
# Docitive Radios

## Centroid of Cognition & Cooperation

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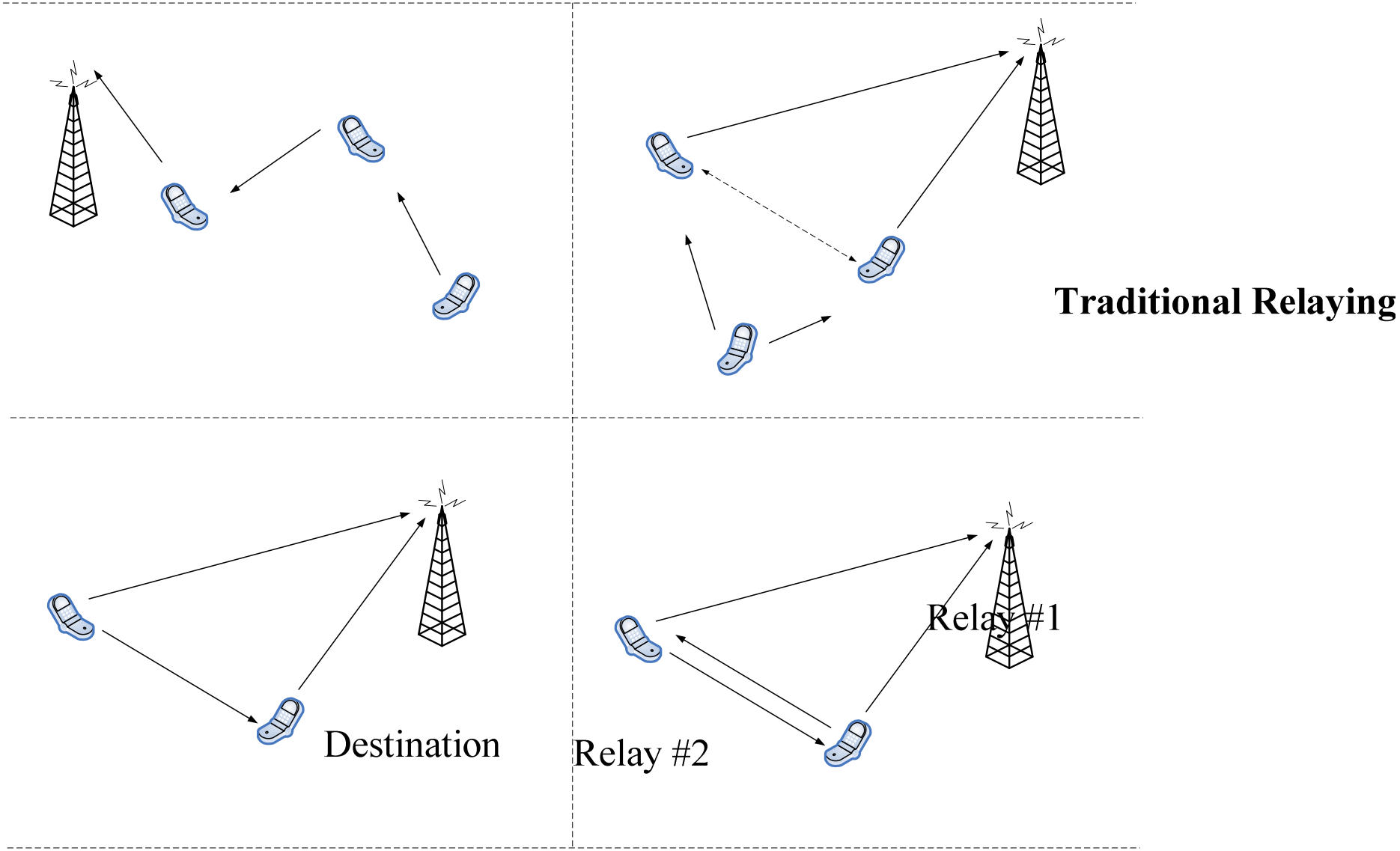
# Outlook

1. Cooperative Networks
2. Cognitive Networks
3. Docitive Networks
4. Conclusions

# 1

# Cooperative Networks

# Canonical Cooperative Architectures



# Different Intro to Cooperation

- Track Record of Cooperative & Relaying Systems:
  - relaying protocols have been implemented in parts by the satellite community for nearly five decades and by the radio community for almost a century
  - supportive relaying has been analyzed in the information theory community for about four decades
  - cooperative relaying & space-time processing over realistic fading channels is now about 10 years old
- Clarification of Some Misconceptions:
  - major gains are due to pathloss not fading
  - AF-type relays are not suited for time-division operation
  - cost and power consumption of AF-type relays is not that low

# Aggregate Pathloss Gain

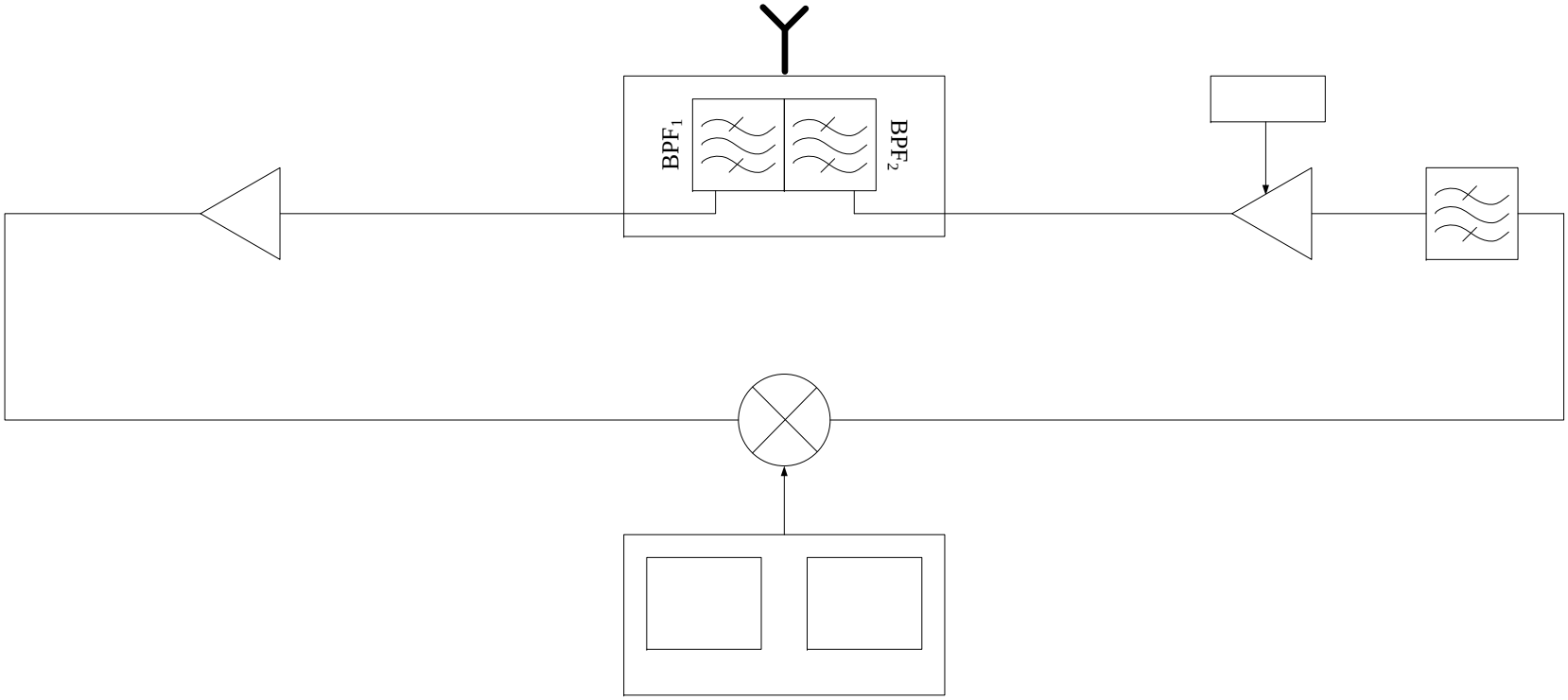
- Pathloss versus distance is highly non-linear, significant aggregate power gains:
  - source and destination separated by *d* meters
  - regenerative relays placed equidistantly yielding N relay segments
  - pathloss equation $L = b + 10 \cdot n \cdot \log_{10}(d / N)$

| Relay Segments | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Relative Gain [%] | 0 | 18 | 32 | 44 | 55 | 65 | 75 | 84 | 93 | 102 |
| Absolute Gain [dB] | 0 | 15 | 23 | 29 | 34 | 38 | 41 | 44 | 46 | 49 |

- Some further observations are:
  - breakpoint distance is changed which impacts signal & interference
  - shadowing gains increase with increasing relaying segments *N*
  - transparent relaying deteriorates e2e shadowing and pathloss

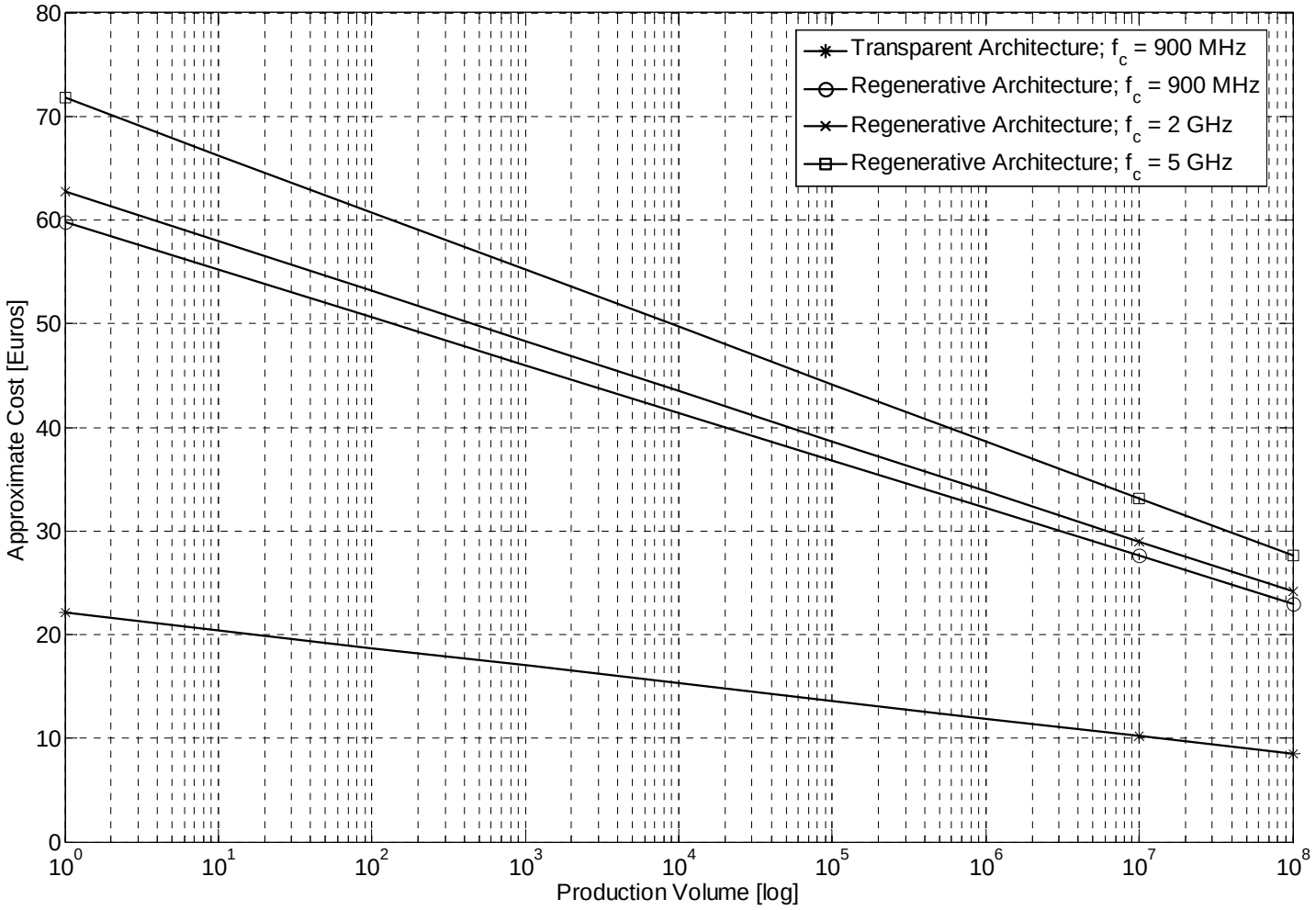
# No Time-Division With AF

- Hardware limitations as of today dictate:
  - no viable in-band relaying (due to absent full duplexing)
  - no storage of analog signal (due to heavy sampling)



# Cost Comparison

- AF versus DF in € with numbers of Q4 2009:



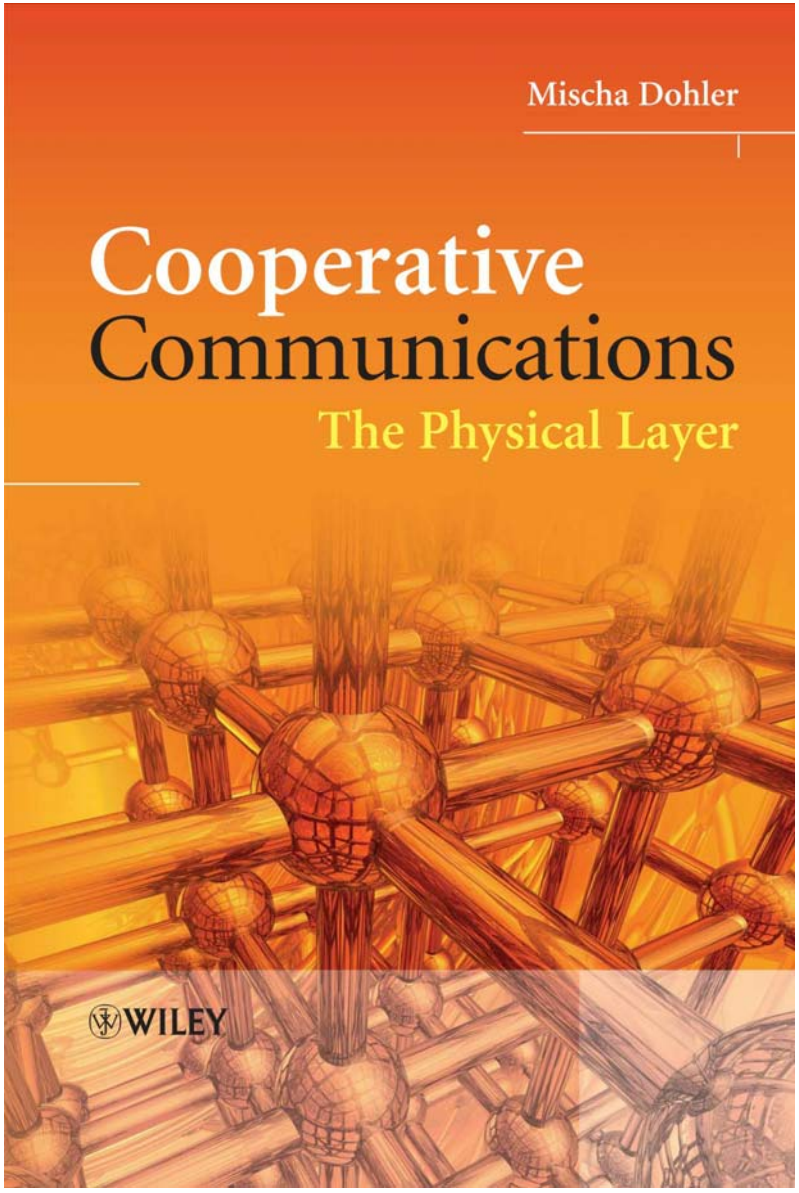
# Complexity/Power Comparison

- 3GPP-type relay based on transparent or regenerative hardware:

| Case Study | **Memory** in kb | **Frequency** in MHz | **Power** in mW |
|---|---|---|---|
| **s-AF$_a$** | 0 | 0 | 1,530 |
| **s-AF$_d$** | 53 | – | 765 |
| **Speech, MRC, s-DF$_d$** | 105 | 930 | 859 |
| **HSDPA, MRC, s-DF$_d$** | 110 | 580 | 818 |
| **HSDPA, MPIC, s-DF$_d$** | 340 | 3,400 | 1,450 |
| **Speech, MRC, c-DF$_d$** | 89 | 320 | 1,442 |
| **HSDPA, MRC, c-DF$_d$** | 96 | 420 | 1,460 |

- Some further observations:
  - an analog AF-type radio needs to be instructed and thus typically also needs digital hardware components

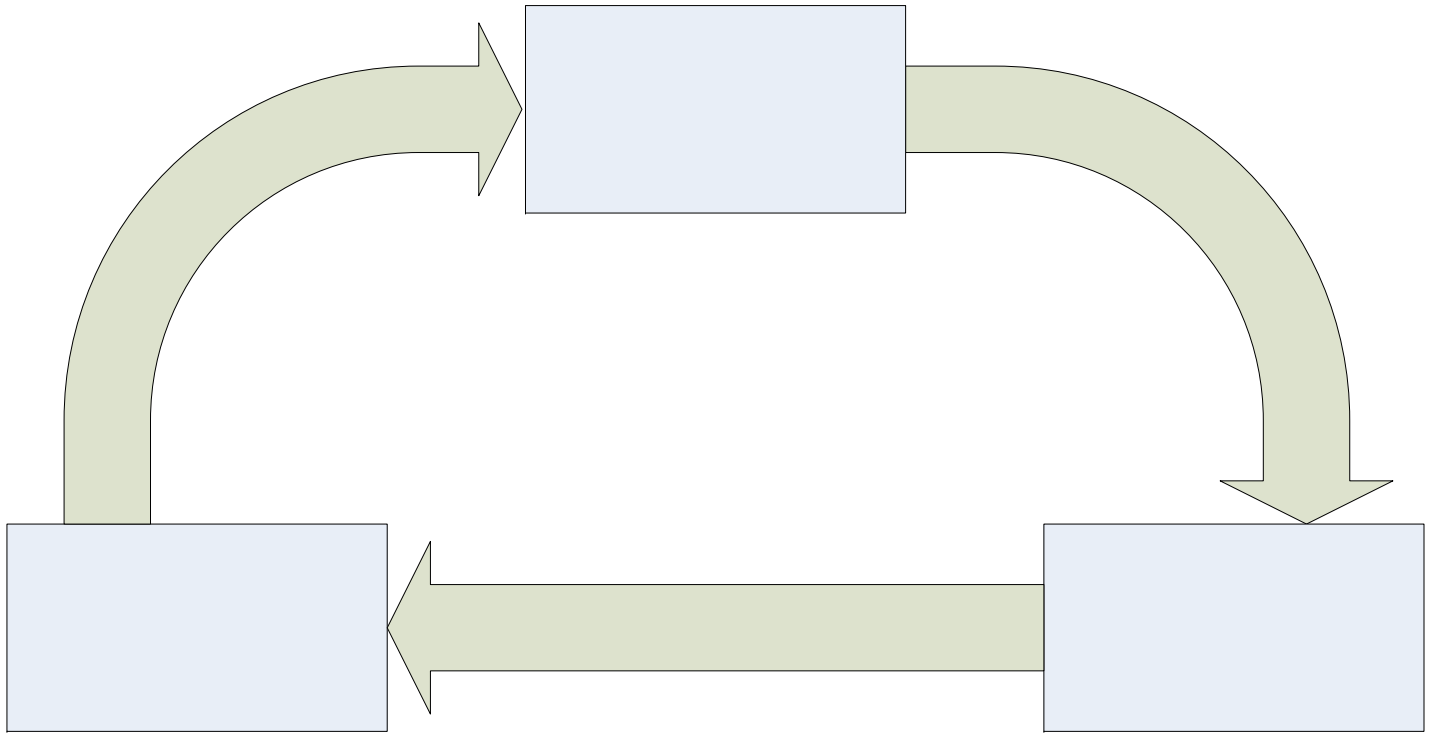
# ... for more detailed information ...



# 2

# Cognitive Networks

# Canonical Cognitive Cycle



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# Different Intro to Cognition

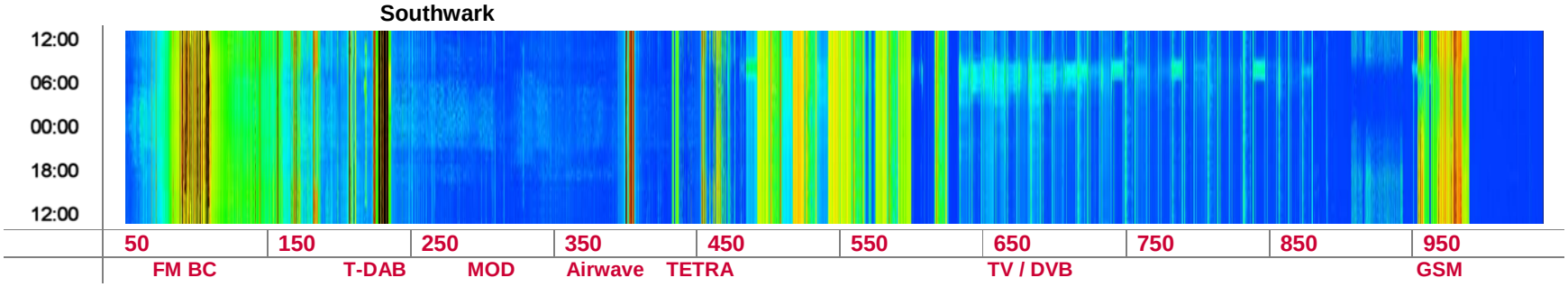
- Definitions of Cognitive Systems:
  - Rigorous: “... processes involved in gaining knowledge and comprehension, including thinking, knowing, remembering, judging, and problem solving.” [1]
  - Alternative: “... a system which is properly working under conditions it was initially not designed for.” [2]

- Some observations on Cognitive Radios / Systems:
  - (CSMA is actually an early form of a simple cognitive system)
  - (most contributions today are actually on opportunistic radios)
  - there are not so many opportunities in the spectrum
  - from 3 methods, geolocation is the unlikely winner
  - learning time does not match channel dynamics

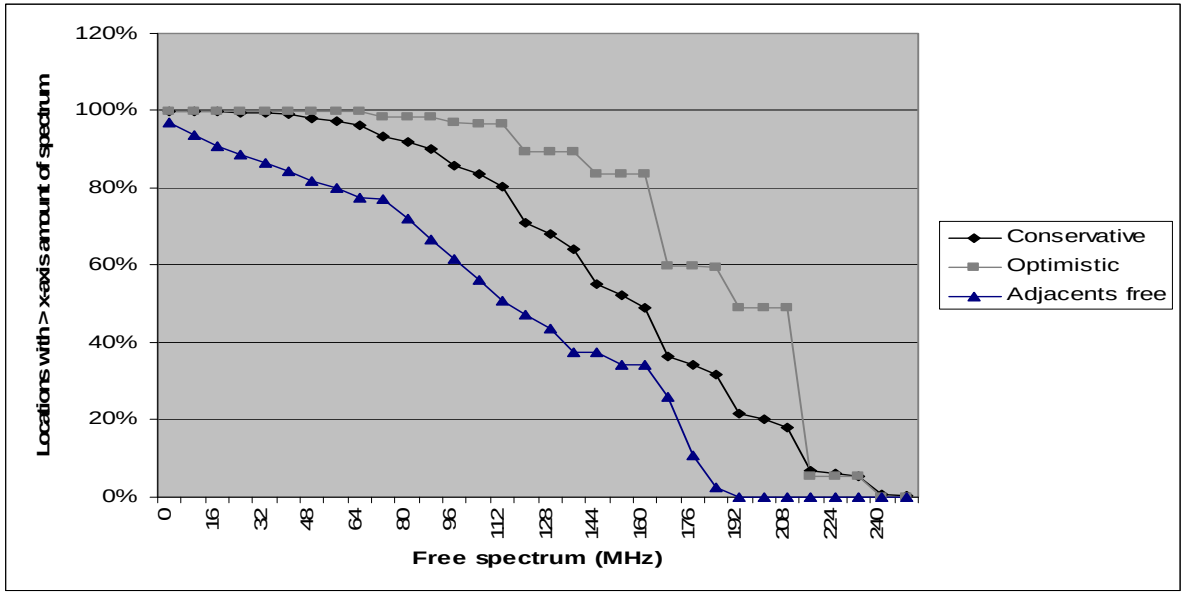
[1] http://psychology.about.com/od/cindex/g/def_cognition.htm
[2] Apostolos Kontouris, Orange Labs, France, 2007.

# Opportunities in Interleaved Spectrum?

- Apparently large amount of spectrum unused [3]:




- However [3]:






[3] @ Prof William Webb, Head of Ofom R&D, UK, from presentation at CTTC, 15 April 2009

# Opportunities in Interleaved Spectrum?

- Study conducted by Ofcom concludes [3]:
  - benefits estimated to have value of £200m-£300m
  - DTT e.g. has an equivalent value in the region of £50bn
  - thus maximum of 0.5% probability of interference
  - should however be less than 0.1% to be sure that benefits will exceed costs
  - (e.g. reduced confidence in DTT may result in a greater loss of value!)
- Hidden Node sensing margin [3]:
  - varies in dependency of environment but is up to 35dB
  - this is beyond any non-cooperative sensing techniques
  - cooperative sensing not answer either (unreliability/costly planning)

| Environment | Hidden node margin (dB) for % of locations | | |
|---|---|---|---|
| | **90 %** | **95 %** | **99 %** |
| **Densely urban** | 18.5 | 22.4 | 29.2 |
| **Urban** | 28.1 | 30.2 | 32.5 |
| **Suburban** | 30.5 | 31.4 | 32.9 |
| **Rural** | 14.9 | 15.6 | 16.6 |

[3] @ Prof William Webb, Head of Ofom R&D, UK, from presentation at CTTC, 15 April 2009

# The Unlikely Winner [3]

- Sensing:
  - no additional infrastructure or standardization needed
  - effective use of white space as long as false positives are avoided
  - hidden terminal problem results in some residual probability of interference
- Beacons (pilot channel):
  - requires an infrastructure to transmit as well as a database
  - Interference / hidden terminal problem still occurs
  - not Ofcom's preferred option
- **Geolocation:**
  - requires a database, devices to self-locate, licence holders to update database
  - makes most effective use of the white space (as long as updated)
  - if correctly set up there will be no interference

[3] @ Prof William Webb, Head of Ofom R&D, UK, from presentation at CTTC, 15 April 2009

# System versus Learning Dynamics

- Dynamics of surrounding environment can be decomposed:
- Highly-dynamic variations yielding short coherence times:
  - mainly due to fading, fast power control, etc.
  - convergence of cognitive algorithms too slow at allowed complexity
  - however, opportunistic access (without thinking) is possible
- Quasi-static variations yielding large coherence times:
  - mainly due to shadowing, seldom but permanent system changes, etc.
  - convergence of cognitive algorithms typically within coherence time
  - however, all terminals in proximity would come to same solution
  - also, complexity considering all factors/states is far too high

# 3

# Docitive Networks

# Case For Doceitive Systems

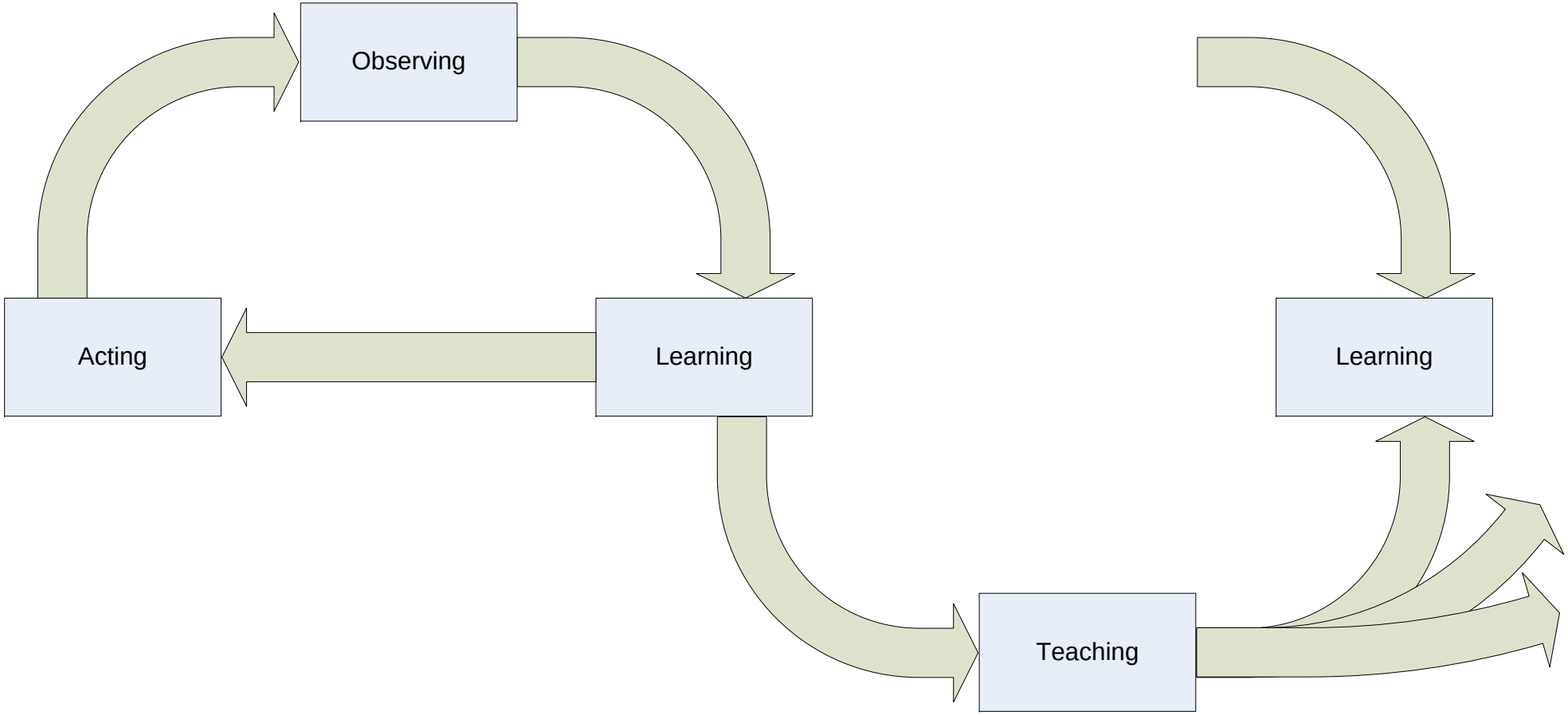
- From cognitive and cooperative approaches we learned:
  - in most interesting cognitive cases, learning alone from scratch is not efficient
  - a lot of vital information facilitating cognitive access will be stored centrally
  - cooperation facilitates exchange of information on local basis

- Docitive Radios / Systems:
  - introduce rigorous framework for above observations, where

**radios are encouraged to teach other radios**

  - origin is from “docere” = “to teach” (“cognoscere” = “to know”)
  - mimics the so-far-successful society-driven teacher-pupil paradigm
  - elements of this are already in cognitive systems (no claim of novelty)

# Canonical Docitive Cycle

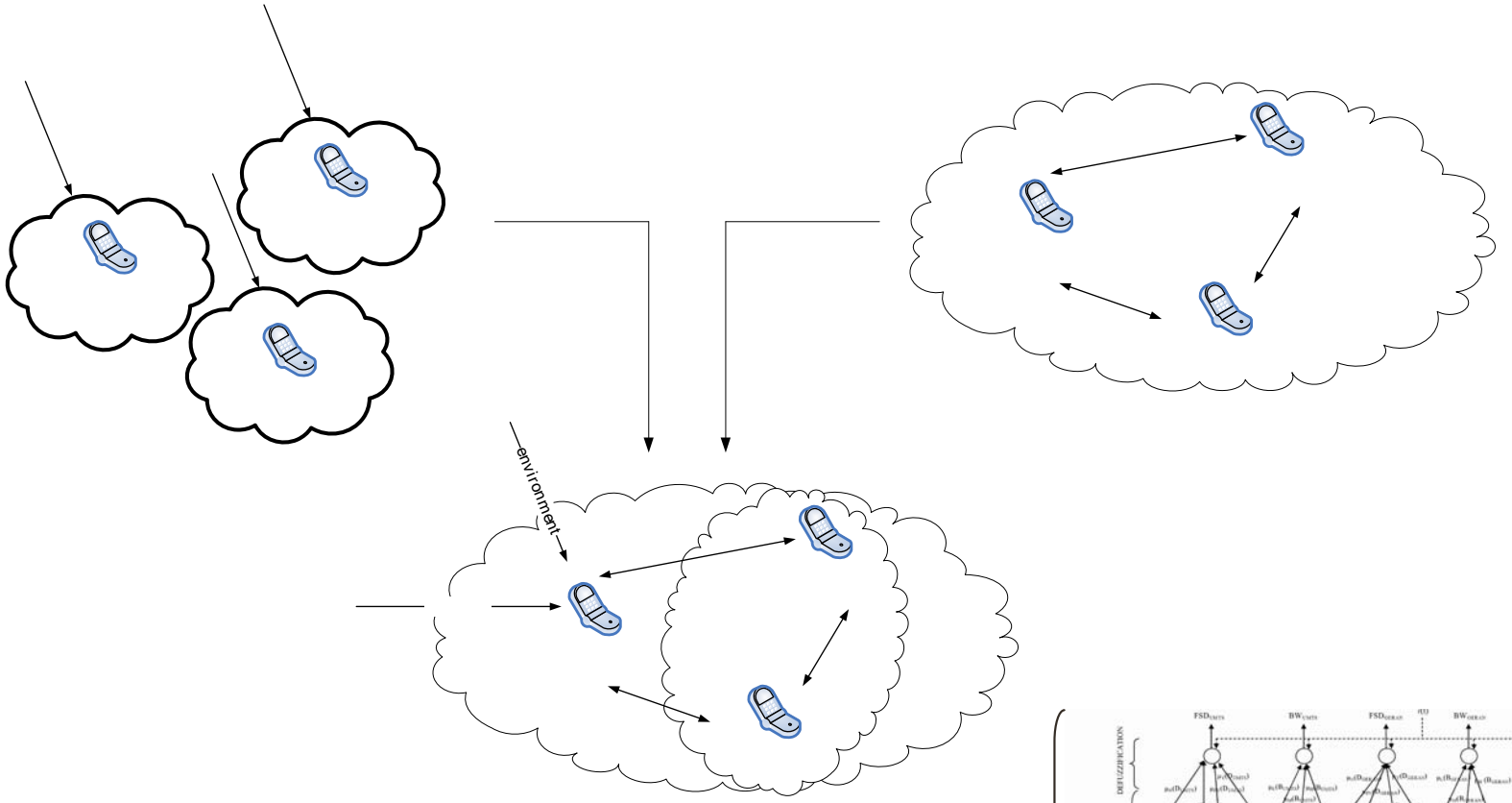


# Problem Based Learning in Society

- Context is very much applicable to Problem Based Learning (PBL):
- Proponents of PBL:
  - Lev Vygotsky, John Dewey, Jean Piaget, Michael Gardener, Jérôme Bruner
- Teachers using PBL:
  - encouraged to be coaches – not information givers
  - provide learning communities where students discuss their methods/outcomes
- Pupils using PBL
  - work as a collaborative team using critical thinking to synthesize and apply knowledge
  - pupil apprehend through dialogue, jigsaw, questioning, reciprocal teaching, and mentoring

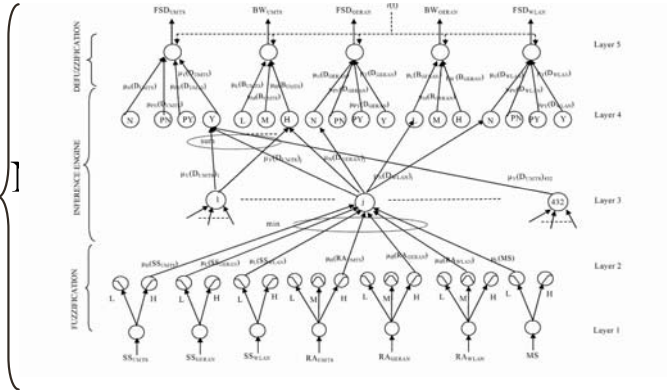
# Projecting into Telecommunications

- Cognitive + Cooperative → Docitive System:




- teaching of vital states in Reinforcement Learning
- teaching of table entries in Q-Learning; etc.

Cognitive Node



# Projecting into Telecommunications

- Finding parallels from PBL in telecommunications, some interesting and pertinent research areas open up, such as:

| | |
|---|---|
| Information Theory: | How much side information needs to be taught to pupils? |
| | Impact of feedback, renewal rate, etc.? |
| Wireless Channel: | What are the coherence times of the channel? |
| | Do they allow sufficient time for learning/teaching? |
| PHY Layer: | How much rate/energy should go into teaching? |
| | Which PHY states should be taught? |
| MAC Layer: | Can we re-use known broadcast approaches? |
| | Which MAC states should be taught? |
| System: | What is the optimal ratio teachers versus pupil? |
| | What is the optimal teaching schedule? |
| | Should every pupil also be teacher? |
| | What exactly is best taught? |
| | Is emergent behavior now possible with this dialog? |

# 4
# Conclusions

# Conclusions

- Cooperative Systems:
  - well understood ... and ... well misunderstood
  - large aggregate pathloss gains, less fading gains
- Cognitive Systems:
  - generic definition has complicated rigorous approach
  - little truly cognitive systems so far as most are opportunistic
- Docitive Systems:
  - yet another generic concept with room for (mis)interpretation
  - framework with no claim for total novelty and open for discussions
  - “bad teacher teaches end-result – good teacher facilitates learning”
  - capitalizes on advantages of both cooperative & cognitive systems
  - CD + DR = more efficient spectrum utilization at minimum cost


**ACK**: Dr Lorenza Giupponi, CTTC, for idea of sharing states & tables in reinforcement and Q-learning methods.