



Docitive Radios

Centroid of Cognition & Cooperation

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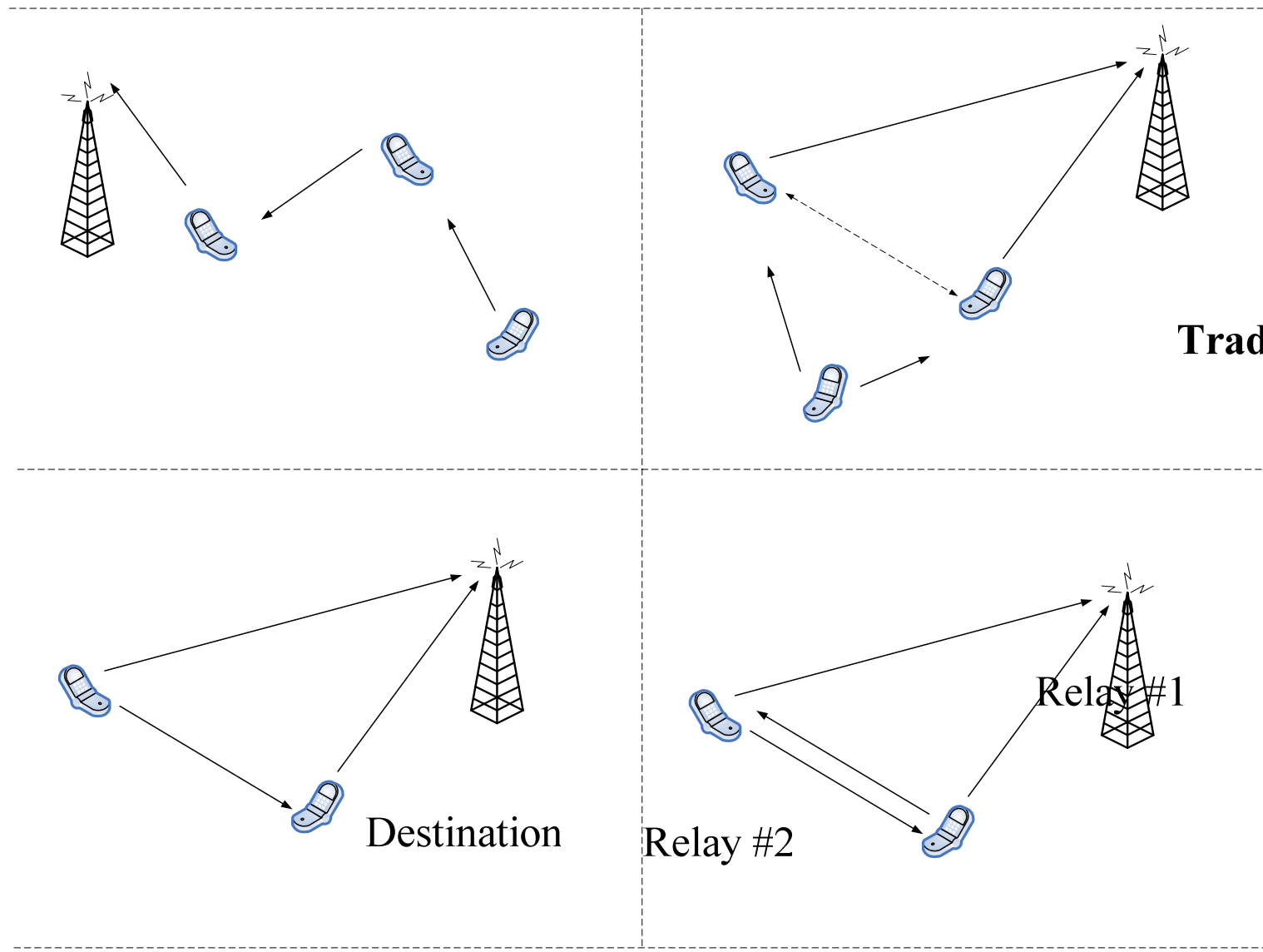
Outlook

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

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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

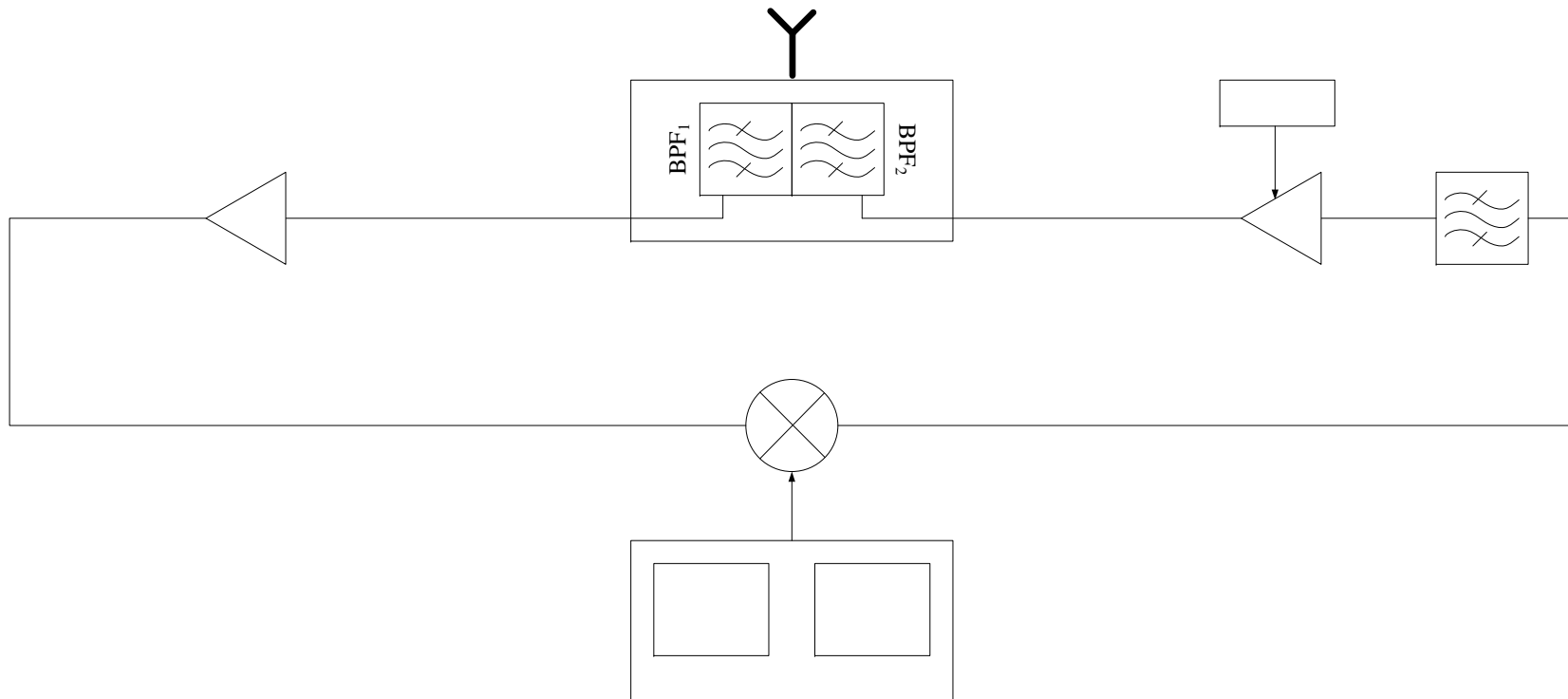
- Pathloss versus distance is highly non-linear, significant aggregate power gains:
 - source and destination separated by d meters
 - regenerative relays placed equidistantly yielding N relay segments
 - pathloss equation $L = b + 10 \cdot n \cdot \log_{10}(d / N)$

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

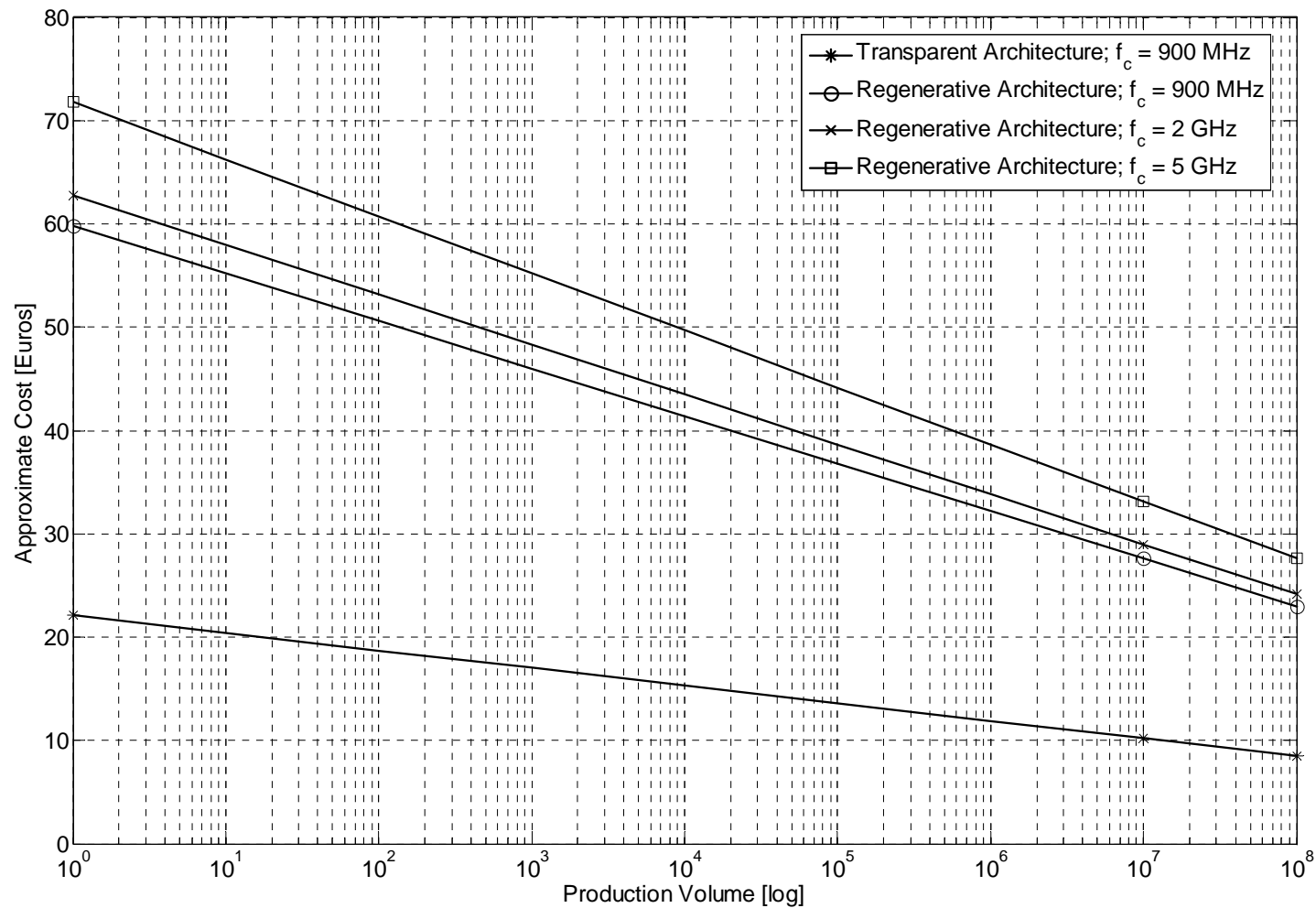
No Time-Division With AF

- 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:



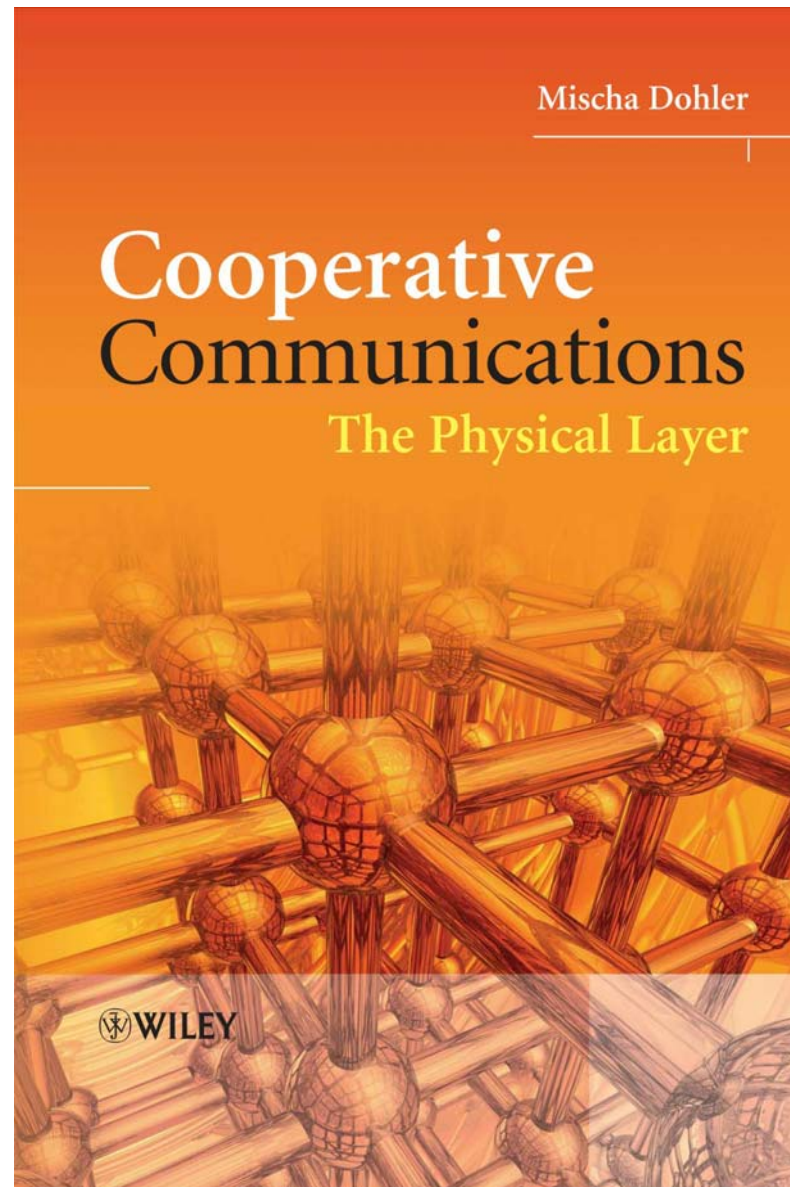
Complexity/Power Comparison

- 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

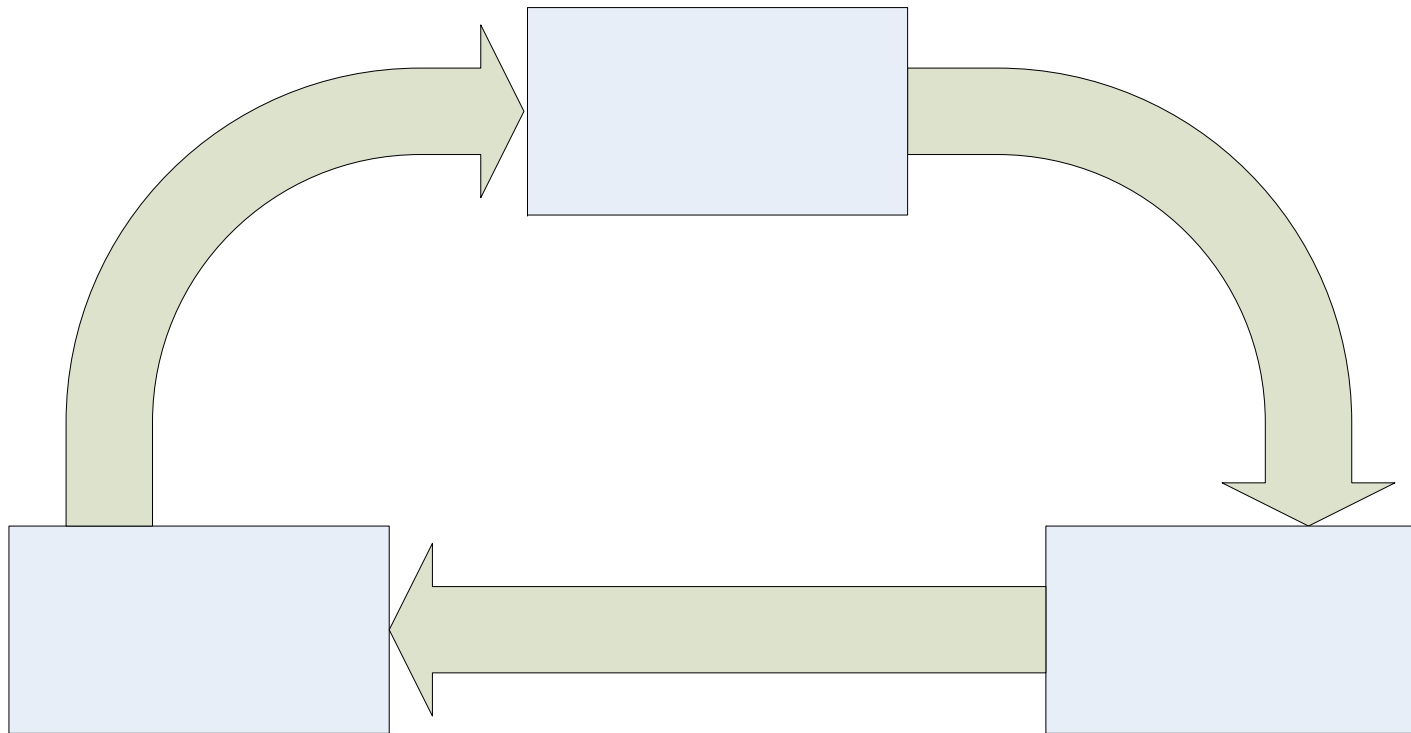
... for more detailed information ...



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Cognitive Networks

Canonical Cognitive Cycle



Obse

Different Intro to Cognition

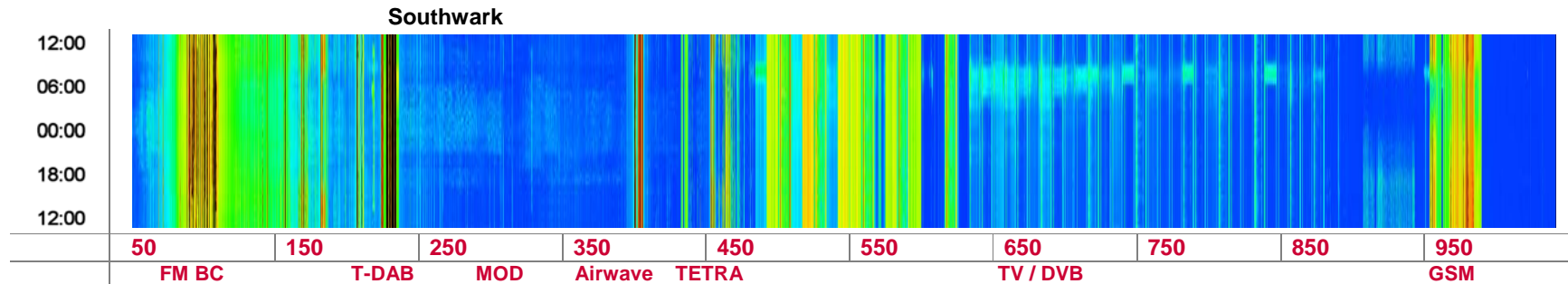
- Definitions of Cognitive Systems:
 - Rigorous: “... processes involved in gaining knowledge and comprehension, including thinking, knowing, remembering, judging, and problem solving.” [1]
 - Alternative: “... a system which is properly working under conditions it was initially not designed for.” [2]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

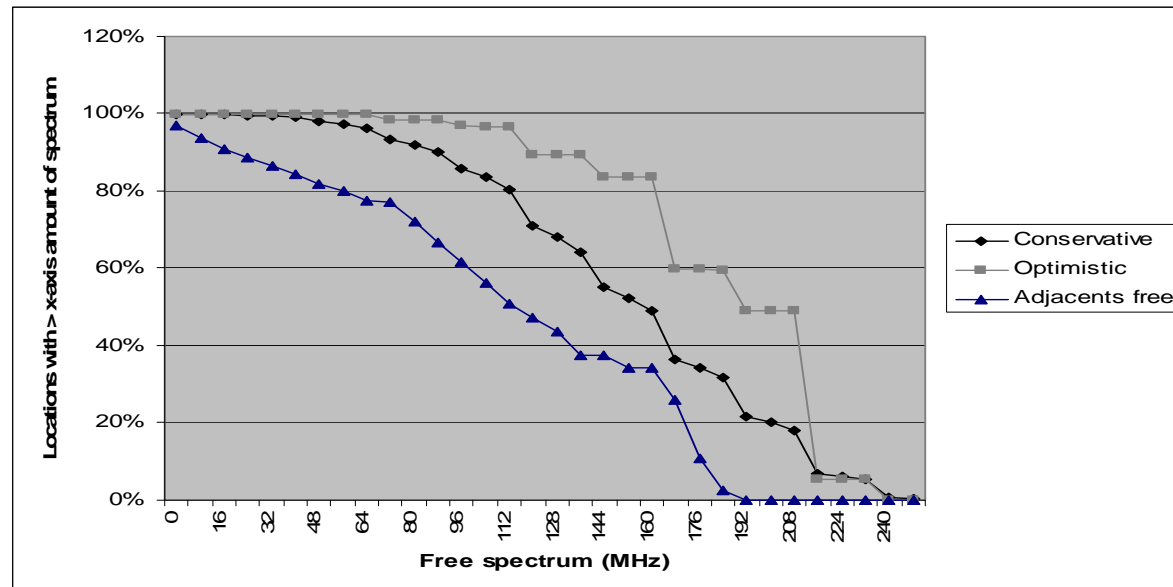
[2] Apostolos Kontouris, Orange Labs, France, 2007.

Opportunities in Interleaved Spectrum?

- Apparently large amount of spectrum unused [3]:



- However [3]:



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

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

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

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Docitive Networks

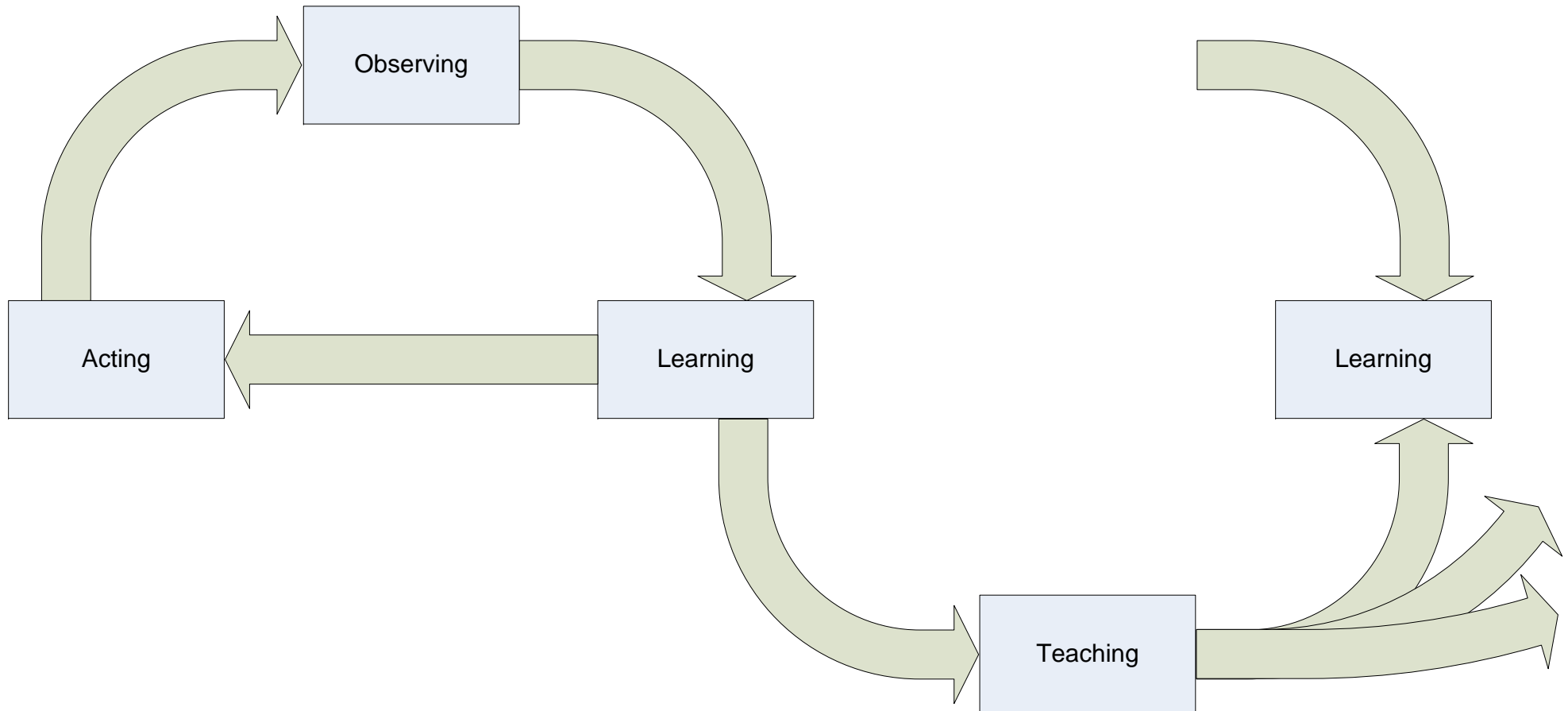
Case For Doceitive Systems

- 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

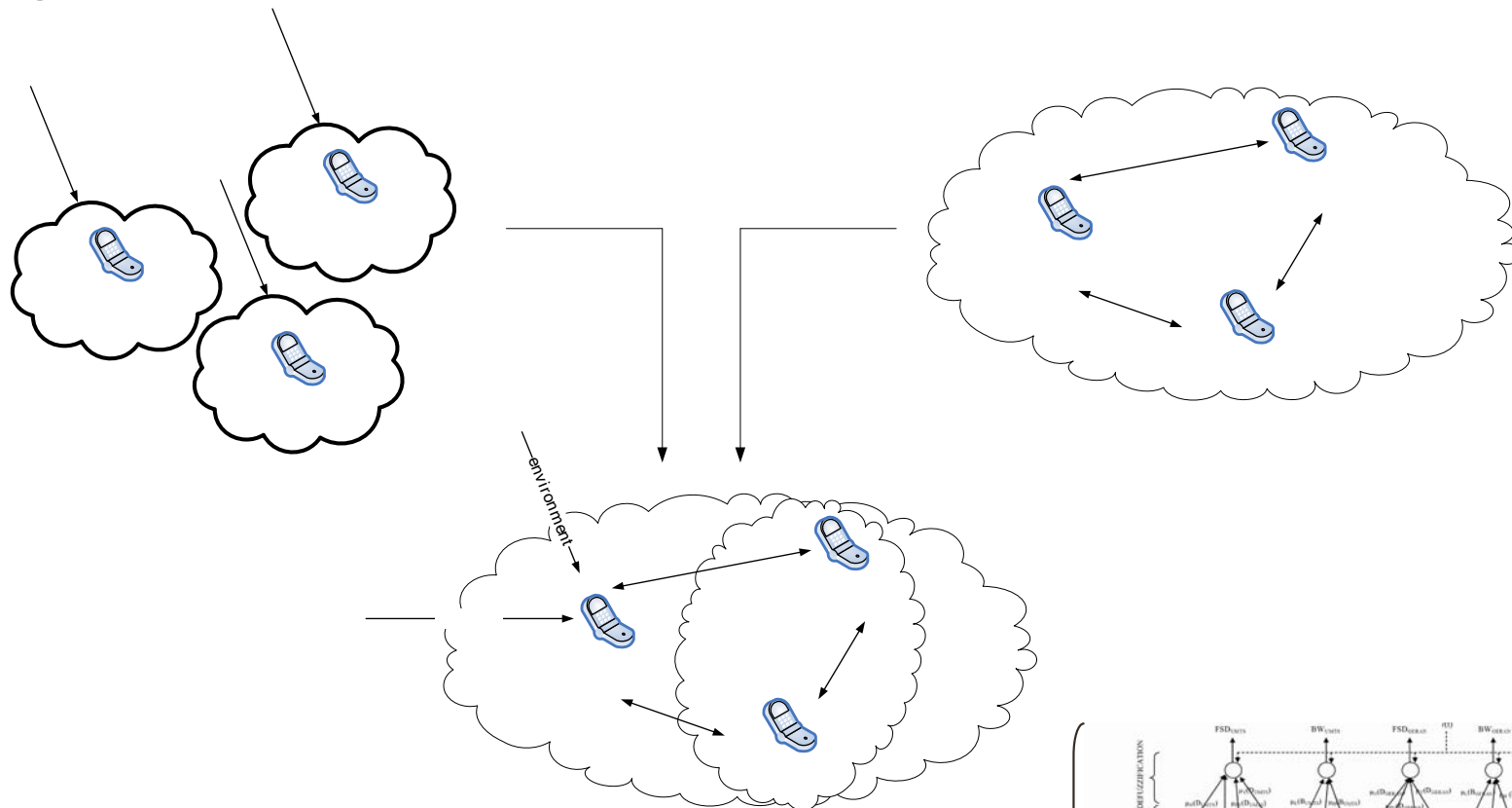


Problem Based Learning in Society

- 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

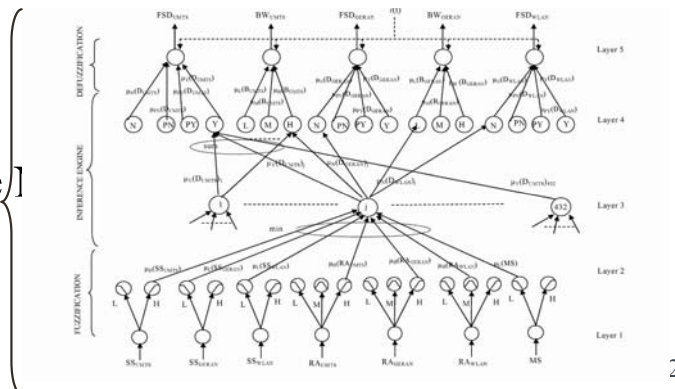
Projecting into Telecommunications

■ 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