Cognitive Radio in the Green Communication Paradigm

Vision of the IC0902 Cost Action

Jocelyn Fiorina
Vice Chair of IC0902 Cost Action
Supélec / France

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IC0902 COST ACTION: Cognitive Radio and Networking for Cooperative Coexistence of Heterogeneous Wireless Networks

Start date: *11/12/2009*

End date: *10/12/2013*

Maria-Gabriella Di Benedetto Chair, “La Sapienza” University of Rome / Italy

Jocelyn Fiorina Vice Chair, Supélec / France

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Outline of the presentation

1. **Green Communications and Cognitive Radio**

2. **Presentation of the COST Action**

3. **Examples of topics linked to the COST Action and related to Green Communications**

Green Communication

- Green Communication is about telecommunication systems which are designed taking care of the environment, saving energy, in a world where the consumer society is always greedier of resources which are precious and not unlimited.

- It promotes the idea that telecommunication engineers, industries and users should be conscious of the environmental issues.

- Pushed by society concerns

Cognitive Radio

- Cognitive Radio is about telecommunication systems which are aware of their environment (electromagnetic but not only) for an efficient use of their shared resource: the radio spectrum.
- It tries to solve the increasing consumer needs while the radio spectrum is a limited resource, with a new conscious use of the spectrum.

- So, Cognitive Radio is green.

Cognitive Radio

- Like water, radio spectrum is a precious, (public?) and limited resource.
- It may suffer of pollution (interference) when it is congested.

- Cognitive radio is here to solve the problem of accessing and sharing this resource by providing intelligent flexible ways.

Cognitive Radio

- Cognitive radio is green because it is about management of scarce resource in the consumer society.

- But it is green also because it faces problems having an impact on the environment: energy efficiency and energy saving, electromagnetic radiations.

Impact on the environment

- Societal Issues:

Paris mayor suspended in october 2011 all the new antennas deployment in Paris, because the operators wanted to pass from a 2V/m radiation limit to a 10 or 15 V/m limit, while the council of Paris wishes to reduce it to 0.6 V/m.

- “Electrosmog”

Cognitive Radio

- Cognitive Radio aims at using the spectrum in a more flexible and efficient way by relying on the cognitive cycle:

Sensing

Analyzing and Learning

Reasoning

Deciding(adaptation)

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- Scientific context and objectives (1/2)

- **Background / Problem statement:**

Significant research efforts that focus on flexibility in spectrum management are currently underway in Europe and worldwide

Open research issues cover a wide range of aspects, such as: 1) Designing hardware for reliable spectrum sensing: this is fundamental to unlicensed secondary systems operation; 2) Defining algorithms for efficient, dynamic link adaptation; 3) Designing protocols for cooperation in spectrum sensing and sharing; 4) Defining network functions, such as routing and admission control, that incorporate internal and external network status; 5) Defining communication and representation languages for cognitive information exchange

This Action proposes to address these challenges, and therefore to bring a significant and practical contribution to the development of cognitive engines for wireless communications

- **Objectives:**

The Action proposes to address the above challenges, and bring a significant and practical contribution to the development of cognitive engines for wireless communications by:

-Coordinating research and development activities in the field of flexible spectrum use, spectrum sharing, and intersystem coexistence, based on cognitive radio and cognitive networks

-Defining a European platform for cognitive radio and networks based on a cross-layer design approach encompassing all layers of the protocol stack

-Active participation and impact on the standardization activities and regulation processes inside and outside Europe

-Formation of Early Stage Researchers towards the development of a new generation of researchers in the field of cognitive radio

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• Scientific context and objectives (2/2)

The Action addresses the following five key Technical Challenges (TCs)

- TC1 Definition of cognitive algorithms for adaptation and configuration of a single link according to the status of external environment
- TC2 Definition of cooperative cognitive algorithms based on information exchange at a local level:
  - Design of cooperative spectrum sensing algorithms
  - Design of cooperative relaying schemes
  - Design of advanced network coding schemes
- TC3 Definition of network-wide mechanisms:
  - Design of admission control strategies
  - Design of routing protocols
- TC4 Definition of mechanisms for intersystem coexistence and cooperation
- TC5 Definition of the cross-layer cognitive engine
- AND
- Definition of a representation language for the exchange of information between the application layer engine and lower layers; such language must be able to describe concepts and variables related to all aspects of the device, from radio parameters to network performance indicators, to application requirements
- Creation of a reference for experimental testbeds and platforms for cognitive radio, collecting and organizing inputs from all over Europe and worldwide: creation of a blog and a wiki http://newyork.ing.uniroma1.it/IC0902/CognitiveTestbeds

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- Working groups

Working Groups (WG) map 1 to 1 the Technical Challenges:

WG1 - single link adaptation, such as spectrum sensing, measurement and shaping, and interference suppression

WG2 - definition of cognitive mechanisms taking advantage of cooperation of devices in spatial proximity, according to the research issues identified as part of TC2

WG3 - extension of cognition from the single network device to the whole network

WG4 - intersystem cooperation and coexistence under both technical and standardization/regulation points of view

WG5 - introduction of cognition in devices above the network layer, exploring the definition of a cross-layer cognitive engine.

Several research topics encompass Technical Challenges. We have formed for now 4 Special Interest Groups:

SIG1 - Information representation languages

SIG2 - Learning and artificial intelligence

SIG3 - Mobility management for cognitive wireless networks

SIG4 - Positioning

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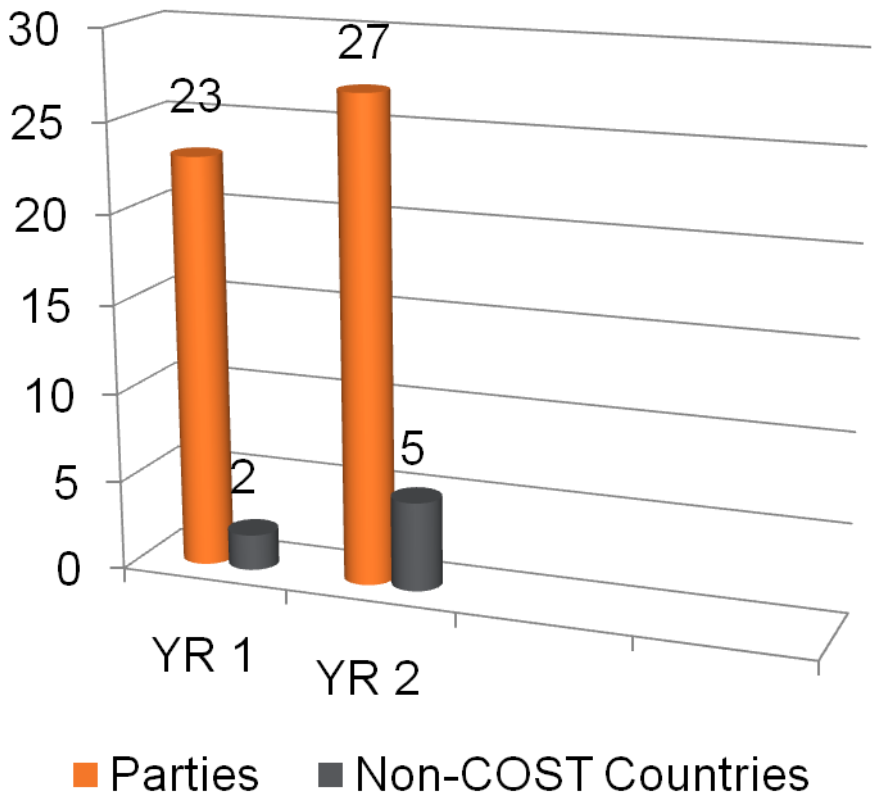
Action participants



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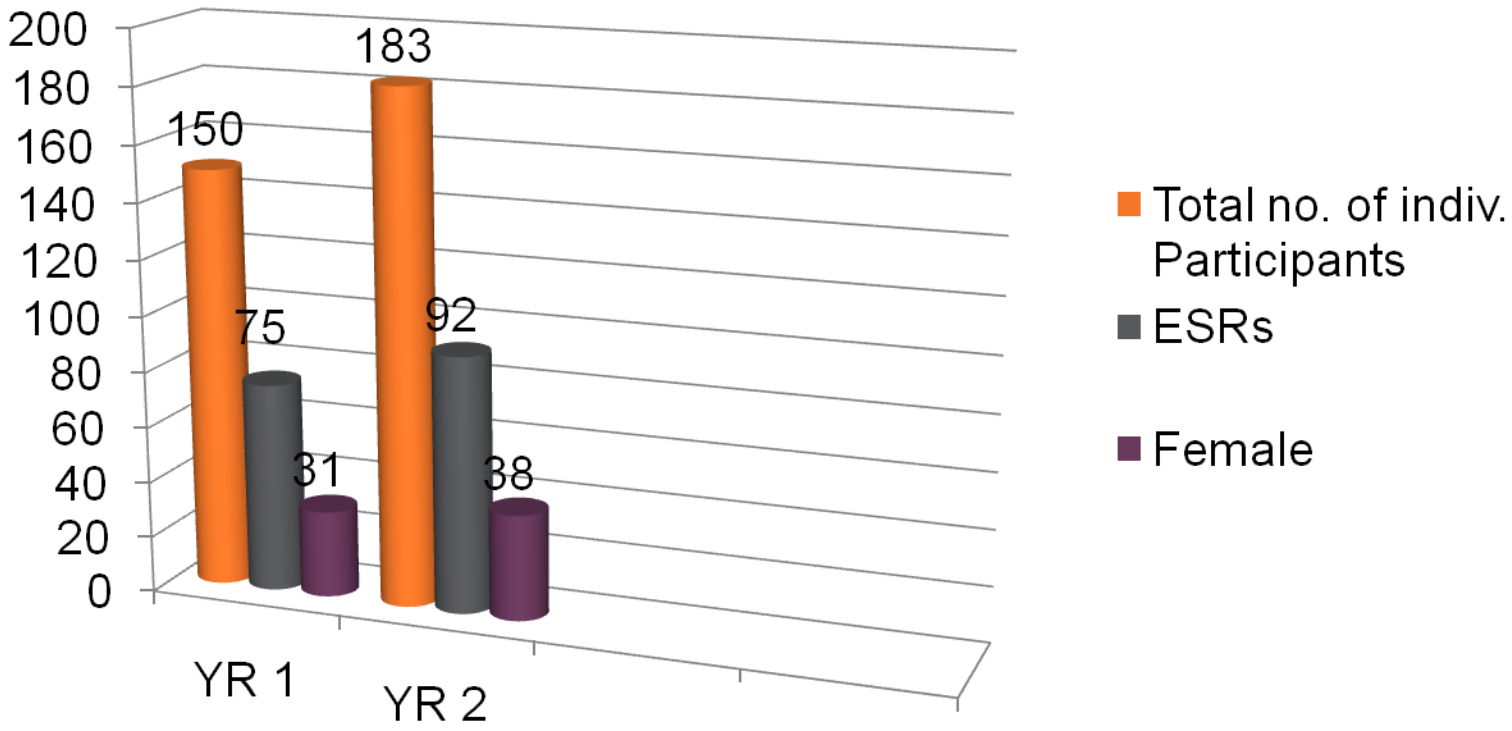
Action participants



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- **Tools: Workshops, Short Term Scientific Mission, Training Schools**

New!

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- Some examples of topics: game theory for spectrum access, signaling scheme which reduces the interferences, cooperative sensing, collaborative relaying…

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- Members of our COST action are involved in project related to cognitive radio enabling technology for Green Communication:

For instance the C2POWER project where some work is done on cooperative strategies for energy saving using context information.

Or GREENET which is a training/research network that focuses on analysis, design and optimization of energy efficient wireless communication system.

Examples of topics

Ultra Wide Band Underlay Systems

Ultra Wide Band Underlay Systems

- One example of technology:

Ultra Wide Band Underlay systems

Ultra Wide Band Underlay Systems

- One example of technology to (re)use the used spectrum (recycling) in cognitive radio are the underlay systems.

- P1900.1 Definitions:

Spectrum Overlay: dynamic spectrum access by secondary spectrum users that exploits spatial and temporal spectral opportunities in a noninterfering manner.

Spectrum Underlay: a type of secondary spectrum access where radiated power limits, power spectral density limits, or modulation requirements on secondary transmissions protect primary users from interference

Ultra Wide Band Underlay Systems

Ultra Wide Band Systems

- Definition (by the FCC in February 2002):

10 dB fractional bandwidth $\Delta f/fc > 0.2$

or

spectral occupation higher than 500MHz

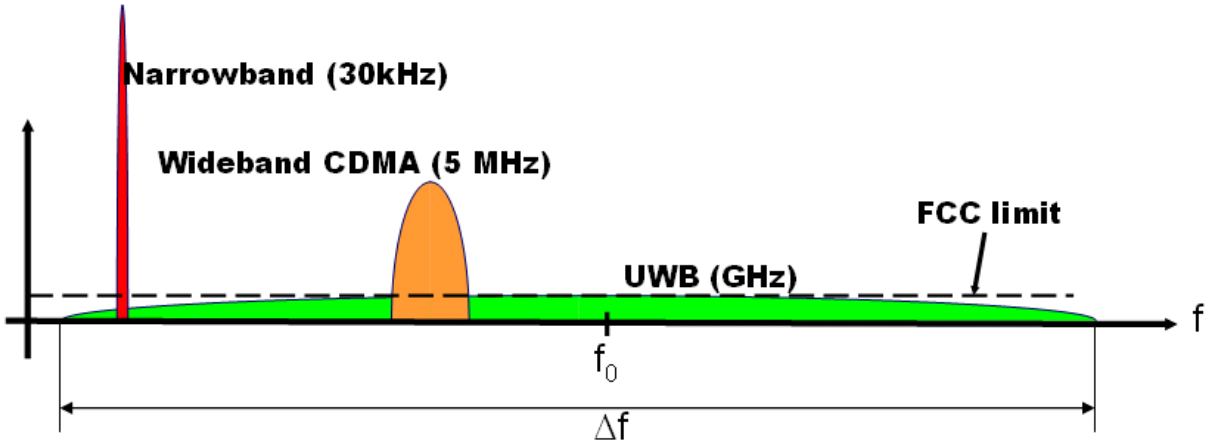
- But first definition in the radar domain: definition by the DARPA in 1989/1990:

20 dB fractional bandwidth $\Delta f/fc > 0.25$

or

spectral occupation higher than 1,5GHz

Ultra Wide Band Underlay Systems

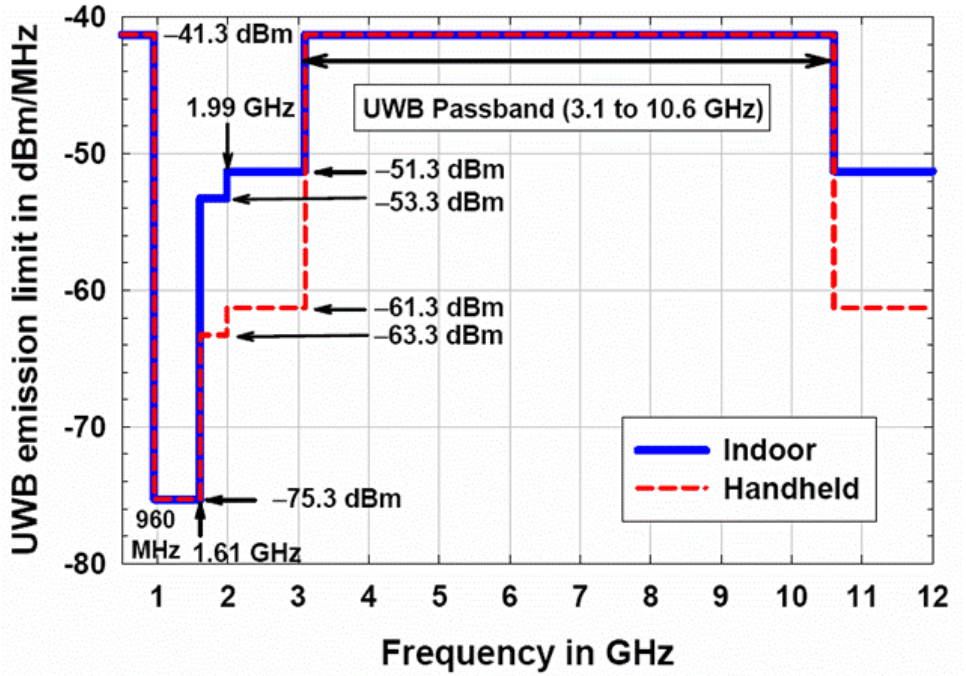


- Reuse of the band, should act as harmless noise on existing systems. LPI/LPD Technology inherited from radar where UWB exists from a long time; the huge bandwidth provides also temporal precision and ranging/localization ability.

Ultra Wide Band Underlay Systems

Regulation

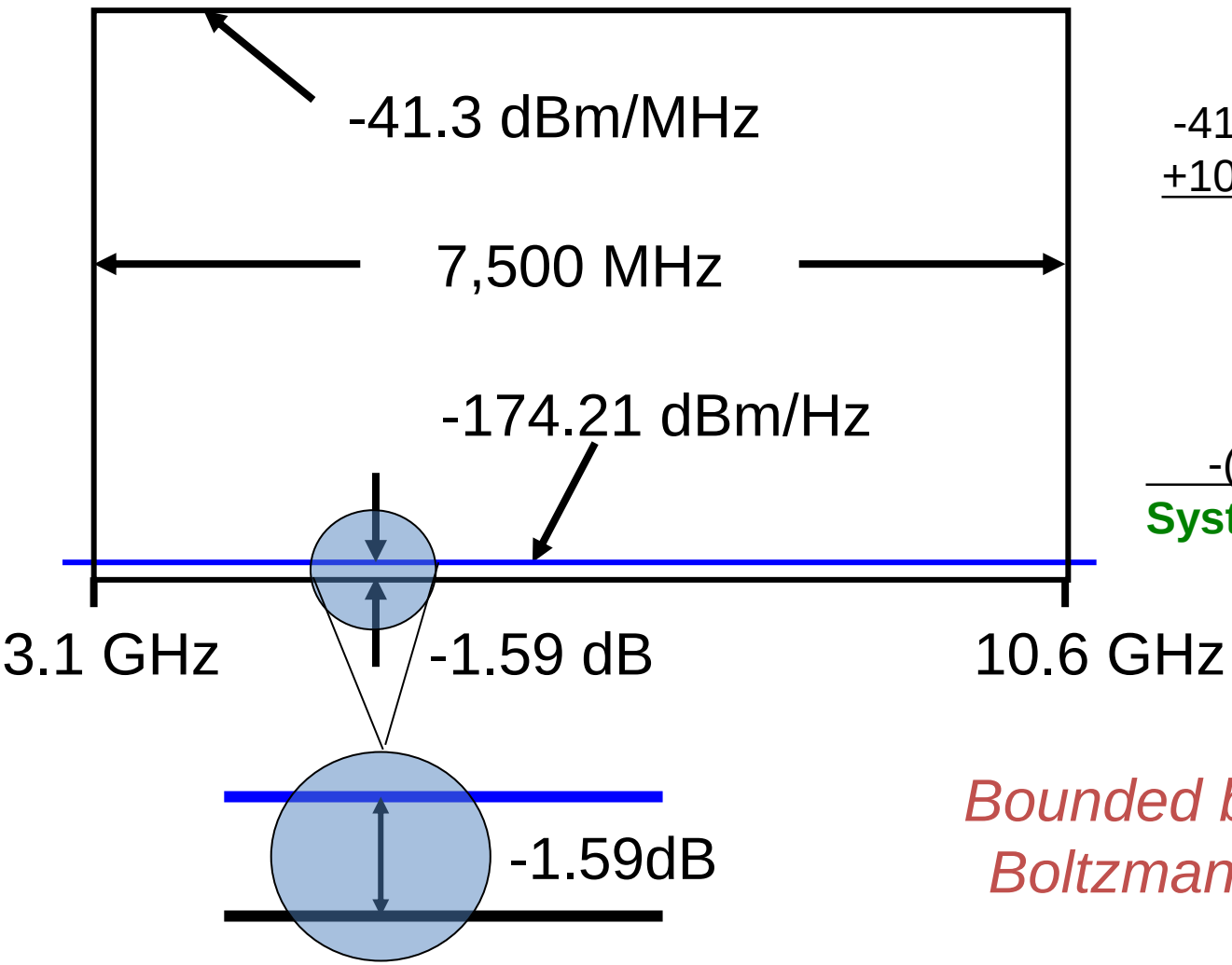
- In 2002, the FCC allowed the use of UWB devices, but with very low power spectral density: the allowed emitted PSD is inferior to the one of unintentional emitters (TV set, electronic devices…)



Ultra Wide Band Underlay Systems

Communication with ultra low PSD

For reliable communication: Eb/No>ln(2)= -1,59 dB, Eb=P/R, so for 1b/s reliable communication is reached for P/No>-1,59 dB



-41.3 dBm / MHz
+10 log(7.5x10^3) MHz
P=-2.5 dBm

-2.5 dBm
-(-1.59) dB
-(-174.21) dBm/Hz (=No)

System Gain = 173.3 dB

Bounded by FCC, Shannon, Boltzmann (thermal noise)

Ultra Wide Band Underlay Systems

Communication with ultra low PSD

- So, a simple link budget computation allows to see that the imposed limit means that a reliable bit rate of 1 bit/s is available over a distance of 1300km!
- Or, if a bit error rate of 10^{-3} is targeted (Eb/No must be 6.8dB) at 10 meters, we can reach a bit rate superior to 1.5 Gbits/s !
- Those results show the potential of such communication systems even with strong regulation constraints.

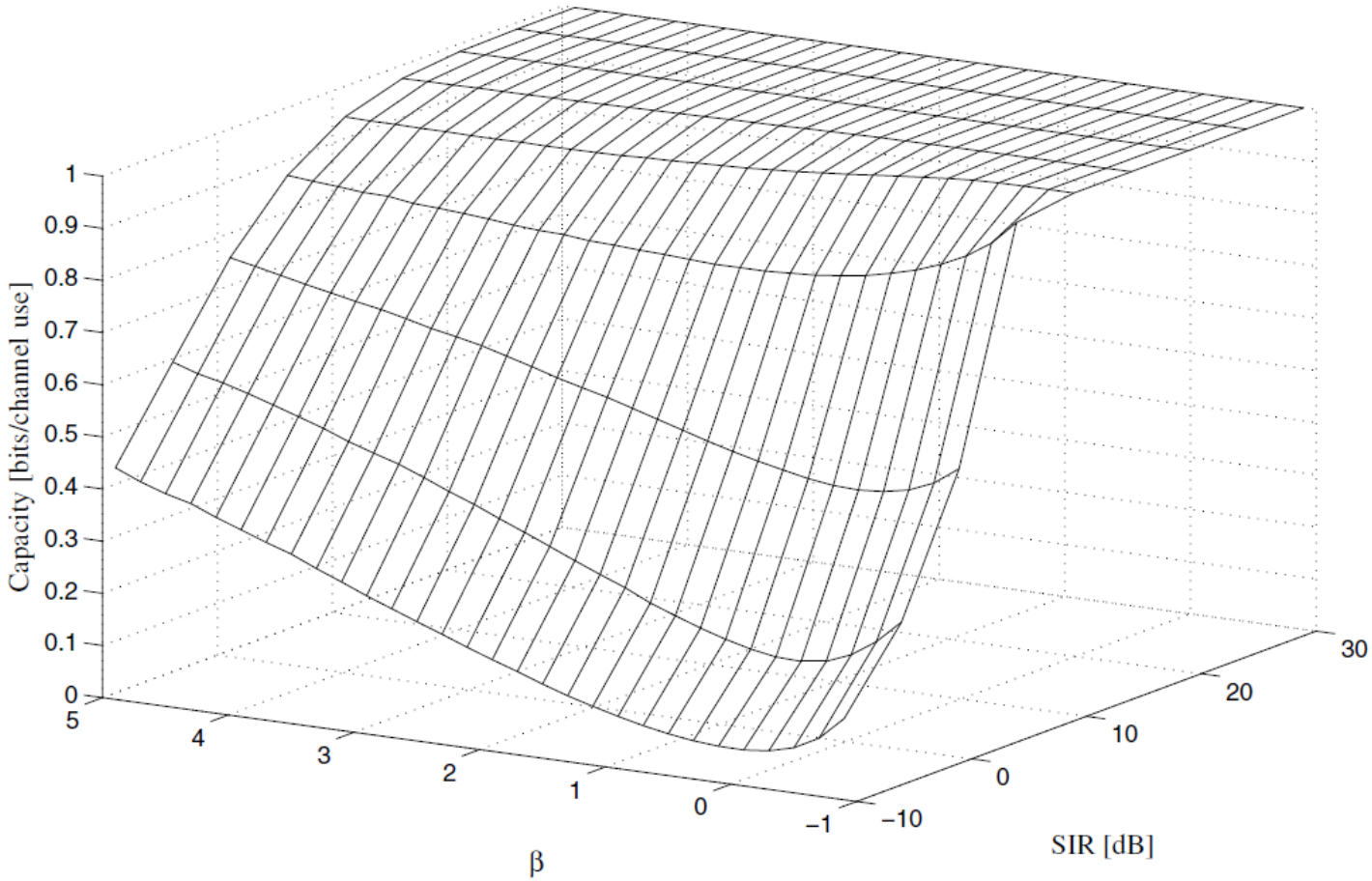
Ultra Wide Band Underlay Systems

Interference Management

- The management of the interference (pollution) has to be taken with care!

- The capacity of the communication depends not only on the power of the interference but also on its distribution

Ultra Wide Band Underlay Systems



- The capacity of the communication depends not only on the power of the interference but also on its distribution, here β is a parameter saying how far the interference is from a Gaussian.
- So the system has to sense the interference to adapt to its power AND its non Gaussianity. But it should also try to create with the same power interference which are less harmful to other systems

Ultra Wide Band Underlay Systems

Another way to tune the interference can be to use Time Reversal (TR) combined to UWB.

TR consists in emulating the correlation receiver by sending the signal convolved with the channel inverted in time (it is a pre-filter), it is then the natural convolution with the channel which will create the correlation at the receiver.

TR focusses the signal in time and space.

- The focussing in space can be used to increase the power received at the intended receiver, so the transmitted power can be reduced, reducing the interference.
- The focussing in time can be used to increase the impulsivness of the signal at a interfered receiver, the non gaussianity being linked to the impulsivness, it will increase the non gaussianity of the interferences and so reduce the harmfulness.
- The focussing in time can be used to reduce the number of fingers of the rake receiver so its complexity, so its consumption.

Other topics

Cognitive Radio as an enabling technology for green communication

We can cite the work of J.Palicot

How CO_2 emissions decrease thanks to power consumption reduction:
-computational efficient algorithms (limitation not only due to speed of computation or capacity of the processor but for green considerations)
-Optimization of the transmitted power by beamforming (optimization of transmitted power but could be use for instance to reduce head exposure also)
-Local decision making (opposed to centralized systems which spend energy for information exchange and where parameters are dimensioned on the base of the worst case).

-Gain by bypassing some unuseful function (ex:when a sensor report good channel condition, equalizer is turned off to save energy). « Architecture
Management of Cognitive Radio Equipments”
-decreasing PAPR of transmitted signal in order to increase the efficiency of HPA and consequently to save energy. Some dynamic spectrum access under this constraint have been proposed

Cognitive Radio as an enabling technology for green communication

-Palicot J, Roland C, *On the use of cognitive radio for decreasing the electromagnetic radiations*, URSI 05, XXVIII General Assembly , New Delhi, India, october 23-29, 2005
-Palicot J, *Cognitive Radio: An Enabling Technology for the Green Radio Communications Concept*, IWCMC'09, 21-24 june 2009, Leipzig, Germany
-Palicot J, Louet Y, Mroue M, Peak to Average Power Ratio sensor for Green Cognitve Radio ; Personnal Indoor and Mobile Radio Communications, Istanbul, Turquie (2010)
-Navin M, Vinod AP, Moy C, Palicot J,Low Power, Flexible FIR Filters in the Digital Frontend of Green Radios, Personnal Indoor and Mobile Radio Communications, Istanbul, Turquie (2010)
-Palicot J, Multilayer Sensors for Green Cognitive Radio, IEEE ICCE Proceedings, january 2010
-Palicot J, Zhang X, Leray P, Moy C, Cognitive Radio and green communications: power consumption consideration,papier invité,ISRSSP 2010 – 2nd International Symposium on Radio Systems and Space Plasma, aout 2010, Sofia,Bulgaria
-Xun Zhang, Wassim Jouini, Pierre Leray and Jacques Palicot, Temperature-Power Consumption Relationship and Hot-spot Migration for FPGA-based Syste", Green Computing and Communications (GreenCom2010), Hangzhou, China, December 18-20, 2010.
-Palicot J, How to Optimize The Spectrum: The Oil Experience, URSI General Assembly,august 2011, Istanbul, Turkey

Intra-operator spectrum sharing

- Spectrum sharing among different bands owned by the same entity, such as a mobile operator, demonstrates considerable potential to improve power efficiency for the network and to increase throughput :
- spectrum sharing through the opportunistic movement of users between bands allowing radio network equipment in other bands to be switched off when possible
- spectrum sharing to opportunistically improve links propagation characteristics therefore reducing necessary transmission power,
- better interference management in spectrum sharing to reduce necessary transmission power

- Holland, O.; Attar, A.; Cabral, O.; Velez, F.J.; Aghvami, A.H."Intra-operator spectrum sharing concepts for energy efficiency and throughput enhancement", ISABEL 2010
- Oliver Holland, Terence Dodgson, A. Hamid Aghvami, and Hanna Bogucka, "Intra-Operator Dynamic Spectrum Management for Energy Efficiency," IEEE Communications Magazine, to appear.

Examples of topics

- Oliver Holland, Christian Facchini, A. Hamid Aghvami, Orlando Cabral, and Fernando Velez, "Opportunistic Spectrum and Load Management for Green Radio," chapter appearing in: E. Hossein, V. Bhargava, G. Fettweis, 2011, *Green Radio Communication Networks*, Cambridge University Press, 2011
- Oliver Holland, Orlando Cabral, Fernando Velez, Adnan Aijaz, Paul Pangalos, and A. Hamid Aghvami, "Opportunistic Load and Spectrum Management for Mobile Communications Energy Efficiency," IEEE PIMRC 2011, Toronto, Canada, Sept. 2011
- Fernando J. Velez, Maria del Camino Noguera, Oliver Holland, A. Hamid Aghvami, "Fixed WiMAX Profit Maximisation with Energy Saving through Relay Sleep Modes and Cell Zooming," Journal of Green Engineering, to appear 2011
- Terence Dodgson and Oliver Holland, "Traffic Loading Impacts on Throughput and Energy Performance related to MIMO Scheduling Techniques and Dynamic Carrier Band Switching," IEEE CogART 2011, Barcelona, Spain, Nov. 2011
- Oliver Holland, Orlando Cabral, Fernando Velez, Adnan Aijaz, Paul Pangalos, and A. Hamid Aghvami, "Opportunistic Load and Spectrum Management for Mobile Communications Energy Efficiency," COST-TERRA meeting, Brussels, Belgium, June 2011
- O. Holland, T. E. Dodgson, A. H. Aghvami, H. Bogucka, "Intra-Operator Dynamic Spectrum Management for Energy Efficiency", accepted for IEEE Communications Magazine

Examples of topics

- H. Bogucka, “Efficient and Rational Spectrum Utilization in Opportunistic OFDMA Networks with Imperfect CSI: a Utility-Based Top-Down Approach”, Wireless Communications and Mobile Computing Journal, Wiley InterScience, 2010
- H. Bogucka, A. Conti, “Degrees of Freedom for Energy Savings in Practical Adaptive Wireless Systems”, IEEE Communications Magazine, June 2011, Vol. 49, No. 6, pp. 38-45
- H. Bogucka, A. Conti, „Utility-Based QAM Adaptation with Diversity and Ambiguous CSI under Energy Constraints”, IEEE International Communications Conference ICC’10, 23-27 May, 2010, Cape Town, South Africa, pp.
- L. Koschel, H. Bogucka, “Energy-Efficient Bit and Power Loading Options for Practical OFDM Systems with Pilot-Aided Channel Estimation”, IEEE International Symposium on Personal Indoor and Mobile Radio Communications, PIMRC’10, 26-29 Sept, 2010, Istanbul, Turkey
- H. Bogucka, “Optimal Resource Pricing Coercing Social Behavior in Wireless Networks”, IEEE International Communications Conference ICC’11, 5-9 June, 2011, Kyoto, Japan
- M. Parzy, H. Bogucka, “Coopetition – practical methodology for efficient sharing of radio resources in wireless networks”, **invited paper,** 4th International ICST Workshop on Game Theory in Communication Networks, Gamecomm 2011, Paris, France, 16th of May 2011

Examples of topics

- The compulsory spectrum sensing is a critical component to facilitate systems co-existence. New energy efficients collaborative sensing schemes are proposed.

- Body Area Network with end-to-end transmission across heterogenous networks. Provide reliable communications with cooperation and operate in a very low power level to conserve energy and reduce the electromagnetic radiation impact on human body.

- Rong Yu, Yan Zhang, Chen Gao, Chujia Huang and Ruchao Gao, “Energy-efficient and Reliability-driven Cooperative Communications in Cognitive Body Area Networks”,Mobile Networks and applications.
- Yi Liu, Shengli Xie, Yan Zhang, Rong Yu, and Victor C.M. Leung “Energy-Efficient Spectrum Discovery for Cognitive Radio Green Networks”, Mobile Networks and applications.

Game theory tools

- *Coopetition – practical methodology for efficient sharing of radio resources in wireless networks*

- New methodology for practical and efficient opportunistic spectrum access. Idea of coopetition which combines the advantages of cooperative and competitive games

- M. Parzy, H. Bogucka, '*Coopetition - practical methodology for efficient sharing of radio resources in wireless networks*', 4th International ICST Workshop on Game Theory in Communication Networks, GAMECOMM 2011, Paris, France

Game theory tools

- Distributed game-theoretic approach to obtain a power allocation method that maximizes the energy efficiency of each user, within the coexistence of primary and secondary users.

- *Enrico Del Re,Renato Pucci Luca Simone Ronga,"Non-Cooperative Fair Game with Pricing for Resource Allocation in Cognitive Networks "*

Game theory tools

Conclusion

Cognitive Radio and Green Communications are two concepts which are closely tied together, because Cognitive Radio is about sharing a scarce resource, being aware of the global environment and its context in order to take it into account, and because it addresses topics like energy saving, electromagnetic radiation reduction, which have an environmental impact.