Cognitive Radio for Green Communications and Networking

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SUPELEC/IETR, Rennes, France
Speaker : Jacques Palicot

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AICT 2013
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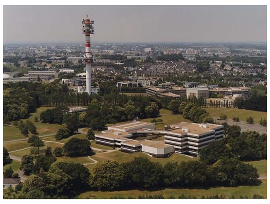
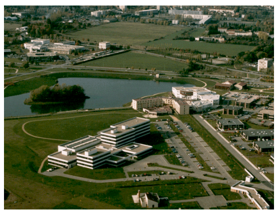
outline

1. SUPELEC/SCEE research team
2. Introduction
3. The « Cognitive Radio » concept
4. CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction
   - At the component level
   - At the network level
5. Electromagnetic Pollution and Spectrum Resources Optimization
6. Recycling the Resources
7. Green Communications as a Mean for an Improved Public Health
8. Conclusion

outline

SUPELEC ENGINEERING SCHOOL





- **SUPELEC is a French "grande école" of engineering: Ecole Supérieure d'Electricité**
  - Academic instititution created in 1894
  - Engineers in electronics, energy, information technology (telecommunications, computer sciences, etc.)
  - 3 campus in France: Paris, Rennes, Metz
  - Faculty: 150 / Research scientists: 90 / 2000 engineering students / 250 Ph.D. students

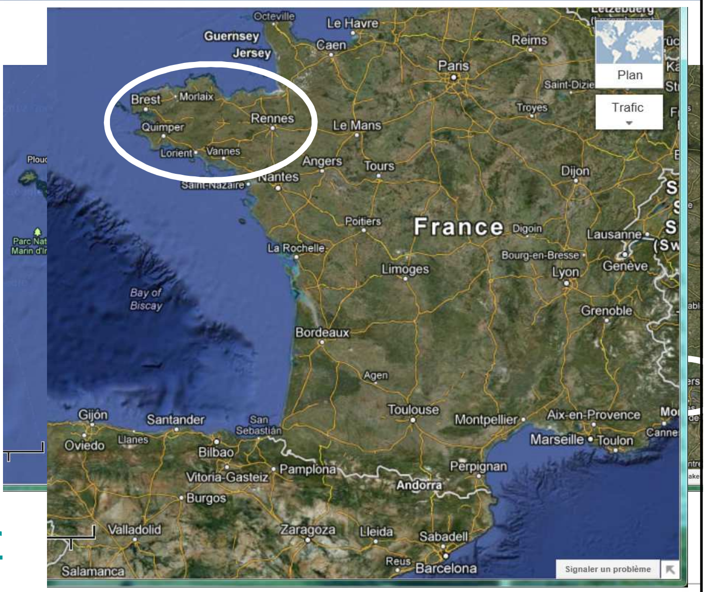
SCEE Team

- **SCEE research team**
  - IETR - Institute of Electronics and Telecommunications of Rennes - CNRS 6164
  - Signal, Communication and Embedded Electronics
  - head: Prof. Jacques PALICOT
- **Study and design of future communication systems based on Software Radio, Cognitive Radio and Green Radio concepts.**
  - 8 professors-researchers / 15 Ph.D. / 3 post-docs
  - Average of 10 journal publications and 25 international conf. per year.
  - 2013-2014: Honggang ZHANG (Inter[al] Chair)
- **SCEE is a team of IETR lab (UMR CNRS 6164)**
  - Communication Department

Where is IETR?

- **Rennes**
- **Lannion**
- **Saint Brieuc**
- **Nantes**
- **Angers**
- **Saint Malo**

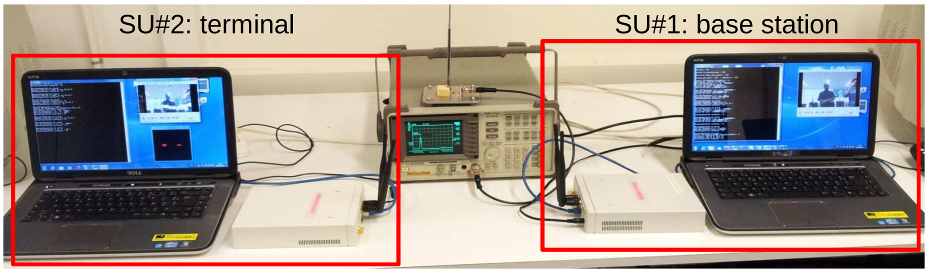
www.ietr.fr



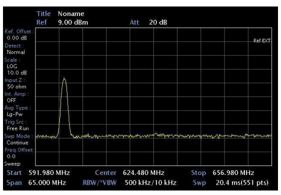
CR demonstrators

- **Opportunistic spectrum access**
  Acropolis Workshop'12
- **Real-time partial reconfiguration of FPGA**
  - CrownCom'10 in Cannes, SDR'07-09 in USA
  - in collaboration with CEA: FAUST platform
- **Blind standard recognition sensor**
  - CrownCom'10, Cannes, Funems'10, Firenze, ISWCS’11, York, DySPAN'11, Aachen.
  - USRP platform
- **Multi-level modeling – systemC HDCRAM modeling and execution on USRP**
  - SDR'10, Washington DC

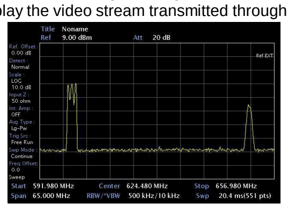
Demonstrator: OSA



Demonstrator: 1) SU#1 is composed of a laptop executing a video service transmitted (simple BPSK modulation scheme) through a USRP (white box) at a RF frequency F1 of 600 MHz (respectively F2 of 650 MHz) – 2) RF signal generator is transmitting at a frequency different form 600 MHz – 3) a spectrum analyzer is used to observe in real-time what is the frequency used by SUs – 4) SU#2 is also composed of a laptop and a USRP platform converting radio signal at 600 MHz (respectively 650 MHz) to baseband so that laptop executes a video player to display the video stream transmitted through a SU channel



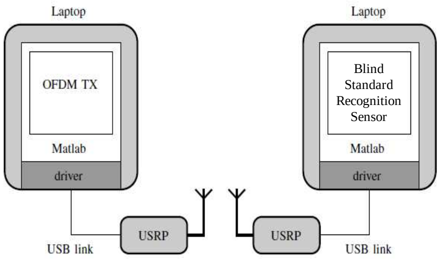
Spectrum analyzer snapshot with SUs communicating at 650 MHz, while PU is at 600 MHz



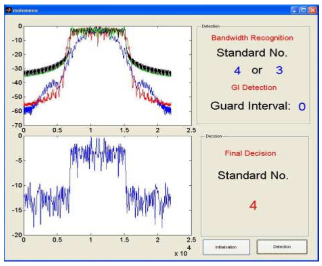
Demonstrator: Blind Std Recognition Sensor (BSRS)

TX

RX



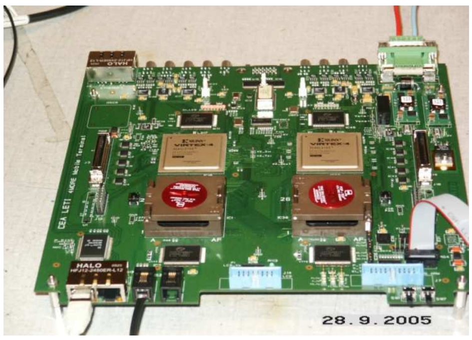
- Real 2.4 GHz transmission with USRPs plateforms
- Blind Bandwith shape recognition (neural network)



Presented in :

WUN CogCom (York, September 2010)
CrownCom (Cannes, June 2010)
FUNEMS (Florence, June 2010)
DySPAN (Aachen, May 2011)

Demonstrator: Partial Reconfiguration of FPGA



- only a sub part of the FPGA can be reconfigured
- fast reconfiguration (few micro sec.)

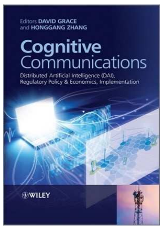
- No video streaming interruption while reconfiguration
- Baseband IPs reconfigutation in NOC context

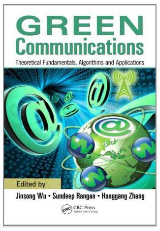
Presented in :

SDR Forum (Washington, Dec. 2008)
CrownCom (Cannes, June 2010)
WUN CogCom (York, September 2010)

International Chair on CGR

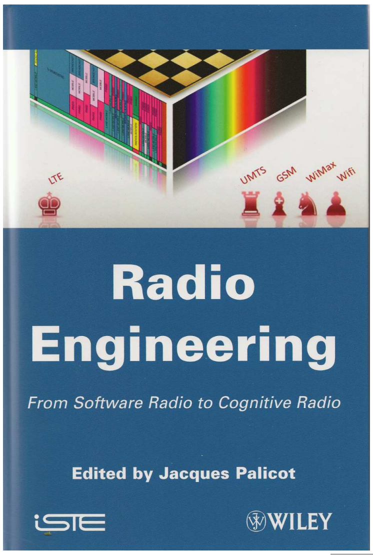
- **International Chair of UEB/CominLabs**
  - Professeur Honggang Zhang
    Zhejiang University - Chine
  - Topic : Cognitive Green Radio
  - Project: **GREAT for (*G*reen Cognitive *R*adio for *E*nergy-*A*ware wireless communication *T*echnologies evolution)**
  - Since 1st December 2012 for 2 years





Two Books

- **In French and in English**



Foreword

Wireless Communications of the 21st Century

Well known :

- demand in services, in throughput increase
- demand in ubiquitous connections
- Ecological issues

But: Spectrum rare and expensive
Near Shannon capacity
Increase in CO_2 emission

What could be done????

Foreword

2 key Words

Intelligence

Sustainable Development

Cognitive Green Radio Concept

« We would like to decrease the electromagnetic level by sending the right signal in the right direction with the optimal power, only when it is necessary, for the same QoS ».[1] Useful radio waves concept

[1]J.Palicot, « Cognitive Radio: An Enabling Technology for the Green Radio Communications Concept », IWCMC, Leipzig, Germany June 2009

IETR

outline

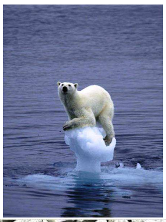
Supélec

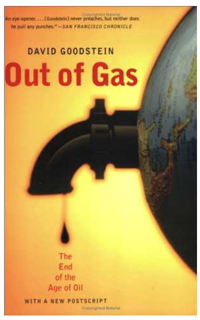
IETR

1 – Introduction 1/12

Supélec

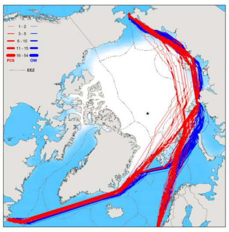
Global Warming – The Most Dangerous Threat ?

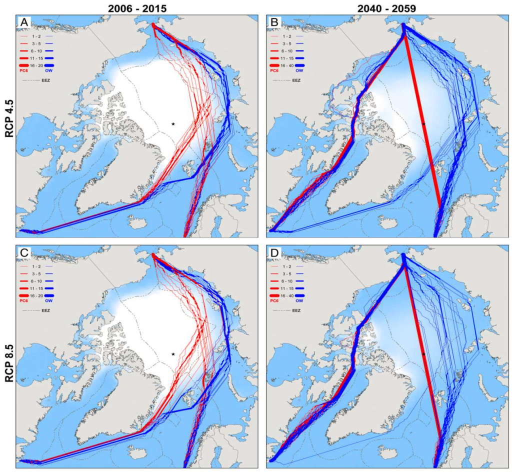




Terrible Climate Change: Trans-Arctic Shipping Routes Navigable 21st-midcentury

Summer Route

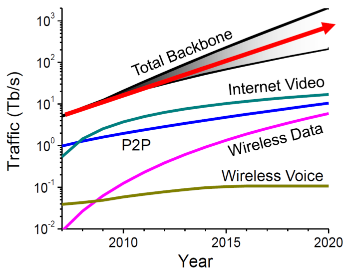


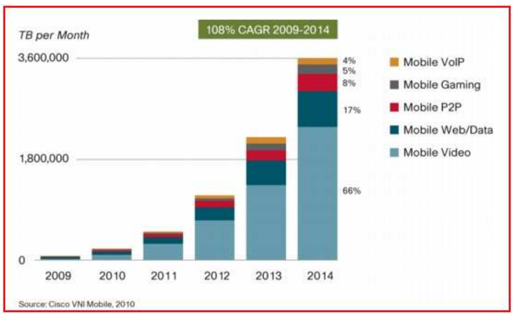


Source: Laurence C. Smith and Scott R. Stephenson, "New Trans-Arctic Shipping Routes Navigable by Midcentury," PNAS, January 2013.

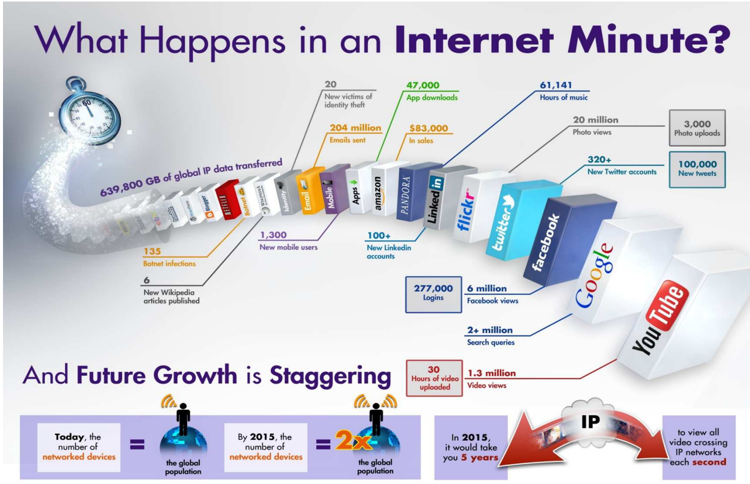
Data Explosion - Exponential Traffic Growth (1/2)

Internet Applications





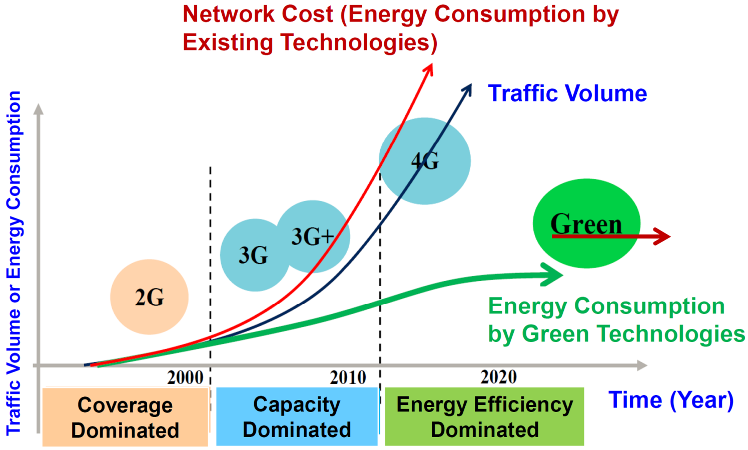
Data Explosion - Exponential Traffic Growth (2/2)



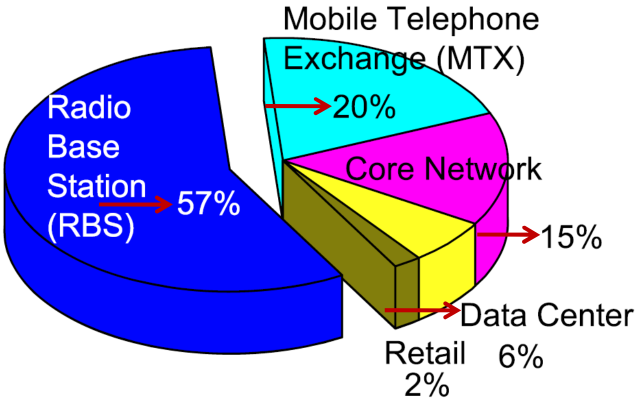
Source: http://bigdatadiary.com/networks-strain-to-keep-pace-with-data-explosion/internetminute/

Green Communications

Paradigm Change from Coverage- & Capacity-Driven to Energy-Efficiency Driven Era

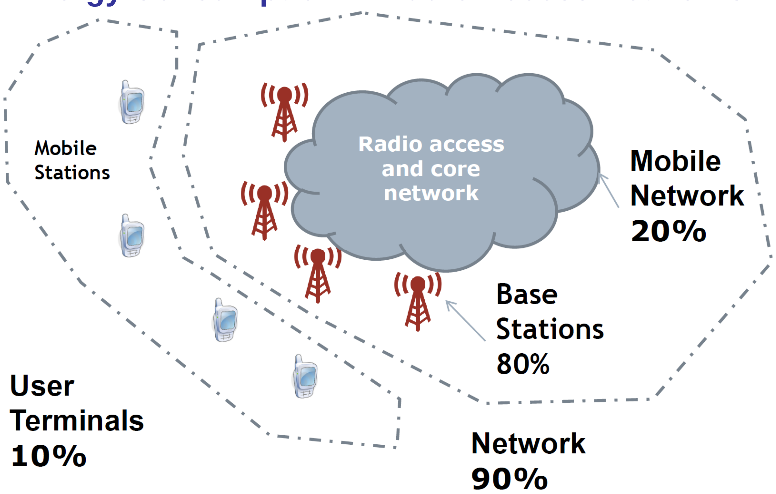


Mobile Telecommunications Networks Power Consumption Breakdown



Energy consumption composition in Vodafone (Source: Vodafone)

Energy Consumption in Radio Access Networks



- First international workshop on Green Wireless[1]

– Currently, 3% of the world-wide energy is consumed by the ICT infrastructure which causes about 2% of the world-wide CO_2 emissions

– which is comparable to the world-wide CO_2 emissions by airplanes or one quarter of the world-wide CO_2 emissions by cars.

A positive way to interpret this fact may be the question
How ICT can contribute in decreasing the rest of 98% ?
•May economize (1 to 4 times) its own emission
•Great R&D challenge

[1]http://www.cwc.oulu.fi/workshops/W-Green2008.pdf

- First international workshop on Green Wireless[1]
  – Another challenge of future wireless radio systems is to globally reduce the electromagnetic radiation levels to have
    - a better coexistence of wireless system (less interference)
    - a reduced human exposure to radiations.

→ inter-disciplinary research challenges

Cognitive Radio may have an important role

Green Communications and Green Spectrum: Is Cognitive Radio an Enabler or Anyone else?[2]

My answer: Yes, it is an enabler[3]

[1]http://www.cwc.oulu.fi/workshops/W-Green2008.pdf
[2]J.Palicot, Honggang Zhang, Panel, CROWNCOM 2009, Germany June 2009
[3]J.Palicot, « Cognitive Radio: An Enabling Technology for the Green Radio Communications Concept », IWCMC, Leipzig, Germany June 2009

1 – Introduction 10/12

IETR · Supélec

- **Specific electricity* consumption in the residential sphere in FRANCE[4]**
  - Gain in consumption of white equipments (washing machine...) lost with the increase in consumption of brown equipments (TV set, PC..)
  - Multimedia equipments are the most power consuming equipments
    - New TV set with flat screens
    - Boxes (built without consumption consideration)
    - with termination of analog TV services
  - Standby mode: 10% of the specific electricity.
  - Cellular mobile consumption very low (< 1%, with new generation larger screen,…)

*Specific electricity: electricity used by equipments that can not use other energy (does not include heating, cooking,..)

[4]H.Breuil, D.Burette, B.Flüry-Hérard, J.Cueugniet, D.Vignolles, « TIC et développement durable », Rapport du ministère de l'Ecologie, de l'énergie, du développement durable et de l'aménagement du territoire, décembre 2008, in French.

1 – Introduction 11/12

IETR · Supélec

ICT Carbon footprint in France

- **Carbon footprint in the residential sphere in FRANCE[4]**
  - ~40% of the ICT emission
- **Carbon footprint in the professional sphere in FRANCE[4]**
  - ~60% of the ICT emission
- **Multimedia equipments ~25% of the ICT emission**
- **Usage carbon footprint: low (French nuclear park)**
- **Production (conception, transport) footprint is preponderant.**
  - Mobile phones footprint no more negligible

[4]H.Breuil, D. Burette, B. Flüry-Hérard, J. Cueugniet, D. Vignolles, « TIC et développement durable », Rapport du ministère de l'Ecologie, de l'énergie, du développement durable et de l'aménagement du territoire, décembre 2008, in French.

1 – Introduction 12/12

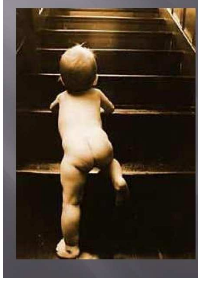
- **CO_2 reduction at two levels:**
  - To reduce the ICT emission itself
  - Use ICT to reduce emission of other human activities (transport, tele-working, e-commerce,…..)
    - First online IEEE conference on Green Communications http://www.ieee-greencom.org/ september 2012
- **Keyword : Intelligence**
  - to put it everywhere
  - Distributed Artificial Intelligence (DAI)
- **Use of Cognitive Radio Technology to meet these objectives**

outline

Cognitive Radio-Introduction 1/5

Basics of Cognitive Radio

- Cognitive Radio & Networking
  - Input - Decision Making - Action
    - Environment awareness (Input)
      - External stimuli
      - Sensing
    - Interpretation & Learning (Decision Making)
      - Reasoning
      - Interpretation
      - Learning
    - Implementation of Decision (Action)
      - Actuation
      - Parameter change



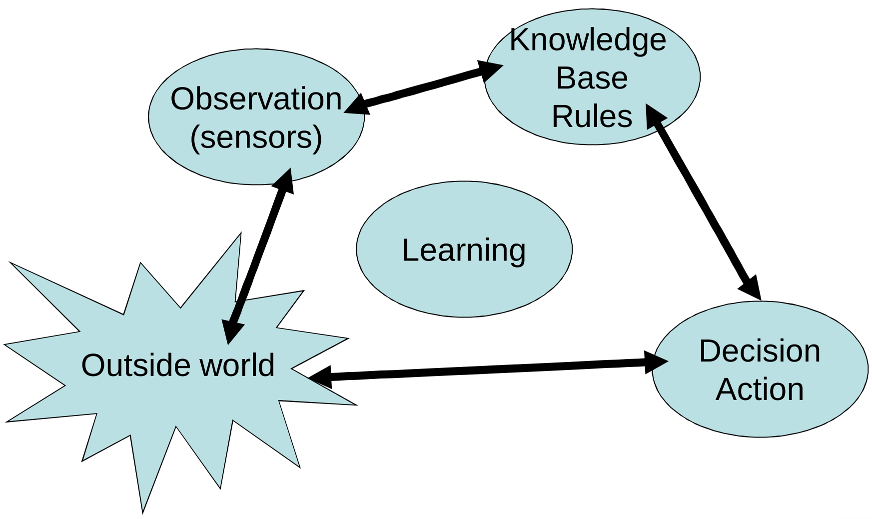
sensing the radio context, service context, location context and user context

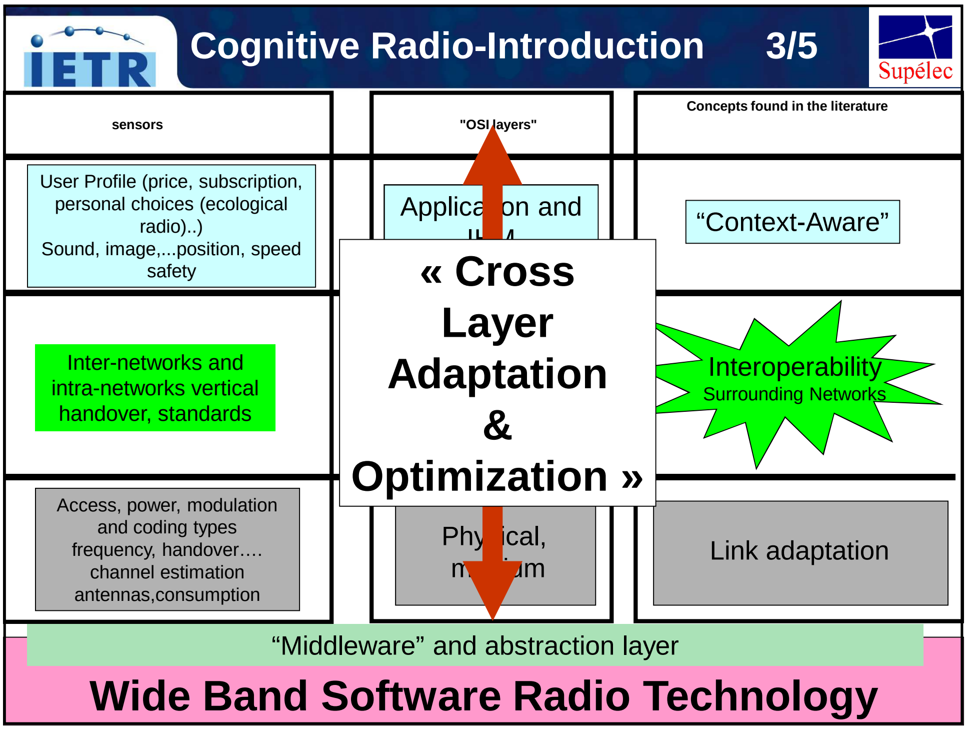
interpreting the radio environment

reacting to the changes (radio protocols), tuning the radio and implementation parameters, fault management

Cognitive Radio-Introduction 2/5

Conventional cognitive cycle

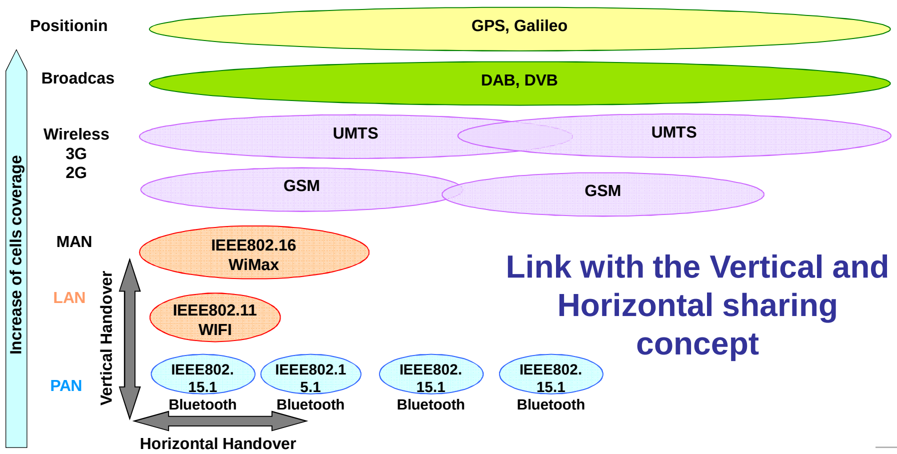




Cognitive Radio-Introduction 4/5

•"Generalized Handover" concept:

– Geographic mobility : Conventional « **Horizontal Handover** »
– Mobility between Networks, Standards, Services :« **Vertical Handover** »



Cognitive Radio-Introduction 5/5

Supélec

- Decentralized view associated with a local optimization of needs and resources versus a centralized view based on the worst case scenario needs.

  - Ex 1 : implementation of an equalizer independently of the channel IR

Cognitive Radio-The sensors 1/5

Supélec

Sensors classification according to the environment

- **electromagnetic environment:** spectrum occupancy, Signal to Noise Ratio (SNR), multi-path propagation…
- **hardware environment:** battery level, power consumption, number of used gates,…
- **network environment:** telecommunication standards (GSM, UMTS, WiFi, etc.), operators and services available in the vicinity, traffic load on a link…
- **user-related environment:** localization, speed, time of day; user preferences, user profile (access rights, contract…), video and audio sensor (presence detection, face, voice recognition)…

The CR sensors according to the simplified three layer model

Sensors	Layers
Use profile (price, operator personal choices, …) Sound, Video, Speed, Position, Indoor, Outdoor, …	Application and IHM
Vertical Handover, Standard Recognition, Load on a link, …	Transport, Network
Access mode, Power, Modulation, Horizontal Handover, channel estimation, Direction of Arrival, Consumption, …	Physical, Data Link

Application layer sensors

- **Application layer sensors ("Context Aware"):**
- **Identify, analyse and interact with the user (audio, video, other,...)**
- **Effects on radio access**
  - Video sensor
  - Obstacle: Unknown face characteristic points precise positioning, in real conditions.
  - Solution obtained thanks to the Appearance Active Models.

Cognitive Radio-The sensors 4/5

Intermediary layer sensors

- Dedicated pilot channel spectrum recognition
- Geo localization spectrum recognition
- Standards blind recognition

Cognitive Radio-The sensors 5/5

Physical layer sensors

- Bandwidth blind recognition
- Mono/Multi carriers detection
- FH/DS-SS Detection
- Available bands detection (Hole detection)

IETR Cognitive Radio-Decision Making 1/32 Supélec

Decision Making: A matter of information

- **Make a decision in a CR equipment or in a network is all about**
  - depending on a goal (criteria)
  - adapt parameters (if possible ➔ SDR)
  - in function of what the environment permits

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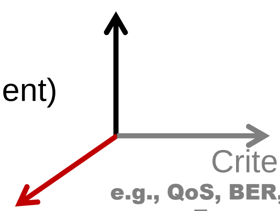
IETR Cognitive Radio-Decision Making 2/32 Supélec

- **The way to solve it depends on the degree of information available on all this**
  - SNR, holes, bands occupation rate

Criteria = f (Parameters; Environment)



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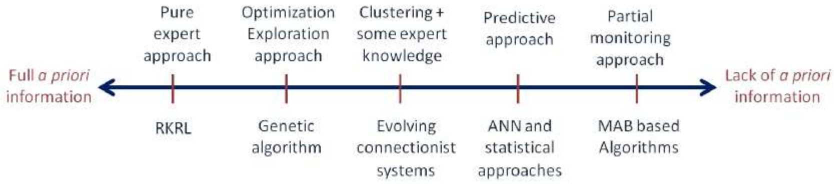
Cognitive Radio-Decision Making 3/32

IETR | Supélec

- **Depending on the degree of knowledge, different decision making solutions may be worth analyzing**
  - the more *a priori* knowledge ➔ left
  - the more uncertainty➔ right



[2] Wassim JOUINI, Christophe MOY, Jacques PALICOT, "On decision making for dynamic configuration adaptation problem in cognitive radio equipments: a multi-armed bandit based approach," 6th Karlsruhe Workshop on Software Radios, WSR'10, Karlsruhe, Germany, March 2010

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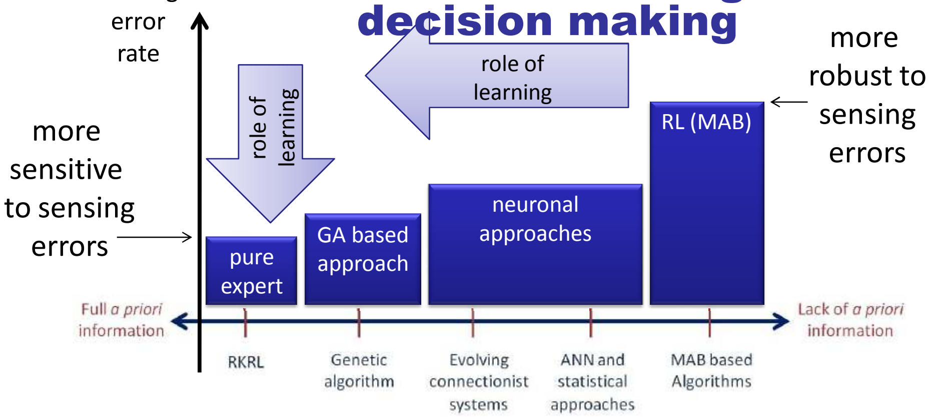
Cognitive Radio-Decision Making 4/32

IETR | Supélec

The role of learning in decision making



[9] Wassim JOUINI, Christophe MOY, Jacques PALICOT "Decision making for cognitive radio equipment: analysis of the first 10 years of exploration" *EURASIP Journal on Wireless Communications and Networking 2012*, 2012:26

EURASIP Journal on Wireless Communications and Networking — IMPACT FACTOR 0.87
8. Review — Open Access — Highly accessed — 2904 Accesses
Decision making for cognitive radio equipment: analysis of the first 10 years of exploration
Wassim Jouini, Christophe Moy, Jacques Palicot
EURASIP Journal on Wireless Communications and Networking 2012, **2012**:26 (25 January 2012)
Abstract | Full text | PDF

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Techniques for decision making

- **Game theory**
- **Information /knowledge propagation (transfer)**
- **Machine learning techniques**
- **Statistical Signal Processing**
- **Swarm Intelligence**
- **Expert algorithms**
- **…**

- **All could be applied in both collaborative or non-collaborative schemes.**

- **Left side (high *a priori*) decision approaches have been addressed a lot in the litterature**
  - also in the CR field

[3] C.J. Rieser, "Biologically Inspired Cognitive Radio Engine Model Utilizing Distributed Genetic Algorithms for Secureand RobustWireless Communications and Networking", PhD thesis, Virginia Tech, 2004

[4] N. Colson, A. Kountouris, A.Wautier, L. Husson, "Cognitive decision making process supervising the radio dynamic reconfiguration", CronwCom 2008

[5] N. Baldo, M. Zorzi, "Fuzzy logic for cross-layer optimization in cognitive radio networks", Consumer Communications and Networking Conference, January 2007

[6] C. Clancy, J. Hecker, E. Stuntebeck, "Applications of machine learning to cognitive radio networks", IEEE Wireless Communications Magazine, vol 14, 2007

[7] T. Weingart, D. Sicker, and D. Grunwald, "A statistical method for reconfiguration of cognitive radios", IEEE Wireless Commun. Mag.,vol. 14, no. 4, pp. 3440, August 2007

[8] T. W. Rondeau, D. Maldonado, D. Scaperoth, C.W. Bostian, "Cognitive radio formulation and implementation", IEEE Proceedings CROWNCOM, Mykonos, Greece, 2006

Expert approach

- **Based on the important amount of knowledge collected by telecom. engineers and researchers for years**
  – theoretical considerations
  – environment measurements (channel imp.resp.)
- **On-line adaptation of the equipment following a set of inference rules (obtained off-line)**
- **Issues**
  – plan every situations the CR equipment meets
  – representation of knowledge (RKRL)

Genetic algorithms

- **CR may be seen as a multi-criteria optimization issue**
  – some relationship exists between observed metrics, parameters to adapt and criteria to satisfy
- **Reflex ➔ genetic algorithms**
  – find best parameters to meet user's expectations
- **But quite much *a priori* knowledge is needed (in order to parameter the implemented GA)**

Decision making and CR

- Often if not always mix techniques
- But we may expect that most of the time a CR equipment will have to make decisions
  - on a high number of criteria
  - with a lot of unknwown, uncertainty
- Hardest case: a minimum of knowledge
- Example of dynamic configuration adaptation (DCA) and opportunistic spectrum access (OSA)

➔ a lot of unknown information

Decision making for DCA

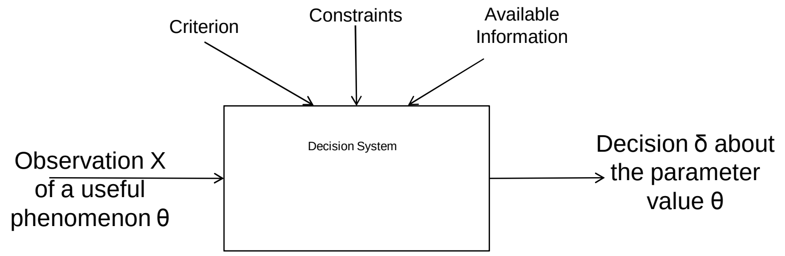
- DCA: dynamic configuration adaptation
- Future scenario of full-free real-time link adaptation (just impact at PHY layer studied here)
- Depending on
  - the environment: propagation, network load, etc.
  - the equipment capabilities in terms of flexibility: constellation, channel coding, interleaving, etc.
  - the user: communication nature, required QoS, contract, location, speed, etc.
- What is the best configuration?
- At every instants?

Decision making for OSA

- **OSA: opportunistic spectrum access**
- **A secondary user (SU) may access the spectrum dedicated to a primary user (PU)**
- **Depending on**
  - the environment: bands availability, BW, etc.
  - the equipment capabilities in terms of flexibility: carrier frequency, filtering, constellation, etc.
  - the user: communication service, required QoS, location, etc.
- **What is the best channel choice?**
- **At every instants? See later section 5**

Decision theory in statistical signal processing

Decision System



Information : statistical model Probability Density Function (pdf) for X and eventually θ

Criterion : average cost in bayesian models or others

Constraints : imposed solution like linear or affine solution in estimation theory

Applications : Detection, Classification, Estimation and Statistical Filtering theories

Example of SPS Decision making in Cognitive Radio 1/2

Sensors of radio environment metrics (Sensing)

➔ Channel estimation / SNR estimation / ISI Inter-Symbol Interference estimation / Channel capacity estimation / AOA estimation / etc ….
➔ Each metric is represented by a random variable

Statistical modeling of these radio metrics : a statistical model for each metric to characterize its behavior

➔ Identify the probability density function (pdf) of each observed metric
➔Estimate the probability density function parameters

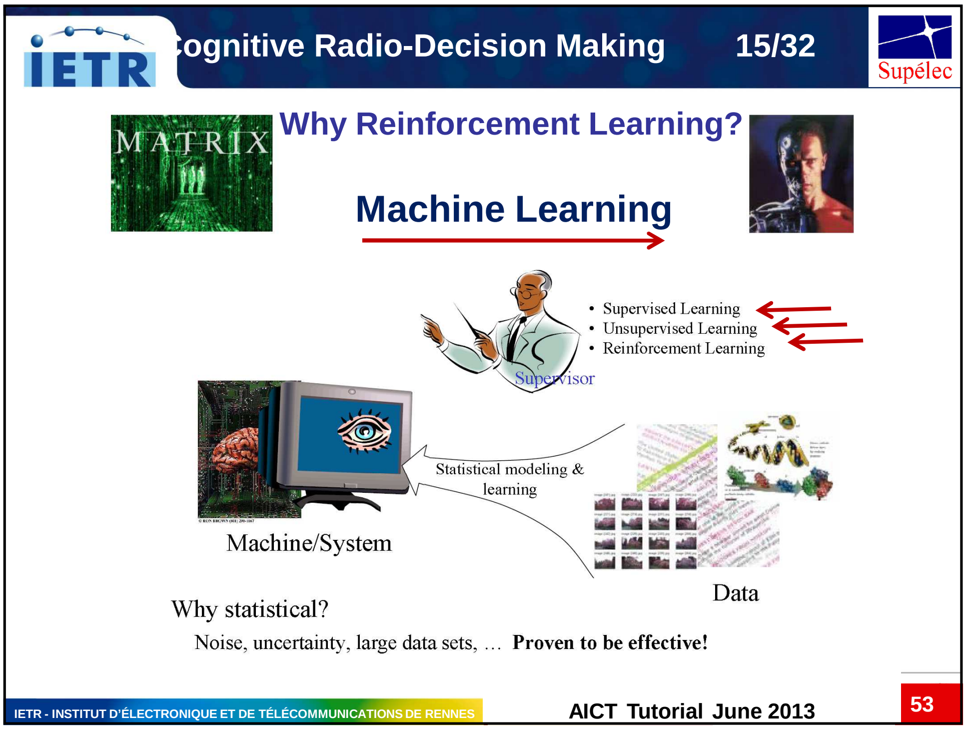
Example of SPS Decision making in Cognitive Radio 2/2

Thresholds determination for qualification of metrics according to :

➔ Standard required performance (BER)
➔User requirements (throughput)

Decision making by statistical hypothesis tests

➔ Likelihood ratios compare to thresholds
➔ Actions decision to take in order to adapt the equipment to the state of its environment


Cognitive Radio-Decision Making 15/32
IETR
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Why Reinforcement Learning?
MATRIX
Machine Learning
Supervised Learning
Unsupervised Learning
Reinforcement Learning
Supervisor
Statistical modeling & learning
Machine/System
Data
Why statistical?
Noise, uncertainty, large data sets, … Proven to be effective!
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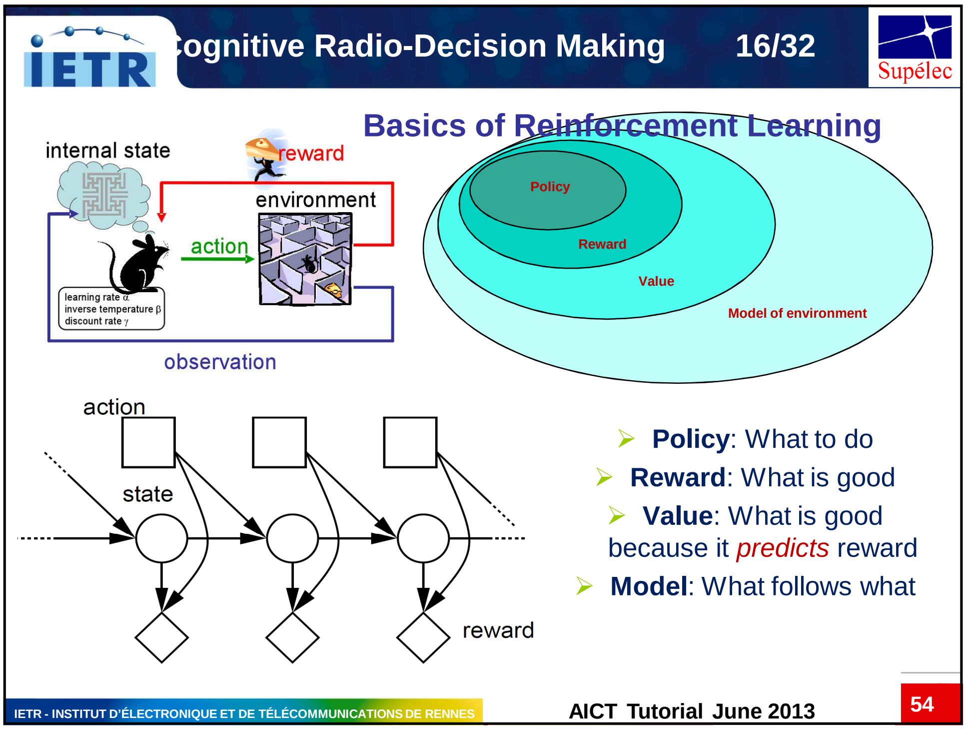
Cognitive Radio-Decision Making 16/32
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Basics of Reinforcement Learning
internal state
reward
environment
action
learning rate α
inverse temperature β
discount rate γ
observation
Policy
Reward
Value
Model of environment
action
state
reward
Policy: What to do
Reward: What is good
Value: What is good because it predicts reward
Model: What follows what
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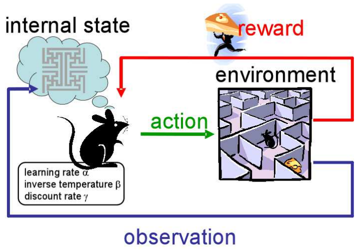


Reinforcement Learning

- Multi Arm Bandit (MAB)
- Weight Driven (WD) University of York
- Actor Critic (ACT)
- Transfer Knowledge (TACT)

Exploration vs exploitation

- **When a priori knowledge is missing**
  ➔ **need to learn**
  ➔ **reinforcement learning: try and regret/reward**
- **First solution**
  - learn then exploit
  - but loose (time or wages) when learning
- **Second solution**
  - mix learning and exploitation
  - example of multi-armed bandit MAB (machine learning domain)

Moreover: can follow variations if not stationary

MAB - Multi-Armed Bandit

- **Las Vegas: which armed bandit to select for the best reward (in terms of money)?**
- **Multi-Armed Bandit (MAB) issue**
  - K possible choices $k \in [1,K]$ (machines)
  - Each choice has a mean performance μ_k
  - At each time t, the gambler plays a machine and obtains a reward r_t
  - Objective: not to find μ_k , but maximise the cumulative reward (his gain) or minimise regret

[10] Lai, T.L. and Robbins, H. Asymptotically efficient adaptive allocation rules. *Advances in Applied Mathematics*, 6:4-22, 1985

Naive approach

- **Let's consider a uniform test of the machines during an exploration phase**
- **We obtain an approximative value of the empirical mean $\overline{X}_k$ for all machines**
- **The probability to choose a sub-optimal machine after the exploration phase is not null**
  - either because exploration not long enough
  - bad scenari may exist statistically
  - ➔ linear regret in t (compared to the best choice)

Multi-Armed Bandits for CR decision making

- **Three steps iterative process: at each time t**
  1. The CR equipment senses the environment (simple example in DCA context: SNR)
  2. It chooses machine (configuration) k depending on an index $B_{k,t}$, a function of the past rewards (data rate & BER) it expects for this environment (SNR) based on its previous experience
  3. It measures the obtained new reward and updates its table of rewards for configuration k

[11] Wassim JOUINI, Damien ERNST, Christophe MOY, Jacques PALICOT, "Multi-Armed Bandit Based Policies for Cognitive Radio's Decision Making Issues", Signal Circuits and Systems Conference, Jerba, Tunisia, 6-8, Nov. 09

UCB for CR decision making using MAB

- **OK if we had full information at each instant t, but what if it is badly estimated ($\bar{X}_k \neq \mu_k$)?**
- **A bias may be added in function of the number of activations of each configuration**
- **Upper Confidence Bound (UCB) index**
  - $B_{k,t,T_k(t)} = \bar{X}_{k,T_k(t)} + A_{k,t,T_k(t)}$
  - for each arm k, in function of time t

    $\bar{X}$: empirical mean of the reward

    A: bias (avoid forgetting good solutions)

    T_k: number of times config. k has been chosen

Simplicity: just a sum! (for each arm)

UCB for CR decision making using MAB

- **Strategy: the higher UCB index for a configuration, the better the reward**
  ➔ select the configuration with biggest index
- **UCB: optimistic estimation of the reward**
  - adds the mean of the measured reward
  - with a positive bias weighted by time & number of activations (several ways exist)
- **Role of the bias**
  - avoid eliminating a good configuration if a bad measure has been done (or vice versa)

Regret notion

- **Regret is what has been lost compared to the choice of the best configuration at each *t***

$$R_t = t.\mu^* - \sum_{m=0}^{t-1} r_m$$

μ^*: reward of the best configuration

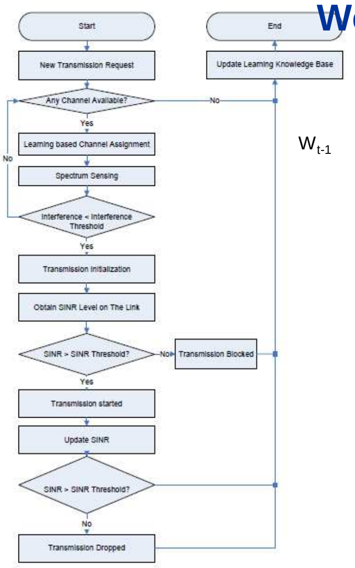
- **Cumulative regret**
  - under certain conditions, it can be proven that asymptotically UCB converges to the best solution (depending on the policy)

$$E[R_t] = \sum_{k=1}^{K} (\mu^* - \mu_k).E[T_k(t)]$$

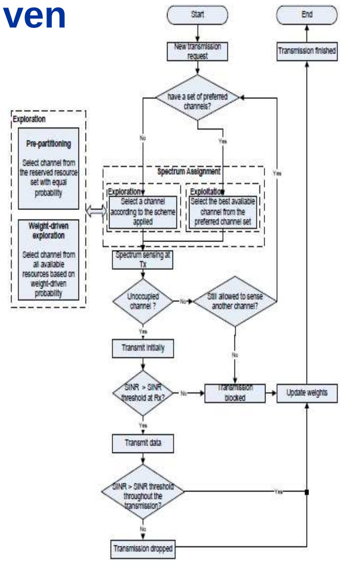
$$\lim_{t\to\infty} \frac{E[R_t]}{t} = 0$$

$$\lim_{t\to\infty} \frac{\sum_{m=0}^{t-1} r_m}{t} = \mu^*$$

Weight Driven (WD)



W_{t-1}



Weight Driven (WD)

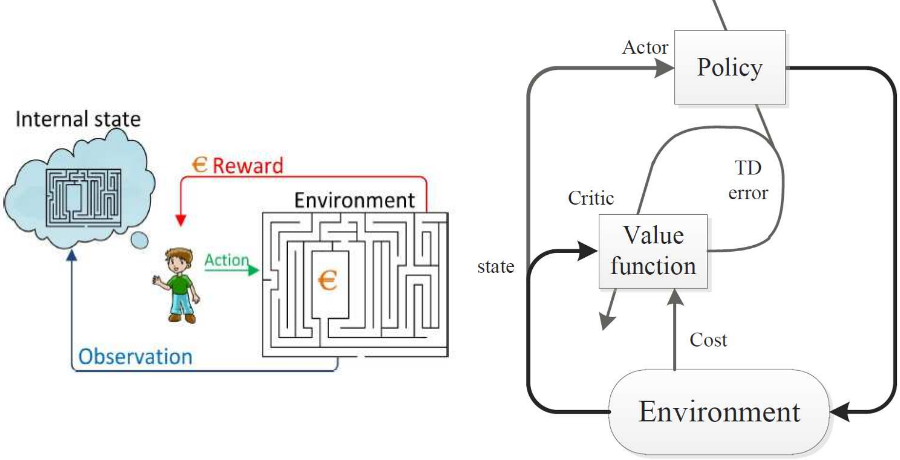
- Band choice probability:

$$P(c) = \frac{w_c}{\Sigma_{c' \in C} w_{c'}}$$

- Weights function:
- $W_t = f_1 W_{t-1} + f_2$
- f_1 et f_2 equal +1 if reward, f_2 à -1 if not.

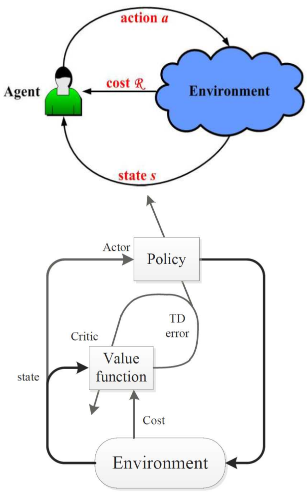
- **Preferred set:**
  - If a channel weight greater than a predefined threshold then it belongs to the predefined set.
  - Then when the set is full, **exploitation phase**
    - ➢ Other channels which are not in the set are no more choose, may never used the best one.

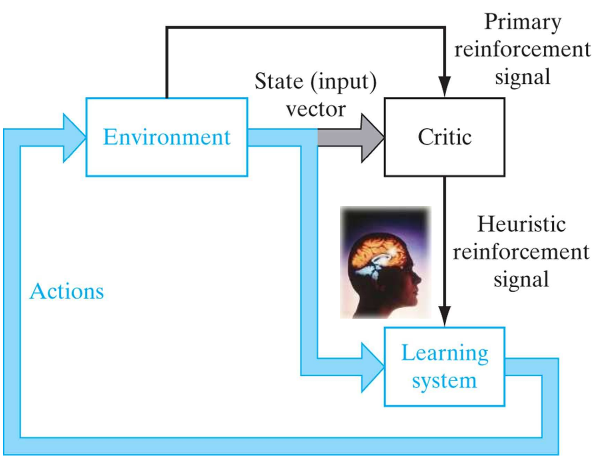
Reinforcement Learning: Actor-Critic Approach



Block Diagram of Reinforcement Learning

- The learning system and the environment are both inside the feedback loop



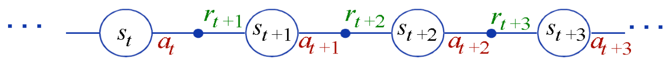


Markov Decision Processes (MDPs)

In Reinforcement Learning, the environment is a modeled as an MDP, defined by

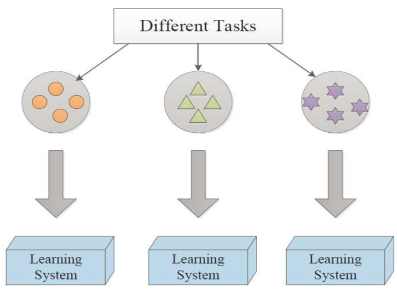
- S – set of states of the environment
- $A(s)$ – set of actions possible in state $s \in S$
- $P(s,s',a)$ – probability of transition from s to s' given a
- $R(s,s',a)$ – expected reward on transition s to s' given a
- γ – discount rate for delayed reward

discrete time, $t = 0, 1, 2, \ldots$

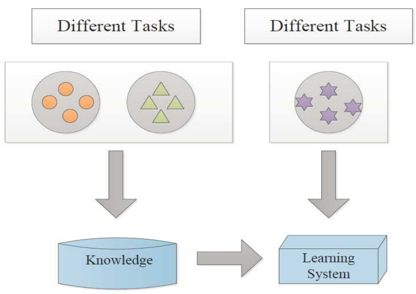


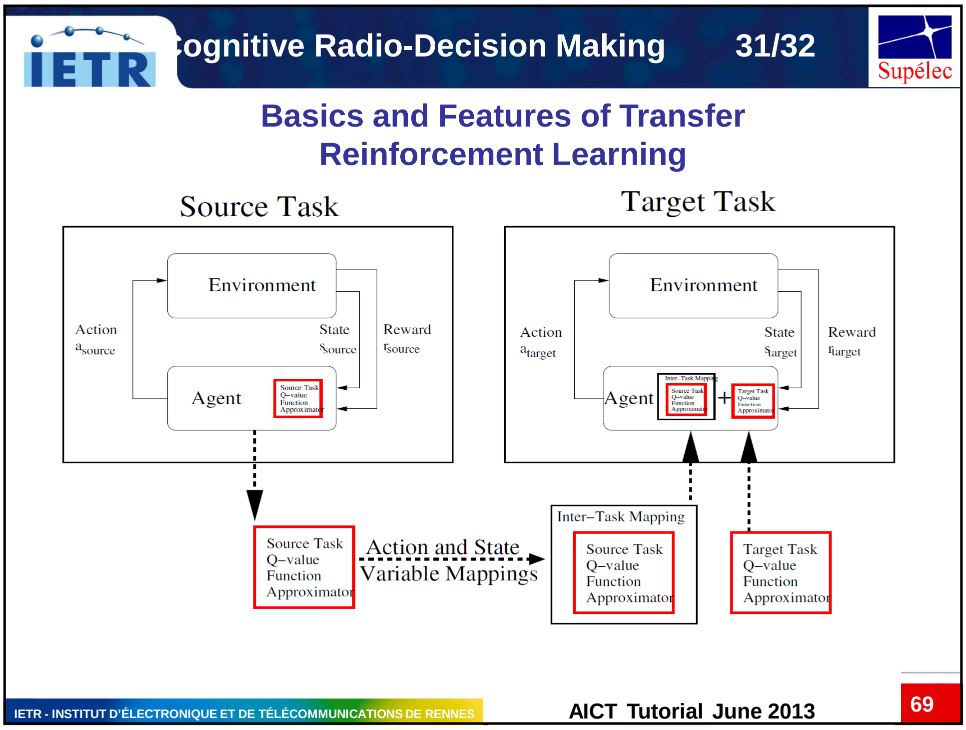
Basics and Advantages of Transfer Learning

Learning Process of Traditional Machine Learning



Learning Process of Transfer Learning

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Basics and Features of Transfer Reinforcement Learning
Source Task
Target Task
Environment
Action
State
Reward
Agent
Source Task Q–value Function Approximator
Action and State Variable Mappings
Inter–Task Mapping
Target Task Q–value Function Approximator
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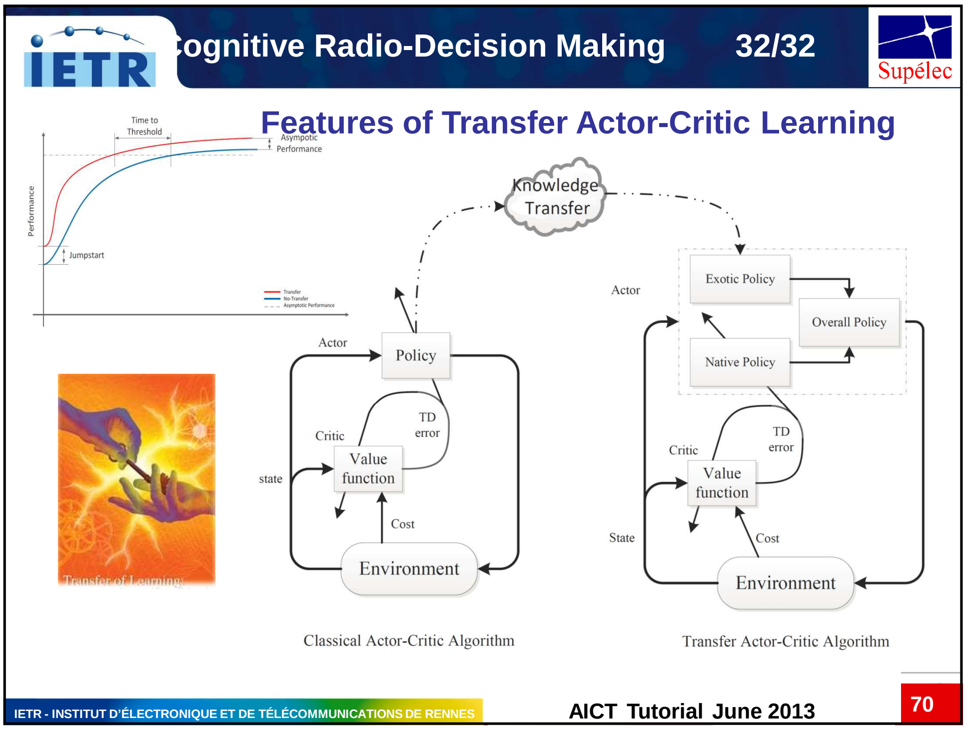
Cognitive Radio-Decision Making 32/32
Supélec
Features of Transfer Actor-Critic Learning
Time to Threshold
Asymptotic Performance
Performance
Jumpstart
Knowledge Transfer
Actor
Policy
Critic
TD error
Value function
state
Cost
Environment
Exotic Policy
Overall Policy
Native Policy
State
Classical Actor-Critic Algorithm
Transfer Actor-Critic Algorithm
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outline

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4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Component Level (1/15)

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- **To decrease the transmission power by putting off unused or unnecessary functions (locally)**
- Equipments are designed to run correctly in the worst situation
- An efficient and computationally costly equalizer is always running
- But, locally, in many situations the channel is good and the equalizer is not necessary
- Using the **Channel Impulse estimator sensor** CR will take into account and therefore put off the equalizer function if the channel is good.

→ Energy consumption gain

Salma Bourbia, Daniel Le Guennec, Khaled Grati, Adel Ghazel « Statistical Decision Making Method for Cognitive Radio, ICT 2012, Jounieh, Lebanon, April 2012

Using SSP-DM

Sensors of radio Environment

$$SNR_p = \frac{\|h_0\|^2 . \sigma_s^2}{\sigma_b^2}$$

$$ISI = E\left\{\left(\sum_{i=1}^{L-1} h_i . s[k-i]\right)^2\right\} = \sum_{i=1}^{L-1} \|h_i\|^2 . E\{[s[k-i]]^2\}$$

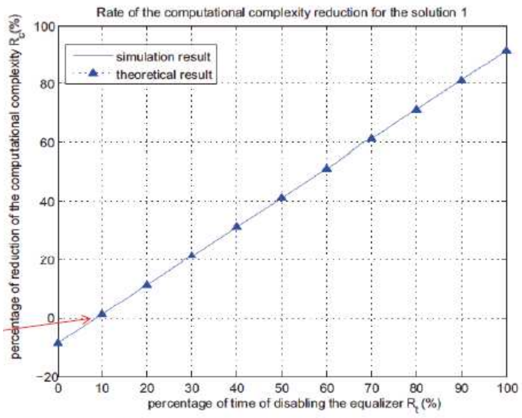
Satistical model

$$(\hat{x}^1_{SNR_p}, \ldots, \hat{x}^n_{SNR_p}) \longrightarrow \hat{X}_{SNR_p} \qquad N(\hat{\mu}^{ML}_{SNR_p}, \hat{\sigma}^{ML}_{SNR_p})$$

$$(\hat{x}^1_{ISI}, \ldots, \hat{x}^n_{ISI}) \longrightarrow \hat{X}_{ISI} \qquad N(\hat{\mu}^{ML}_{ISI}, \hat{\sigma}^{ML}_{ISI})$$

Salma Bourbia, Daniel Le Guennec, Khaled Grati, Adel Ghazel « Statistical Decision Making Method for Cognitive Radio, ICT 2012, Jounieh, Lebanon, April 2012

Complexity Gain Using SSP-DM



Maximum Gain 91%

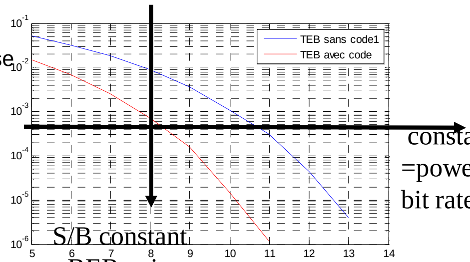
Complexity Gain starts at 9%

Salma Bourbia, Daniel Le Guennec, Khaled Grati, Adel Ghazel « Statistical Decision Making Method for Cognitive Radio, ICT 2012, Jounieh, Lebanon, April 2012

4- CO_2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Component Level (4/15)

- **Activating some functions so as to decrease the transmitting power**

Possible CR sensors to activate these gains
- SNR
- Channel Impulse Response
- Direction of Arrival
- Blind standard recognition
- ……



constant BER =power gain or bit rate gain

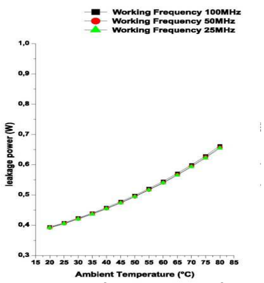
S/B constant =BER gain

Example: The **SNR sensor** gives (locally) a very good value. Then Tx and Rx agree to use a channel code to decrease the power

If choice of power decrease then indirect gains (HPA efficiency, less temperature....)

4- CO_2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Component Level (5/15)

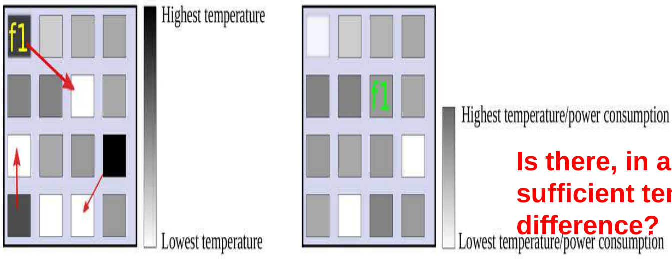
Function migration, in reconfigurable hardware, for temperature and power consumption management



relationship between temperature and consumption, leakage power example

4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Component Level (6/15)

Function migration, in reconfigurable hardware, for temperature and power consumption management

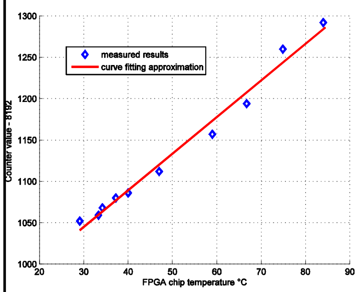


Is there, in a FPGA, a sufficient temperature difference?

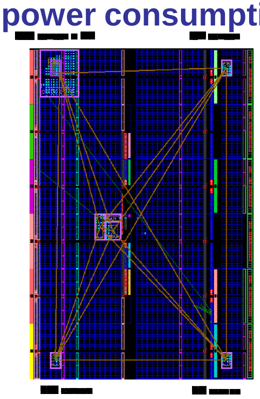
A.Nafkha, P.Leray, Y.Louët, J.Palicot, "Moving a processing element from hot to cool spots: is this an efficient method to decrease leakage power consumption in FPGAs?" ***Green Communications*** **-**Theoretical Fundamentals, Algorithms and Applications, **CRC Press**, ISBN: 9781466501072, July 2012.

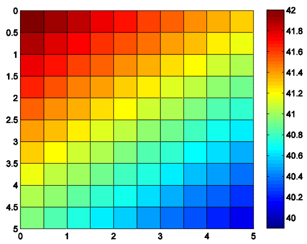
4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Component Level (7/15)

Function migration, in reconfigurable hardware, for temperature and power consumption management



Reference temperature provided by the System monitor versus measured counter cycle value.





Thermograph obtained by interpolating the sensors responses.

A.Nafkha, P.Leray, Y.Louët, J.Palicot, "Moving a processing element from hot to cool spots: is this an efficient method to decrease leakage power consumption in FPGAs?" ***Green Communications*** **-**Theoretical Fundamentals, Algorithms and Applications, **CRC Press**, ISBN: 9781466501072, July 2012.

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4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Component Level (8/15)

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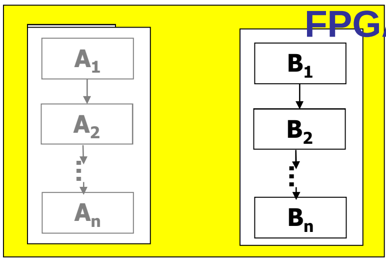
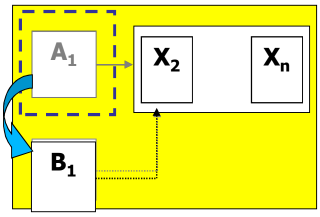
Use of Partial Reconfiguration to decrease FPGA size



Big FPGA FOR SEVERAL STANDDARDS



Small FPGA USING Partial Reconfiguration of functionsin real time to offer the same standards

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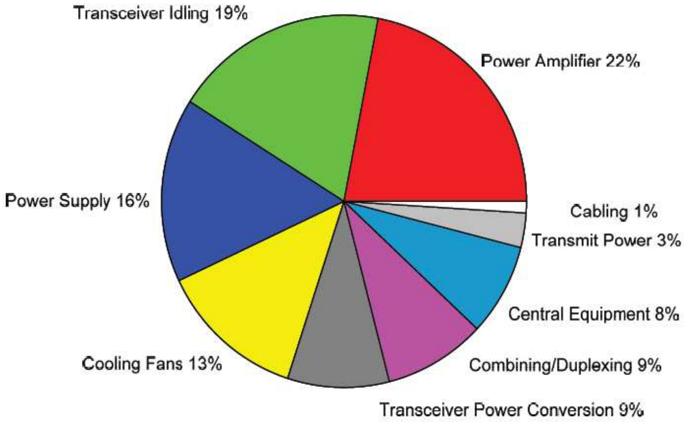
4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Component Level (9/15)

Supélec

Consumption sharing at the Base Station



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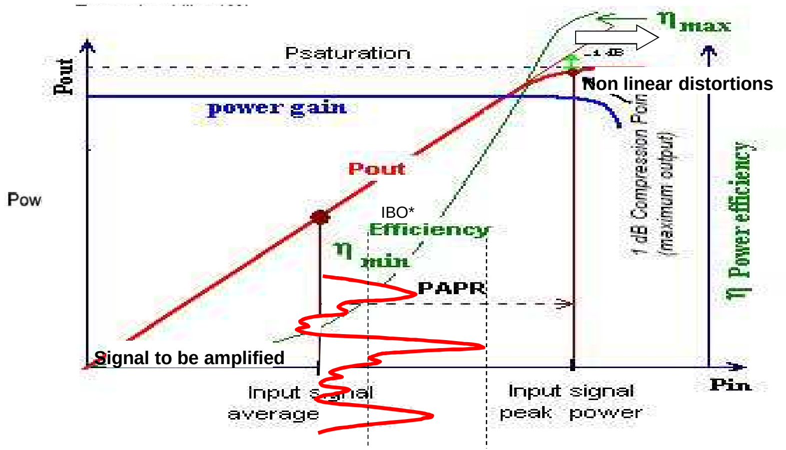
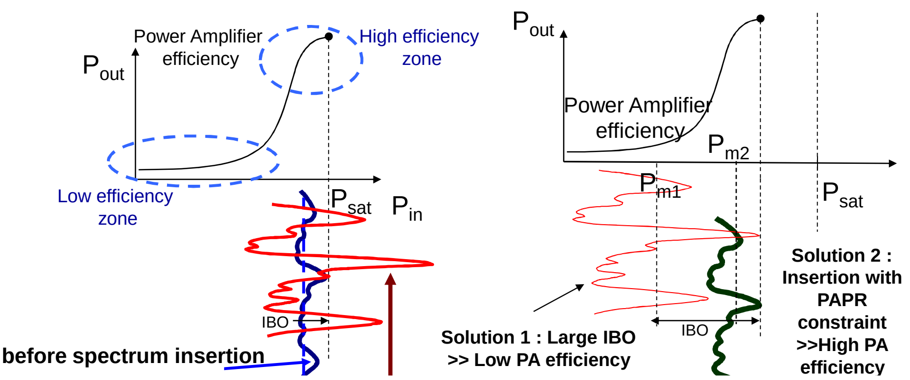
Power Amplifier Efficiency



Palicot J, Louet Y, Hussain S, Zabre S, *Frequency Domain Interpretation of Power Ratio Metric for Cognitive Radio Systems*, Proceedings of IET Communications Journal, N° 2, pp 784-793, june 2008

Optimization of the transmitted power at the High Power Amplifier level using PAPR, ACPR & hole spectrum sensors



Palicot J, Louet Y, Hussain S, Zabre S, *Frequency Domain Interpretation of Power Ratio Metric for Cognitive Radio Systems*, Proceedings of IET Communications Journal, N° 2, pp 783-793, june 2008

4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Component Level (11/15)

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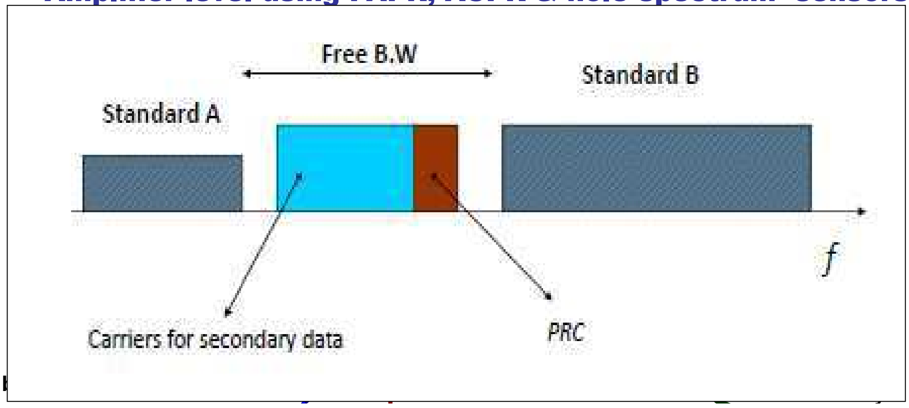
Supélec

Optimization of the transmitted power at the High Power Amplifier level using PAPR, ACPR & hole spectrum sensors



Palicot J, Louet Y, Hussain S, Zabre S, *Frequency Domain Interpretation of Power Ratio Metric for Cognitive Radio Systems*, Proceedings of IET Communications Journal, N° 2, pp 783-793, june 2008

4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Network Level (1/16)

IETR

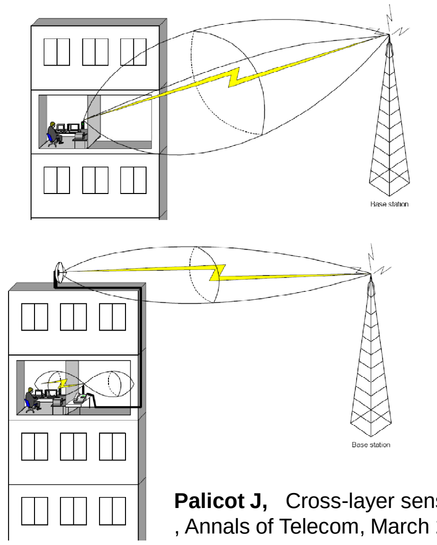
Supélec

Optimization of the overall network by intelligent and dynamical BS management

- **Relaying Technique:** is being studied in 3GPP as a technology that offers the possibility to extend coverage and increase capacity
- **ON/OFF schemes** for constant QoS (need to extend some coverage) (see https://www.ict-earth.eu/default.html)
- **wired backhauling** rather than wireless backhauling in order to become greener[1]
- **Improved RRM** in heterogeneous multi RAT context
- **Network coding** approach
- **Decrease cell size**
- **MIMO techniques** see Massive MIMO approach by Bell Labs within GREENTOUCH

[1]Peter Briggs, Rajesh Chundury, Jonathan Olsson, "Carrier Internet for Mobile Backhaul", IEEE Communications Magazine, October 2010, Vol 48, N° 10, PP94-100

Network Management



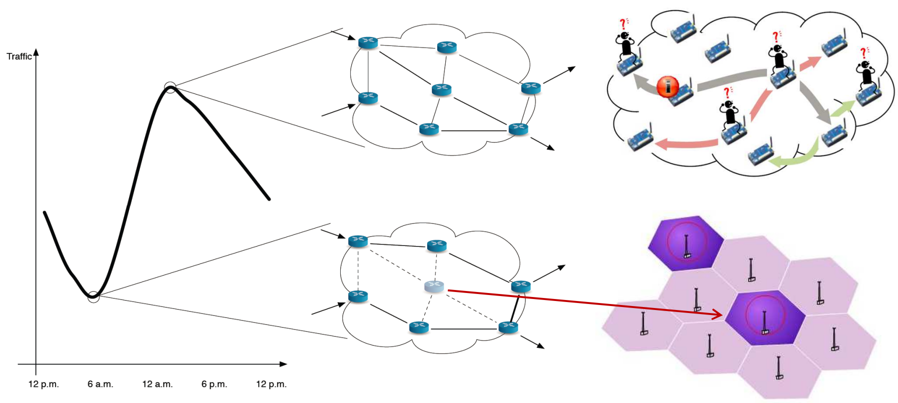
•The terminal or the Base Station could recognize the spectrum occupancy and therefore decide which band (with the associated power) is the best from the point of view of electromagnetic radiation. This could be performed thanks to the **standard recognition sensor**

•It is always better to have a local wireless connection or a wired indoor connection and to have a roof connection with the cellular network

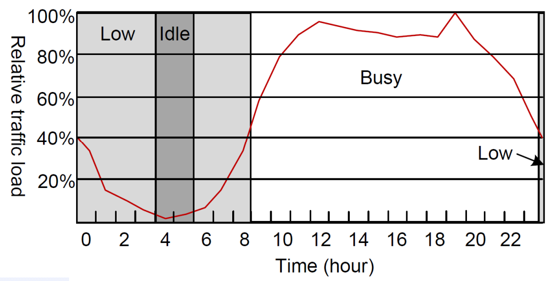
Palicot J, Cross-layer sensors for green cognitive radio, Annals of Telecom, March 2012, DOI: 10.1007/s12243-012-0292-0

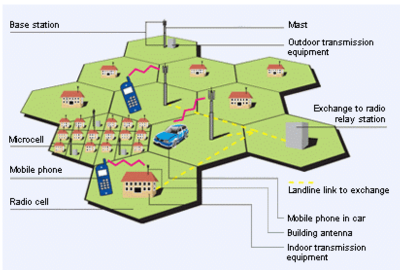
Energy Saving for Greener Cellular Mobile Networks

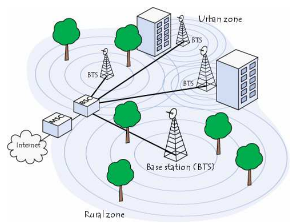
“Tidal Effect” of Cellular Networks’ Traffic Flow & Loads



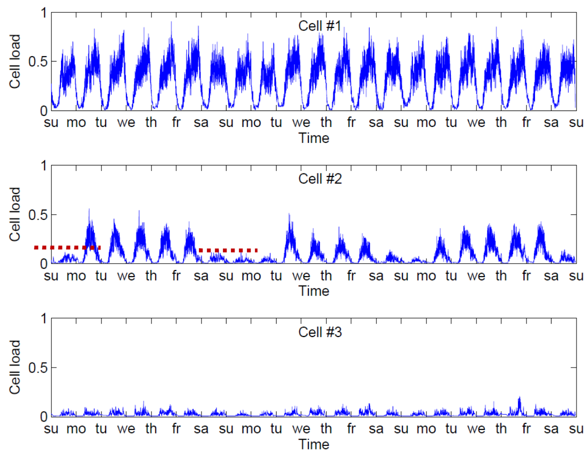
Representative Patterns of Traffic Loads during One Day (Cellular Networks)







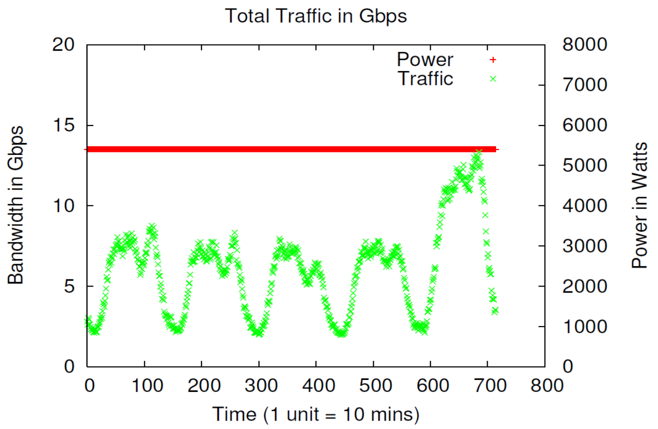
Representative Patterns of Traffic Loads during 3 Weeks (Cellular Networks)



Normalized load of three different cell sectors over 3 weeks. The moving average of each cell over one second has been plotted. The cells show high load (Top), varying load (Middle), and low load (Bottom).

Source: Daniel Willkomm et al., "Primary User Behavior in Cellular Networks and Implications for Dynamic Spectrum Access".

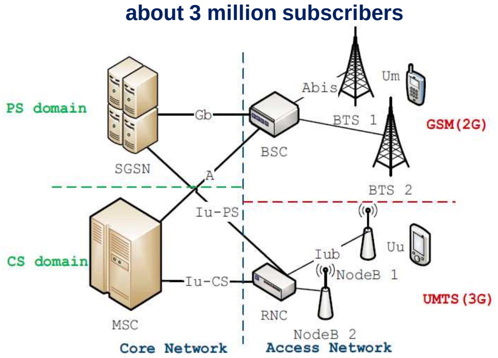
4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Network Level (6/16)



E-commerce website: 292 production web servers over 5 days. (Traffic varies by day/weekend, power doesn't.)

4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Network Level (7/16)

- **Traffic records from 9 MSCs and SGSNs with about 7000 BSs with coverage of 780 km²**
- **Both GSM and UMTSBSs traffic from January to December in 2012, serving about 3 million subscribers**



Base Stations' Traffic Loads Measurement Campaigns in Zhejiang (China)

Source: Xuan Zhou, Zhifeng Zhao, Rongpeng Li, Yifan Zhou, and Honggang Zhang, "The Predictability of Cellular Networks Traffic," IEEE ISCIT2012, October 2012.

4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Network Level (8/16)

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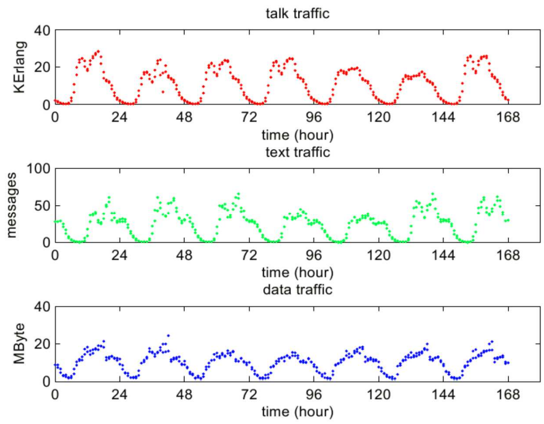
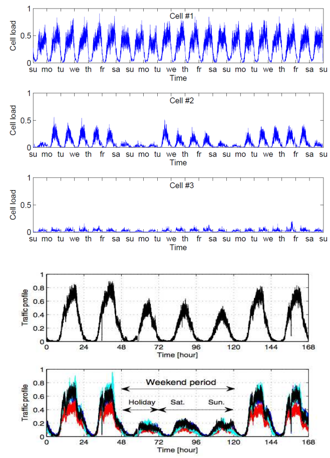
Measured Traffic Loads Variation Patterns at BSC (One Week)





Same Behavior everywhere in the world

4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Network Level (9/16)

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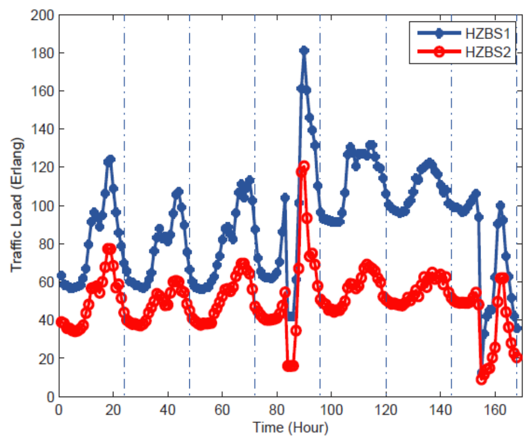
Typical Examples of Measured Base Stations' Traffic Loads in Zhejiang (China)

Average on several BS at BSC level.



Source: Rongpeng Li, Zhifeng Zhao, Yan Wei, Xuan Zhou, and Honggang Zhang, "GM-PAB: a grid-based energy saving scheme with predicted traffic load guidance for cellular networks," in *Proceedings of IEEE ICC 2012, Ottawa, Canada, Jun. 2012.*

4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Network Level (10/16)

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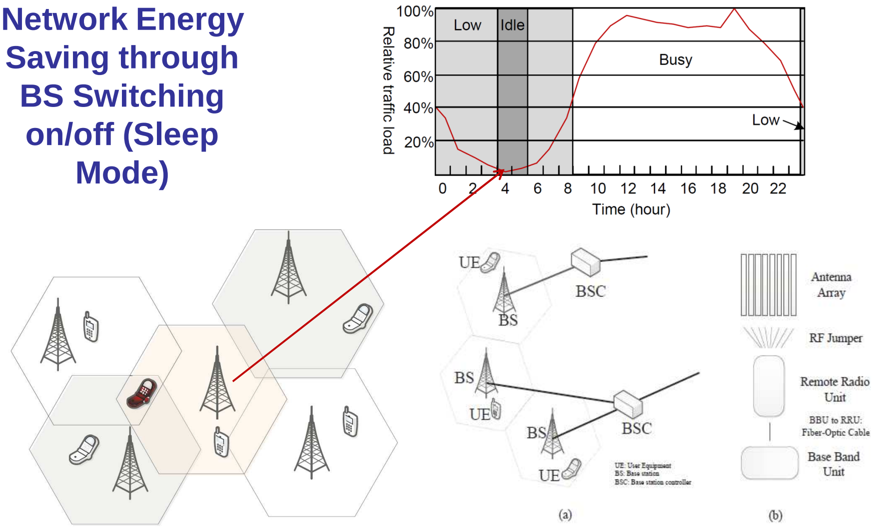
Network Energy Saving through BS Switching on/off (Sleep Mode)



4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Network Level (11/16)

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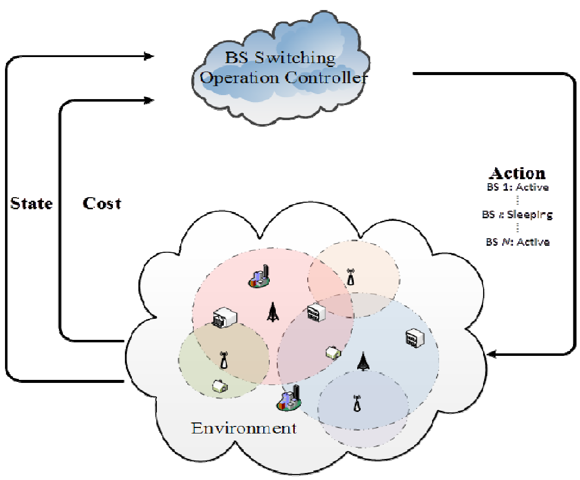
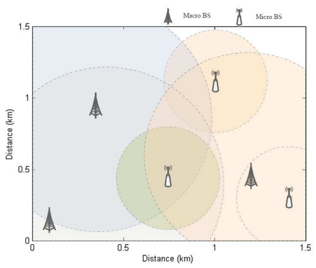
Stochastic BS Switching Operation with Actor-Critic Learning



Source: Rongpeng Li, Zhifeng Zhao, Xian Chen, and Honggang Zhang, "Energy Saving through a Learning Framework in Greener Cellular Radio Access Networks," in *Proceedings of IEEE Globecom 2012, Anaheim, USA, Dec. 2012.*

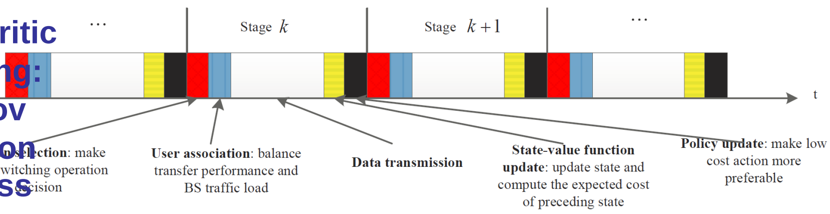
Stochastic BS Switching Operation with Actor-Critic Learning (2)



Scenario

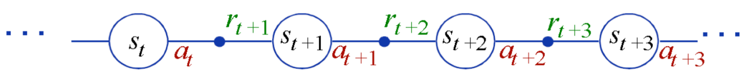
- A region $\mathcal{L} \in \mathbb{R}^2$ served by a set of BSs $\mathcal{B} = \{1, \ldots, N\}$;
- A BS switching operation controller to turn on/off some BSs in a centralized way;
- A traffic load density as $\gamma(x) = \frac{\lambda(x)}{\mu(x)} < \infty$: arrival rate per unit area $\lambda(x)$ and file size $\frac{1}{\mu(x)}$;

Actor-Critic Learning: Markov Decision Process



An MDP $M = < \mathbb{S}, \mathbb{A}, p, C >$,

- $\mathbb{S}$: the state space;
- $\mathbb{A}$: the action space;
- p: a state transition probability function;
- C: a cost function.



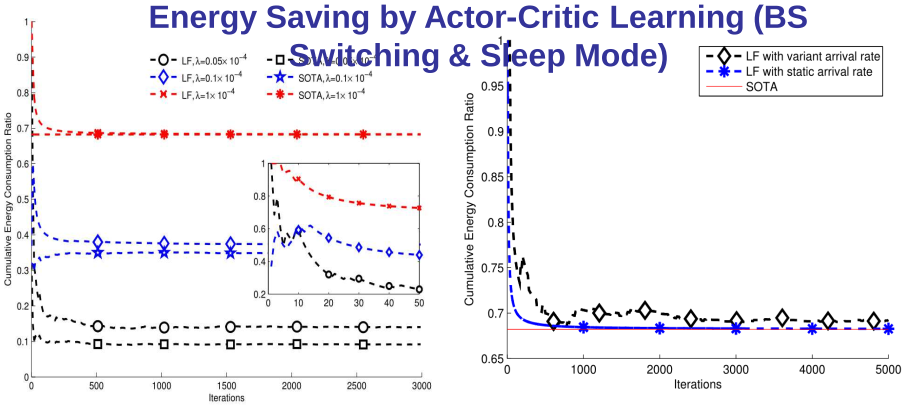
4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Network Level (14/16)

Numerical Analysis

Parameter description		Value
Simulation area		1.5km * 1.5km
Maximum transmission power	Macro BS	20W
	Micro BS	1W
Maximum operational power	Macro BS	865W
	Micro BS	38W
Height	Macro BS	32m
	Micro BS	12.5m
Intra-cell interference factor		0.01
Channel bandwidth		1.25MHz
File requests	Arrival rate	$5 \times 10^{-6} \sim 10^{-4}$
	File size	100kbyte
Constant power percentage		0.1 ~ 0.9

4- CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction-Network Level (15/16)

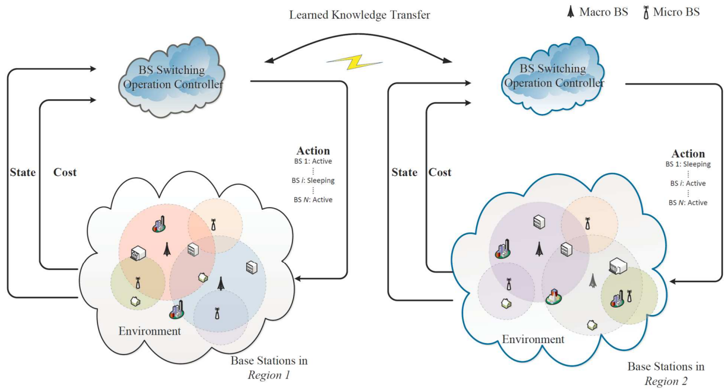
Energy Saving by Actor-Critic Learning (BS Switching & Sleep Mode)



Performance comparison between Actor-Critic learning framework (LF) based energy saving scheme and the state-of-the-art (SOTA) scheme (JSAC, Sept. 2012) under various static/variant traffic arrival rates.

Source: Rongpeng Li, Zhifeng Zhao, Xian Chen, and Honggang Zhang, "Energy Saving through a Learning Framework in Greener Cellular Radio Access Networks," in *Proceedings of IEEE Globecom 2012, Anaheim, USA, Dec. 2012.*

Stochastic BS Switching Operation with Transfer Reinforcement Learning



Source: Xuan Zhou, Zhifeng Zhao, R. Li, Y. Zhou, J. Palicot, and Honggang Zhang, "TACT: A Transfer Actor-Critic Learning Framework for Energy Saving in Cellular Radio Access Networks," arXiv:1211.6616, November 2012.

outline

5- Electromagnetic Pollution and Spectrum Resources Optimization 1/18

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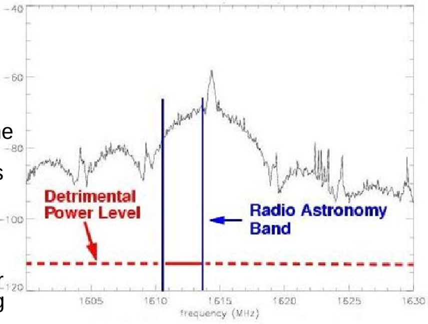
➢Electromagnetic Pollution

•increase in the absolute level of electromagnetic noise.
•increase the noise level on many frequency bands.
•Astronomic and meteorology communities are concerned over this increase of noise level (debate within URSI)

- "Ironically, the technology that has made possible so many exciting astronomical discoveries is now jeopardizing the future of observational astronomy"[6]
- "almost everyone can relate, first-hand, to the issue of light pollution. It is more difficult for people to relate to the astronomical windows in the electromagnetic spectrum"[7].
- radio-astronomy signals coming from the universe are millions of times weaker than signals used by human communication systems. Radio-astronomers would consider that a cellular phone on the Moon is a strong radio source



[6]Derek McNally, "The Vanishing Universe", pp. 208. ISBN 0521450209. Cambridge, UK: Cambridge University Press, October 1994
[7]John Percy, "Preserving the Astronomical" Windows" by/for Education and Culture", ASP Conference Series, vol. 139, 1998

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5- Electromagnetic Pollution and Spectrum Resources Optimization 2/18

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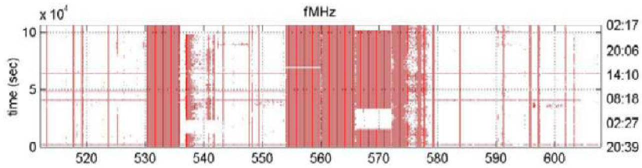
– Frequency Spectrum Resources

- **Today** spectrum allocation is fixed, done for a long period
- The frequency spectrum is underused.
- "Hic et Nunc" frequency spectrum occupancy concept.



TV band occupancy
01/September/2004
in New York

- Optimize the spectrum use: Green spectrum[5]
- From a worldwide sustainable development point of view, this spectrum should be shared between countries and continents

Honggang ZHANG, "Cognitive Radio for Green Communications and Green Spectrum", COMNETS 08 Co-located with CHINACOM 08,August 25-27, 2008, Hangzhou, China

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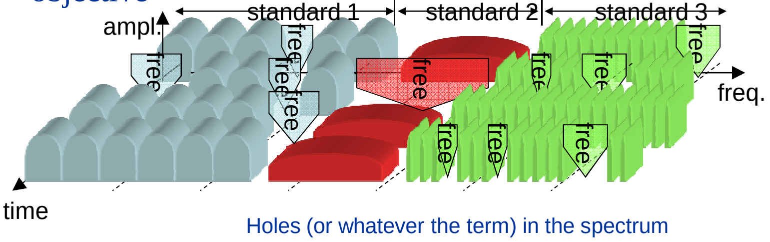
5- Electromagnetic Pollution and Spectrum Resources Optimization 3/18

Spectrum use optimization: Green spectrum[1]

•CR is obviously an enabler because it was one of its main objective



Holes (or whatever the term) in the spectrum

Opportunistic Communications (5 phases)

- Filtering phase
- Detection phase (sensing itself)
- Characterisation phase.
- Learning and Decision phase
- Insertion phase (modulation with good PSD), under sensor constraints as ACPR,PAPR,….

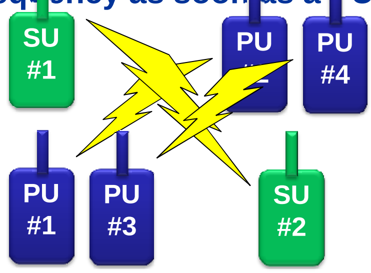
But this implies advance signal processing algorithms which are computationally expensive and then consume power!

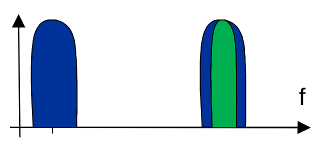
[5]Honggang ZHANG, "Cognitive Radio for Green Communications and Green Spectrum", COMNETS 08 Co-located with CHINACOM 08,August 25-27, 2008, Hangzhou, China

5- Electromagnetic Pollution and Spectrum Resources Optimization 4/18

Opportunistic Spectrum Access - OSA

- **In a radio network of primary users (PU)**
- **Secundary users (SU) are allowed to use free frequencies**
- **At the condition that SUs leave the occupied frequency as soon as a PU wants to use it**





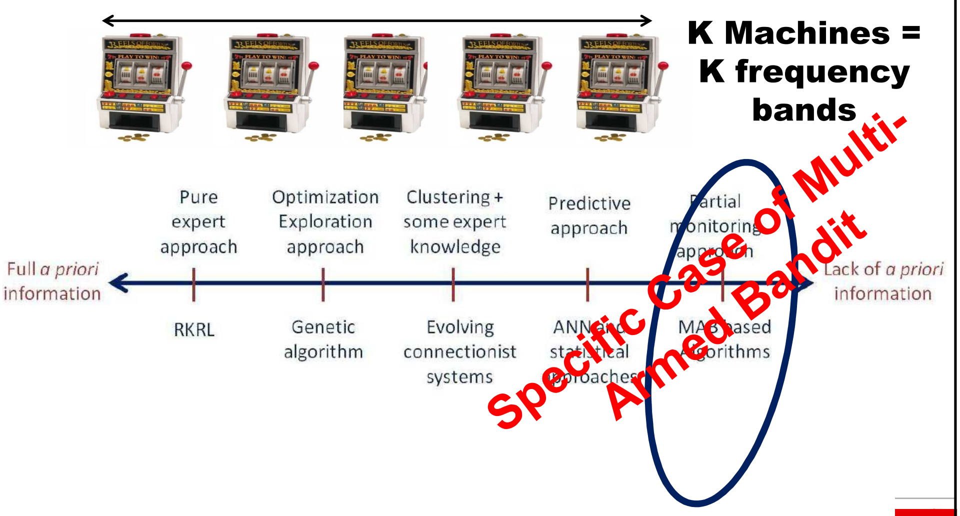
Secundary user requirement

- **Secundary users need to incorporate cognitive radio (CR) features in the equipments**
  - sensors
  - reconfigurable radio capabilities

➔ **in addition to usual radio processing**

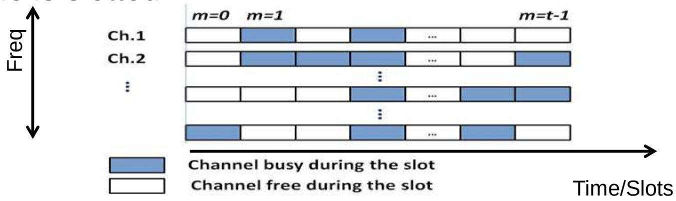
- **Sensor**
  - detection of primary user at the same frequency
- **Reconfigurable operators**
  - carrier frequency, etc.
- **Learning means to predict the band availability**

No a priori knowledge



Primary network hypothesis

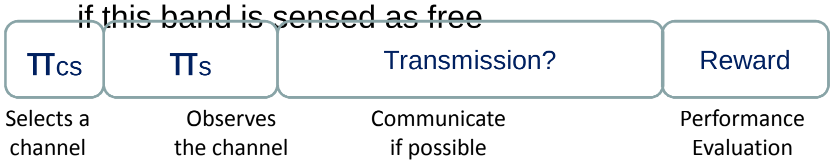
- **Primary network: bands occupation**
  - time is slotted



- **Secundary network**
  - minimum interference with PUs
  - sense PUs activity with imperfect sensing
  - available spectrum: shared among SUs

Secundary network hypothesis

- **At every iteration, a SU selects (sense) only one channel**
  - analog front end is not more complex than usual (only one band at a time)
  - learning is done step by step
  - SU tests (explore) a band and transmits (exploit) only if this band is sensed as free



  - impact of sensing errors?
  - effect of SUs' collaboration?

MAB and UCB for OSA

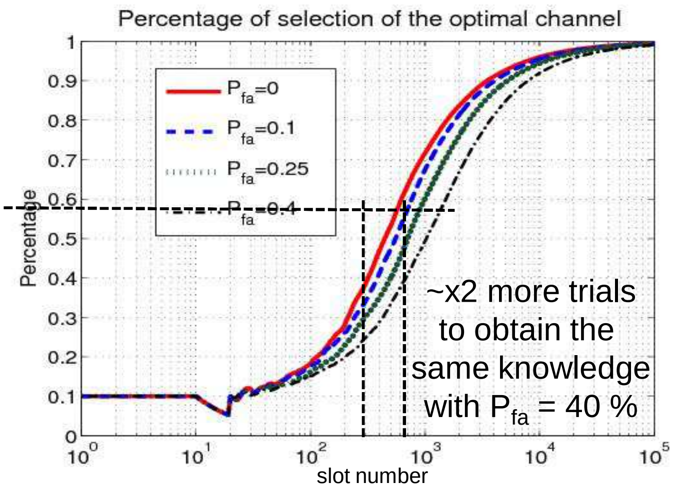
- **Hypothesis**
  - Each arm is a frequency band
  - All bands have the same bandwidth (same reward per band in terms of data rate)
  - Reward if {0,1}
    - 0 if the band is already occupied by PU
    - 1 if the band is free
  - UCB_1

$$B_{k,t,T_k(t)} = \overline{X}_{k,T_k(t)} + A_{k,t,T_k(t)} \quad \nearrow \quad A_{k,t,T_k(t)} = \sqrt{\frac{\alpha.\ln(t)}{T_k(t)}}$$

[14] Wassim JOUINI, Damien ERNST, Christophe MOY, Jacques PALICOT, "Upper confidence bound based decision making strategies and dynamic spectrum access," International Communication Conference, ICC'10, Cape Town, South Africa, 26-29 May 2010

Effect of sensing errors I

- **10 channels**
- **for several false alarm probabilites**



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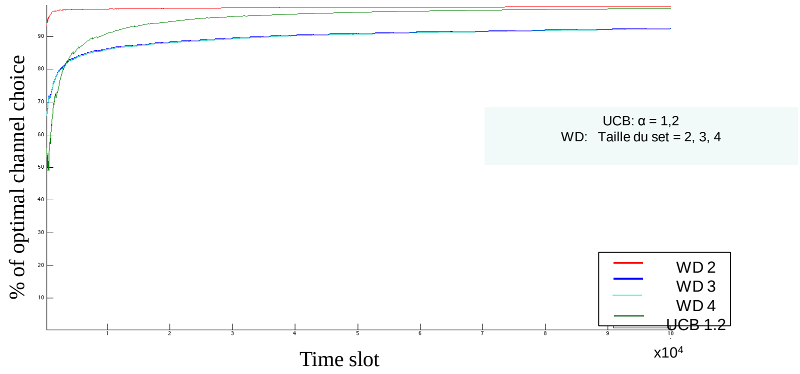
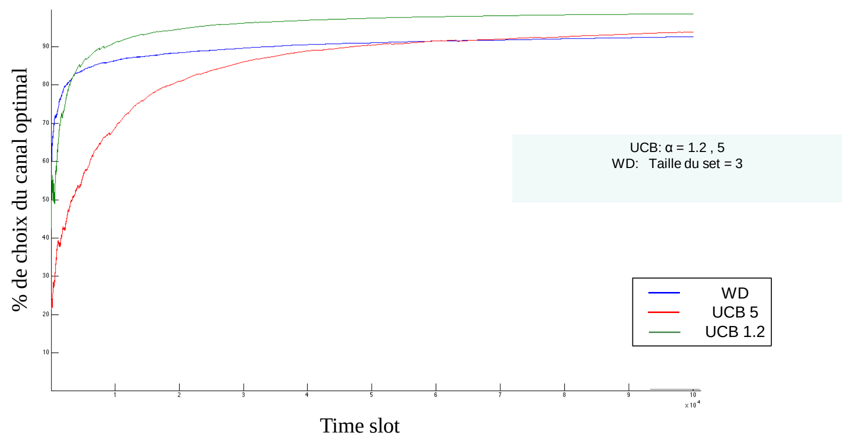
Percentage of optimal Channel choice



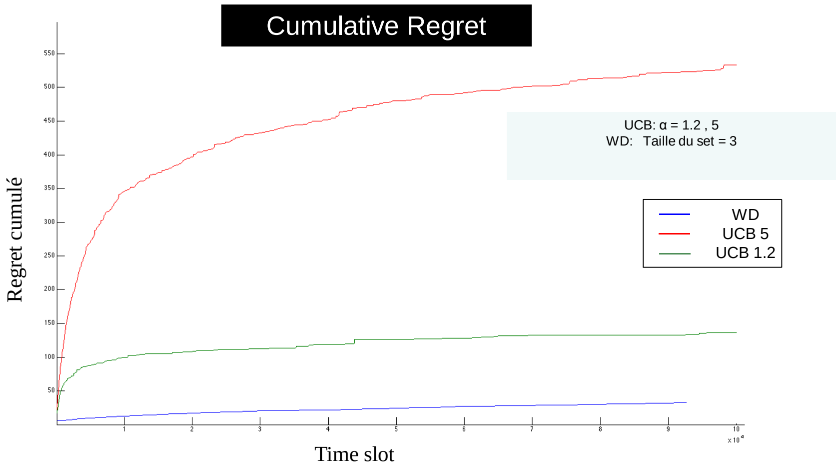
- Smaller the set is , faster the algorithm choose the optimal channel (if it belongs to the set)
  - But divergence may occur

IETR Supélec

Percentage of optimal Channel choice

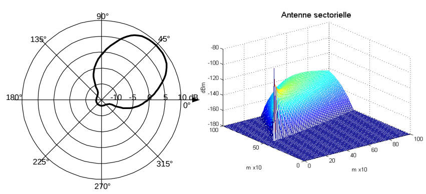


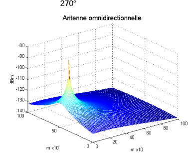
- Smaller α is, faster UCB converges (more reliability to previous experiments).



- Smaller α is, smaller the regret is (less exploration)
- Small regret for WD algorithm depending on the set dimension

decreasing electromagnetic pollution and by the same way decreasing the transmitting power:Beam forming to decrease the radiation level





The question here is: can an operator accept to use this gain for the same user number instead of increasing the user number?

[1]Jacques Palicot, Christian Roland "On The Use Of Cognitive Radio For Decreasing The Electromagnetic Radiations",URSI 05, XXVIII General Assembly , New Delhi, India, October 23-29, 2005.

5- Electromagnetic Pollution and Spectrum Resources Optimization 18/18

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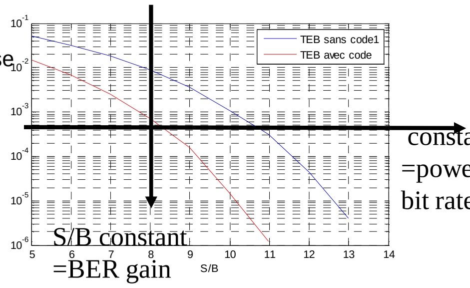
- **Activating some functions so as to decrease the transmitting power**

Possible CR sensors to activate these gains
- SNR
- Channel Impulse Response
- Direction of Arrival
- Blind standard recognition
- ......



constant BER
=power gain or
bit rate gain

Example: The **SNR sensor** gives (locally) a very good value. Then Tx and Rx agree to use a channel code to decrease the power

If choice of power decrease then indirect gains (HPA efficiency, less temperature....)

outline

IETR · Supélec

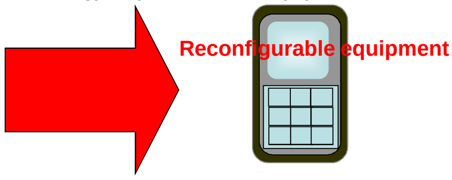
1. SUPELEC/SCEE research team
2. Introduction
3. The « Cognitive Radio » concept
4. CO2 Emission Decrease Obtained Thanks to Power Consumption Reduction
   - At the component level
   - At the network level
5. Electromagnetic Pollution and Spectrum Resources Optimization
6. **Recycling the Resources**
7. Green Communications as a Mean for an Improved Public Health
8. Conclusion

6- Recycling the Resources

– Recycling the resources

- Recycling of the equipments
  - » Clearly an industrial & operator problem
  - » Mobile phone price is often included in the contract
  - » No motivation to increase the equipment life time

•SoftWare Radio (SWR) may decrease the number of devices (multistandard, multimode,..)
•SWR Technology may increase the equipment life time



6- Recycling the Resources

– Recycling the resources

- Recycling of the radio waves
  - – The radio waves exist if & only if there is sufficient energy to generate them
  - – Almost all the radio waves are lost (particularly in broadcasting systems)
    - » to use these waves in such a way that they generate small quantity of energy. (energy harvesting)
    - » to use the waves for learning the electromagnetic environment (as done by sensors of CR), in order to better use these radio waves.

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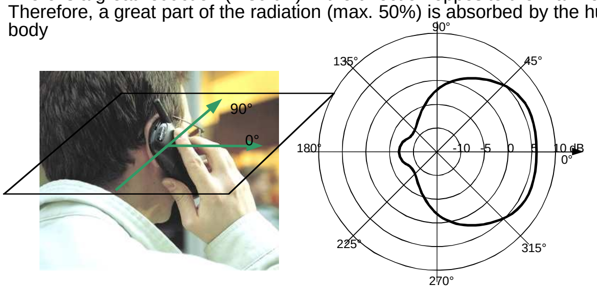
8. Conclusion

7-Green Communications as a Mean for an Improved Public Health

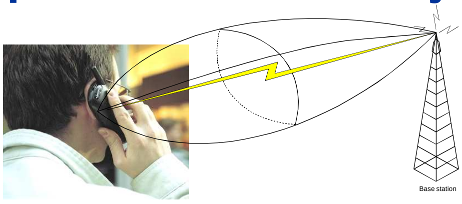
- Human aspects
  - Health aspect (Human exposure aspect)
    - » There is a great reduction (> 30 dB) in the direction opposite the main lobe. Therefore, a great part of the radiation (max. 50%) is absorbed by the human body



  - Social aspects
    - » How it is possible to use wireless communications in order to help in the reduction of CO_2 emission in human being activities?
    - » How it is possible to use wireless communications for helping the development of underdeveloped countries?

7-Green Communications as a Mean for an Improved Public Health

Beam forming: to avoid transmitting power in the human body



Proposed Algorithm

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1. Activate DoA sensor, which determines the relative position of the BS and the terminal.
2. User interface requests the user to turn in the right direction.
3. Form the main beam towards the BS.

Of course, there remain some questions:

- This is difficult to execute for fast moving terminals.
- This implies advance signal processing algorithms which are computationally expensive and consume power. Therefore a power consumption budget should be done carefully.
- This solution is not yet validated by experiments.

outline

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8. **Conclusion**

Conclusion (1/4)

- **Electromagnetic radiation problem should be taken into account:**
  - For the future networks design,
  - For the future standards definition & normalization,
  - For the future smart terminals .
- **Promote the use of Cognitive Radio for Green Radiocommunications[1]**
  - Validation of our proposals through real platforms and measurements.

[1] J.Palicot, « Cognitive Radio: An Enabling Technology for the Green Radio Communications Concept », IWCMC, Leipzig, Germany June 2009

Conclusion (2/4)

- **Environmental-friendly Green Communications:**
  - A paradigm change from traditional coverage- & capacity-driven to energy-efficiency driven communications and networks (*S*mart, *S*ustainable, and *S*elf-harmonized greener ICT).
- **Cognitive Green Radio Communications:**
  - Besides spectrum and energy, intelligence is the THIRD kind of resource, but without limitation of scarcity.
  - Learning and decision making algorithms under green constraint can play a significant role in enabling energy- and spectral-efficient greener future communications.
  - Effective energy saving can be realized by using various learning approaches in mobile cellular networks.

Cognitive Green Communications:
From Concept to Reality!

Conclusion (3/4)

- **Questions**:
  - Can an operator accept to use the **technological gain for the same user number** (decreasing the transmitted power) instead of increasing the user number?
  - Is there a market for CR terminals that takes into account this **ecological aspect of electromagnetic transmission**?
  - Is there a financial argument for operators willing to find the best compromise between **health, spectrum efficiency, power consumption and cost** etc.?
  - Can an operator/manufacturer make a selling point out of the fact that **its mobile phones transmit less radiation** than those of its competitors?
  - Are users prepared **to pay more for a less polluting mobile phone**?
  - ……

Conclusion (4/4)

- **Green Communications and Green Spectrum: Is Cognitive Radio an Enabler or Anyone else?**
  - My answer: Yes, it is an enabler[1]
- **Cognitive Radio:**
  - Thanks to sensors in a broad sense
  - Thanks to efficient decision making algorithms under green constraint
  - Can reach Green Radio Communications

Cognitive Green Radio Concept

- **We strongly believe that**:

  Bringing progress to people, improving their confidence in this technological field, and dissipating their fears of radio evolution is instrumental in providing the radio domain with a good prospect in the 21st century. Green Cognitive Radio Communications developments should provide this confidence.

[1]J.Palicot, « Cognitive Radio: An Enabling Technology for the Green Radio Communications Concept », IWCMC, Leipzig, Germany June 2009

Acknowledgments

- Acknowledgments to the entire team (current and former PhDs) SCEE of SUPELEC fully involved in these activities. Also, many thanks to current and former PhD students of ZJU (Dr. Tao Chen (VTT), Dr. Xianfu Chen (VTT), Mr. Rongpeng Li (ZJU), and Mr. Xuan Zhou (ZJU)) for their supporting materials and suggestions

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  - Honggang.Zhang@supelec.fr

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- .