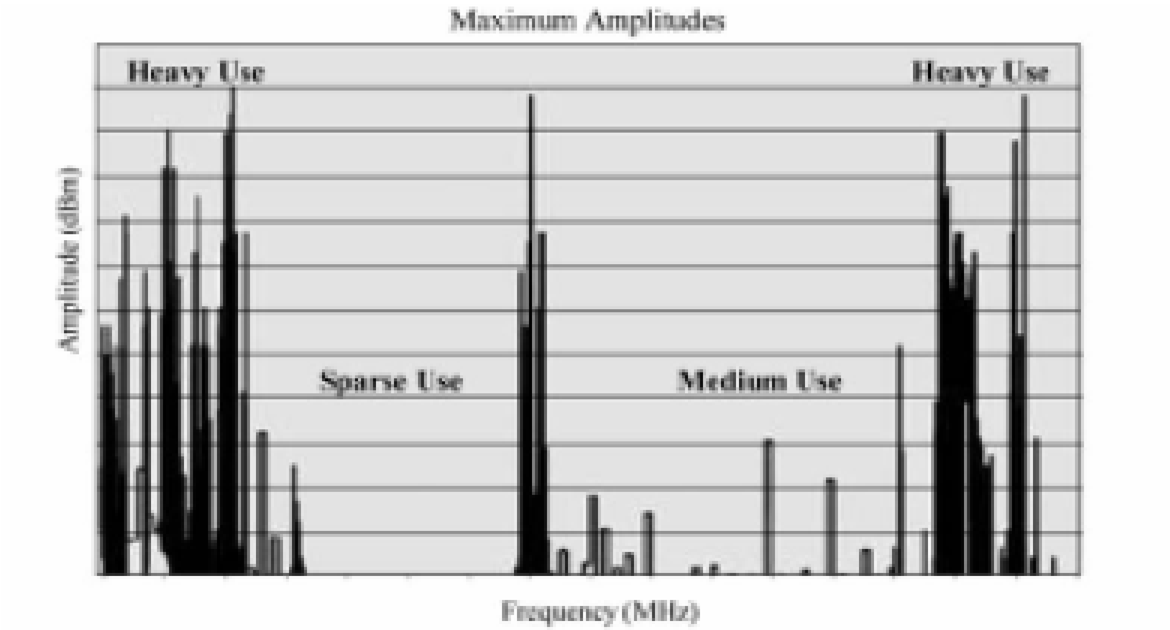
- Cognitive radio is an emerging concept in wireless access, aimed at improving the way radio spectrum is utilized.
- The principle of cognitive radio is temporal, spatial and geographic "re-use" of licensed spectrum.
- The idea is that an "unlicensed" (secondary) user shall be permitted to use licensed spectrum, provided that it transmits with low enough power and that it is so far from any primary users that it does not interfere with.
- The motivation for cognitive radio is various measurements of spectrum utilization, that generally show that spectrum is underutilized.
- Cognitive radios should be able to exploit spectrum holes by detecting them and using them in an opportunistic manner.
- Cognitive radios could be permitted to transmit if they cannot ``hear'' any primary transmission: `transmit-if-you-cannot-hear-primary'' paradigm
- "Spectrum Etiquette" (Listen before talk)

Spectrum occupation from 1.39 to 5.923 GHz



Spectrum utilization

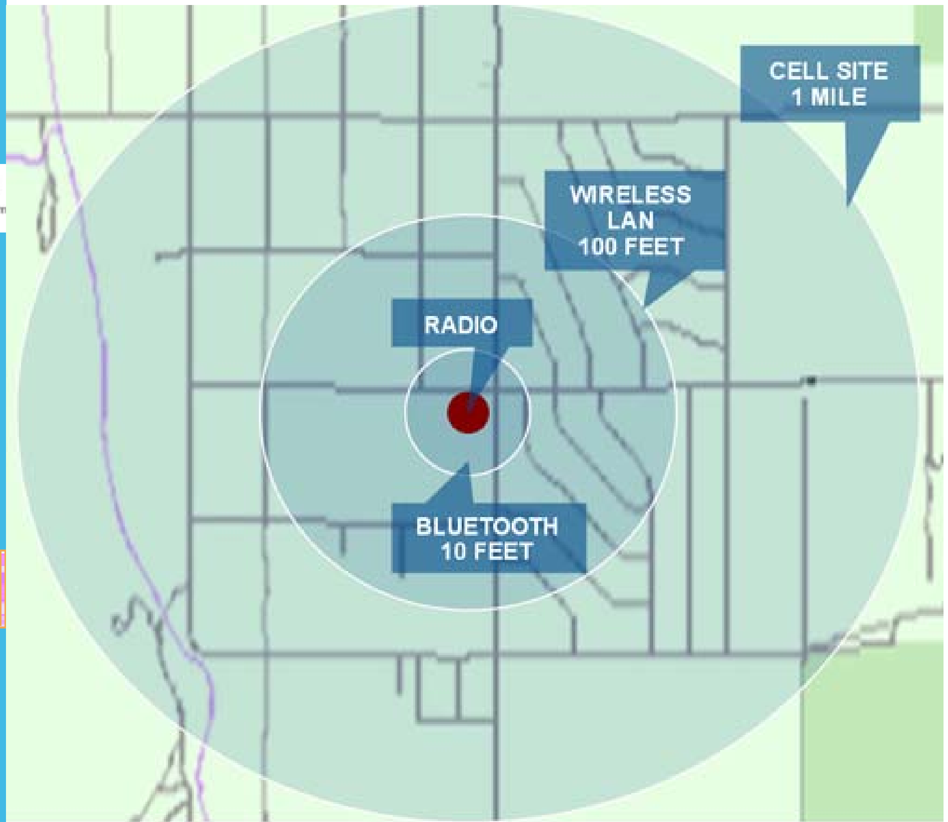
- In some locations and/or at some times of the day, 70 percent of the allocated spectrum may be sitting idle.
- The FCC has recently recommended that significantly greater spectral efficiency could be realized by de-ploying wireless devices that can coexist with the licensed users.



Cognitive radio: Definitions

- A new class of radios was defined by the term cognitive radio
- Several definitions (and variations) of Cognitive Radio exist:
  - Mitola- "Cognitive radio signifies a radio that employs model based reasoning to achieve a specified level of competence in radio related domains".
  - FCC - "A cognitive radio (CR) is a radio that can change its transmitter parameters based on interaction with the environment in which it operates".
  - E2R: Cognitive radios (CR) are aware of the electromagnetic spectrum environment around them and make adjustments to their transmission characteristics accordingly, in a manner consistent with the tiered access rights model.
- Such devices must be able to:
  - sense the spectral environment over a wide bandwidth,
  - detect the presence/absence of legacy users (primary users),
  - adapt the parameters of their communication scheme
- the communication does not interfere with primary users.

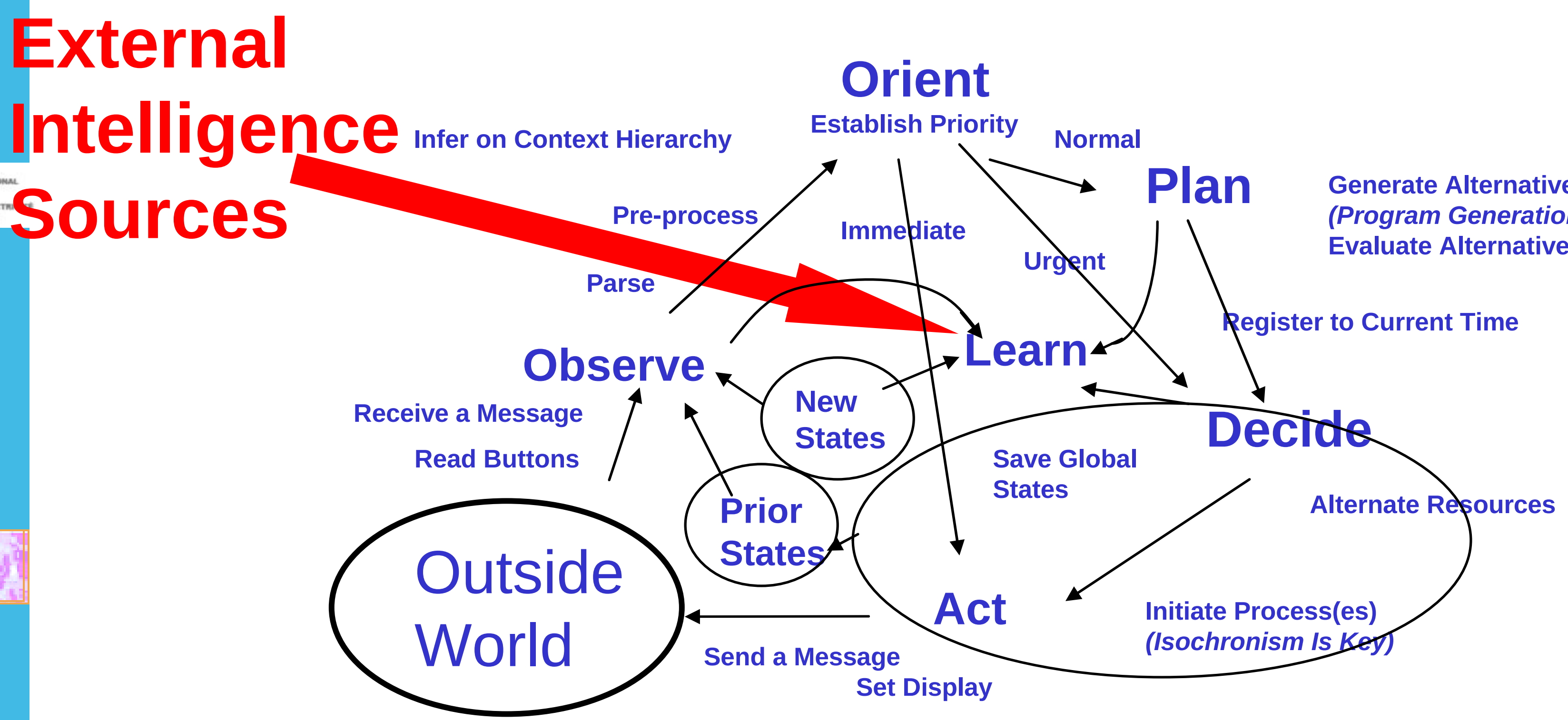
Cognitive Radio Means “Smart” and “Alert”



- It knows where it is
- It knows what services are available, for example, it can identify then to 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
- Flexible architectures

Source: General Dynamic Decision Systems

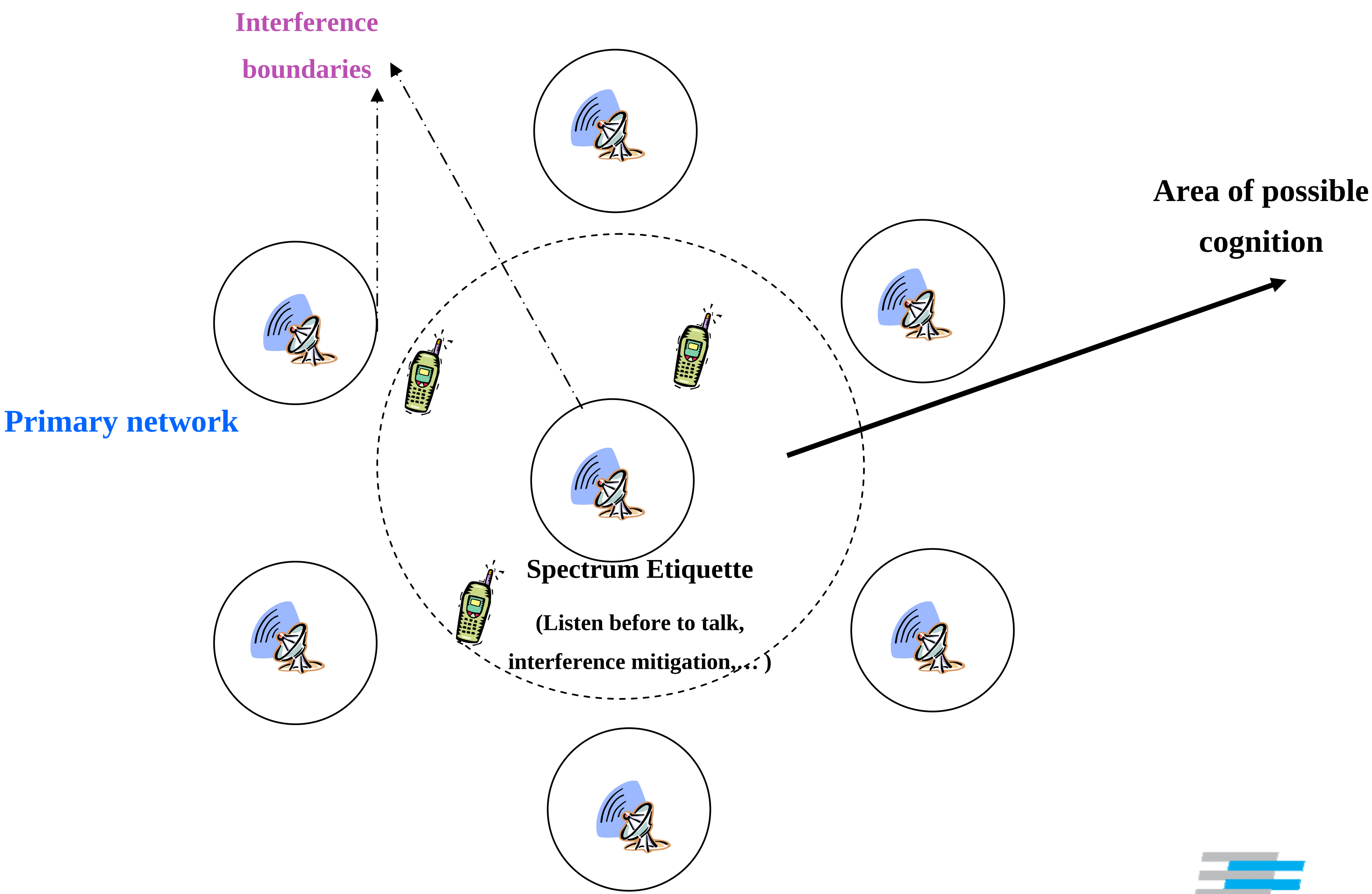
How Does a Cognitive Radio Get So Smart?



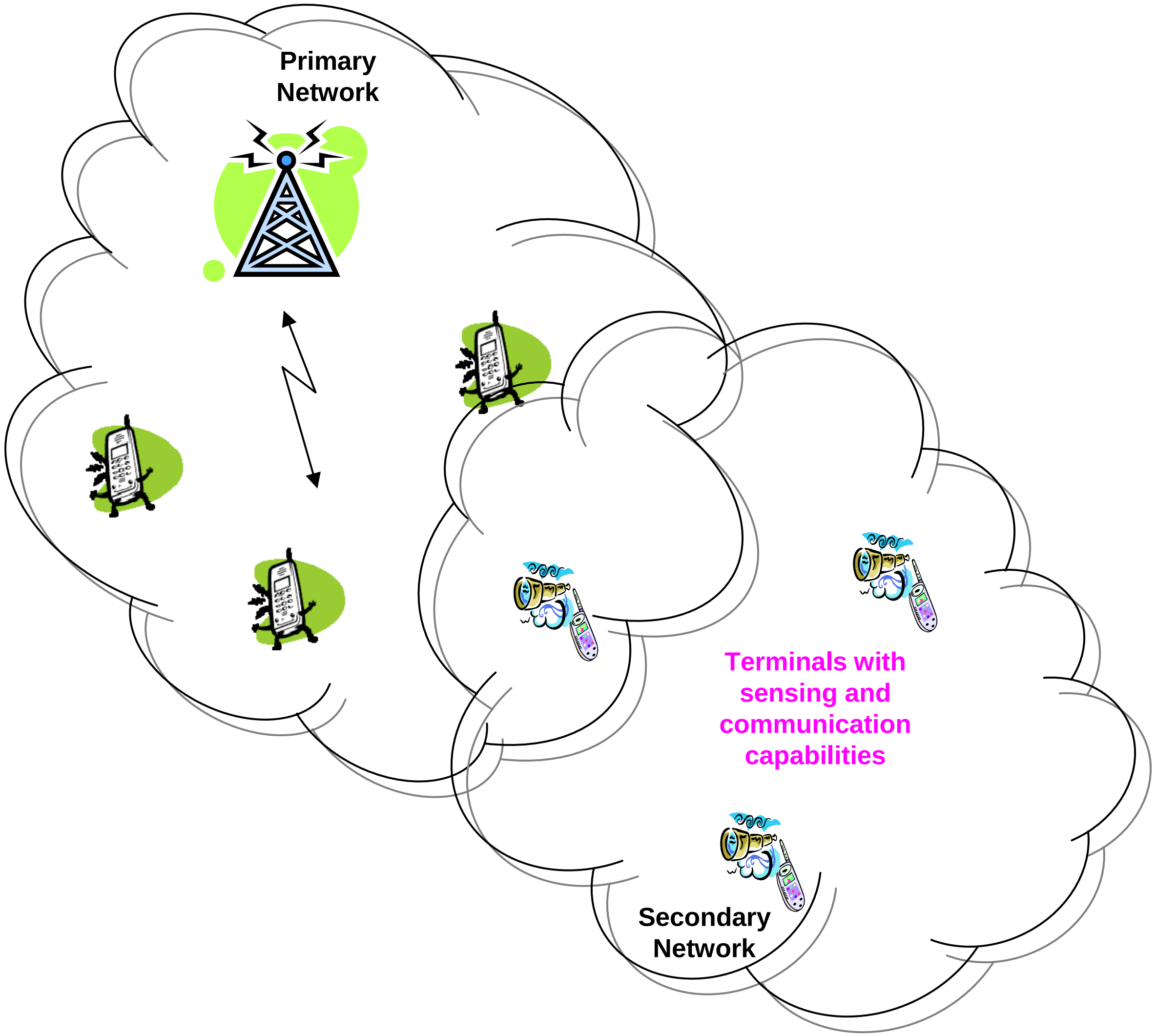
The Cognition Cycle

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

Area of possible cognitive radio operation

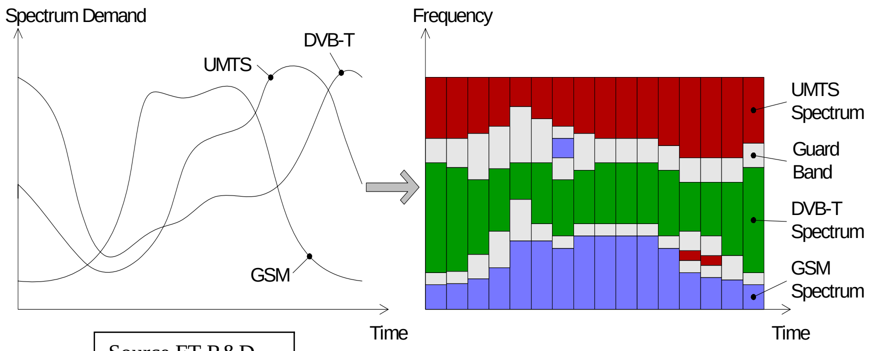


Cognitive radio generic scenario



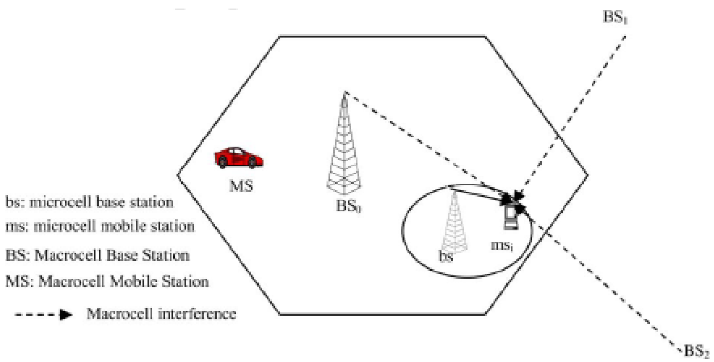
Cognitive radio scenarios: Examples

Spectrum Sharing



Source FT R&D

Co-existence Macro/Micro Cells



Source FT R&D

Cognitive radio objectives

- Efficient spectrum management and utilization
- Cognitive and flexible radio architectures: Hardware/software design
- Multistandards reconfigurability
- Novel spectrum sensing techniques enabling opportunistic spectrum utilization decisions
- Frequency selection
- Interference management and control enabling multistandards co-existence
- Resource management and power allocation algorithms
- Localization techniques
- Environment discovery
- Model Based Reasoning for better match between user needs, local content and environmental context
- Distributed resource allocation and scheduling
- Collaborative communication strategies
- Distributed protocols
- Regulation issues

Reconfigurability Through Generic Operators

Orthogonal Multiple Access:

$$\begin{bmatrix} \boldsymbol{y}[0] \\ \boldsymbol{y}[1] \\ \vdots \end{bmatrix} = \begin{bmatrix} \boldsymbol{n}[0] \\ \boldsymbol{n}[1] \\ \vdots \end{bmatrix} + \begin{bmatrix} \boldsymbol{S}[0] & \boldsymbol{0} & \\ \boldsymbol{0} & \boldsymbol{S}[1] & \boldsymbol{0} \\ & \boldsymbol{0} & \ddots \end{bmatrix} \begin{bmatrix} \boldsymbol{b}[0] \\ \boldsymbol{b}[1] \\ \vdots \end{bmatrix}$$

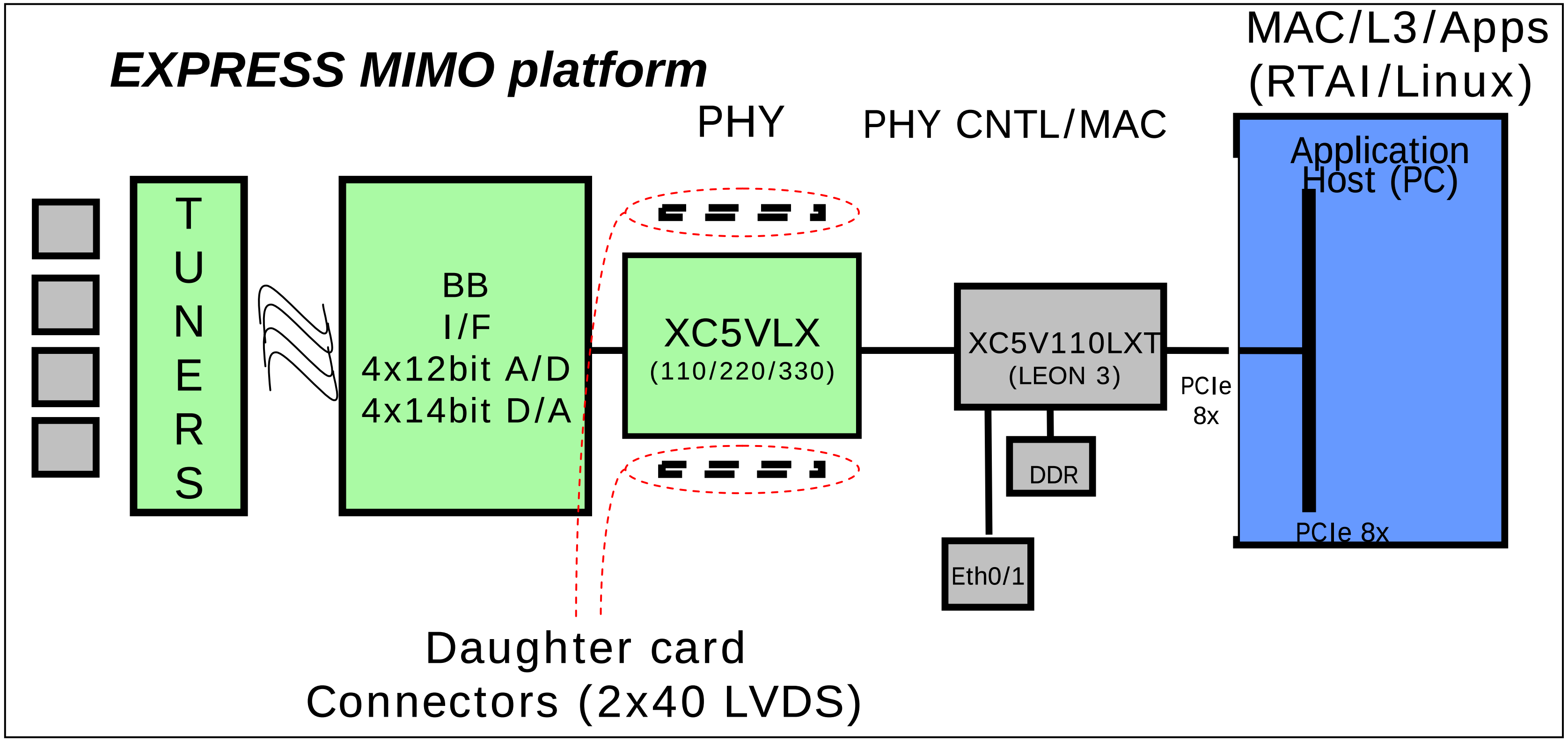
$$\underset{N \times 1}{\boldsymbol{y}[\mu]} = \underset{N \times 1}{\boldsymbol{n}[\mu]} + \underset{N \times K}{\boldsymbol{S}[\mu]} \; \underset{K \times 1}{\boldsymbol{b}[\mu]}$$

TDMA: S is a weighted permutation matrix

OFDM: S is FFT matrix

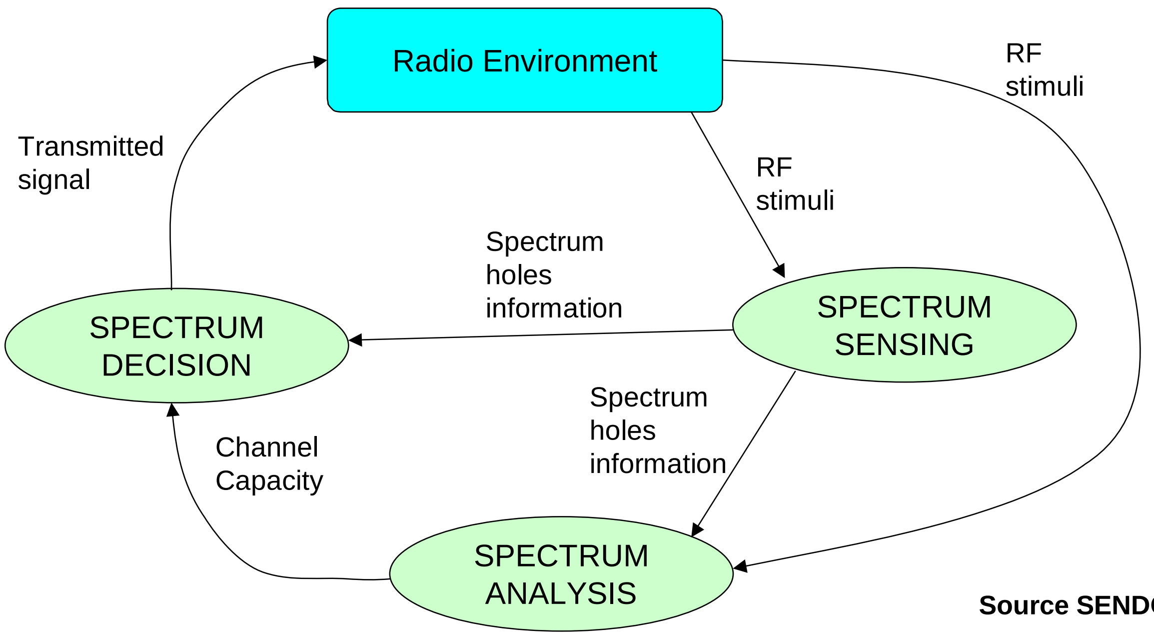
CDMA: Walsh-Hadamard Matrix

Reconfigurable and flexible platform design



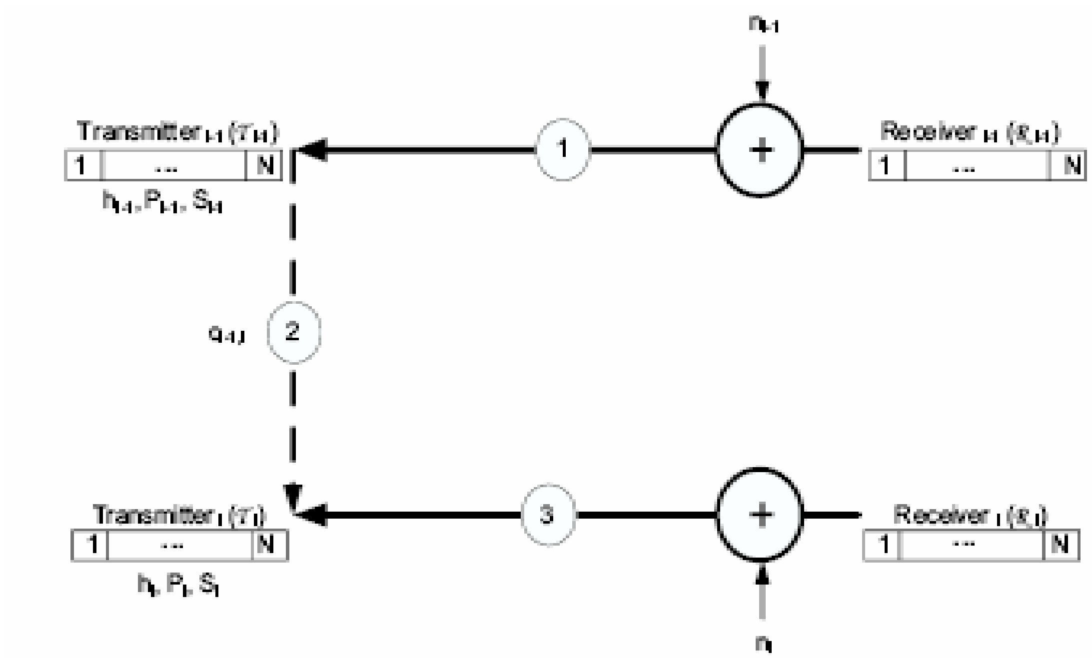
- PHY/MAC evolutions (Reconfigurable PHY, MIMO 4x4, OFDMa, ...)
- Reconfigurability Through Generic Operators

Novel spectrum sensing techniques

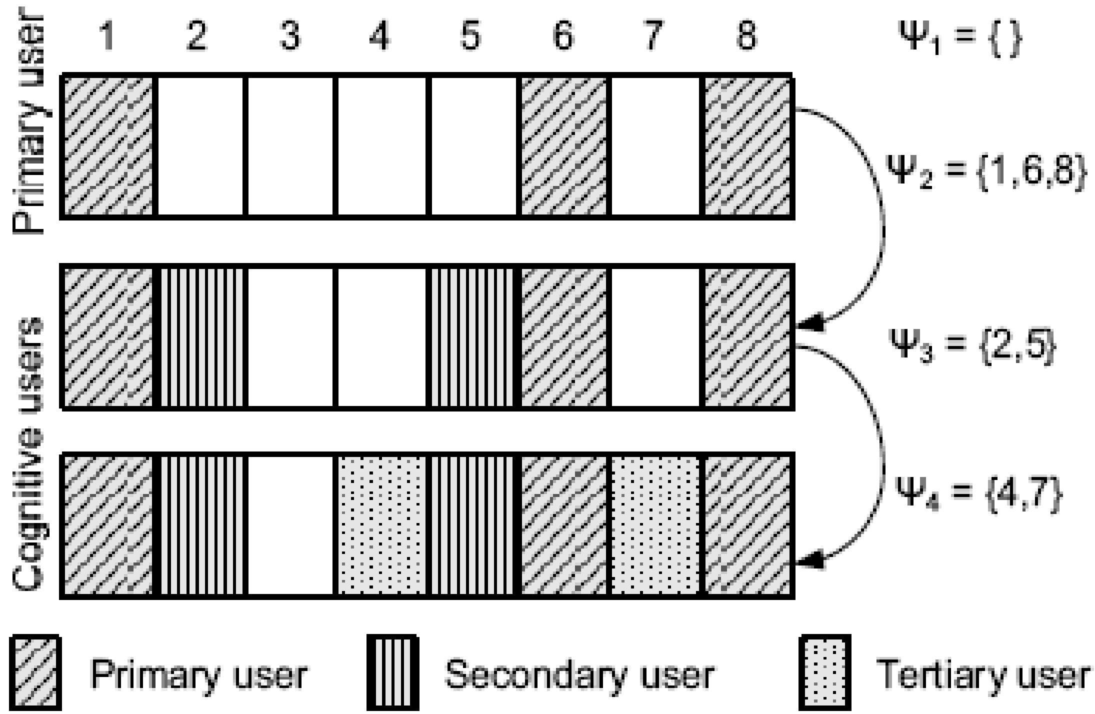


Source SENDORA Project

Resource allocation strategies: Example (1)



Resource allocation strategies: Example (2)



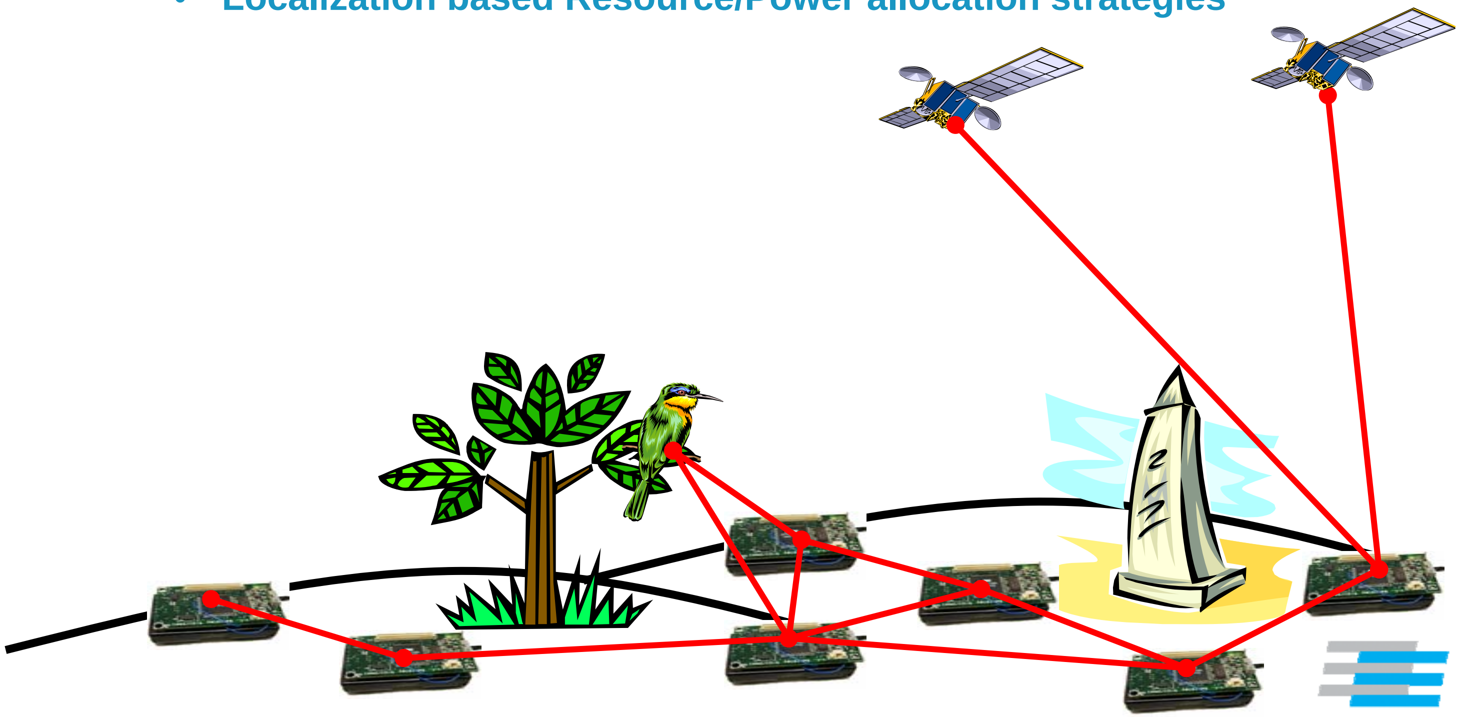
Cooperative communications and relaying protocols

- Novel cooperative transmission techniques have to be designed in accordance with the various interference constraints, in order to maximize or minimize various QoS metrics of interest (e.g. capacity, delay, etc…) in the presence of primary users.
- Design of novel co-operative processing algorithms optimising (separately or jointly) the various processes involved, such as channel estimation, detection, synchronization, MIMO coding...

Why is Localization Important?

– **Very fundamental component for many other services**

- **GPS does not work everywhere**
- **Smart Systems – devices need to know where they are**
- **Geographic routing & coverage problems**
- **Localization based Resource/Power allocation strategies**



Model based reasoning

Cognitive radio: I think therefore I might be!

Cognitive radio is:

- **aware of its environment,**
- **capable of redefining its operating parameters in order to adapt to its context.**