

# Cognitive Communications. Managing Complexity in Wireless Communications Systems

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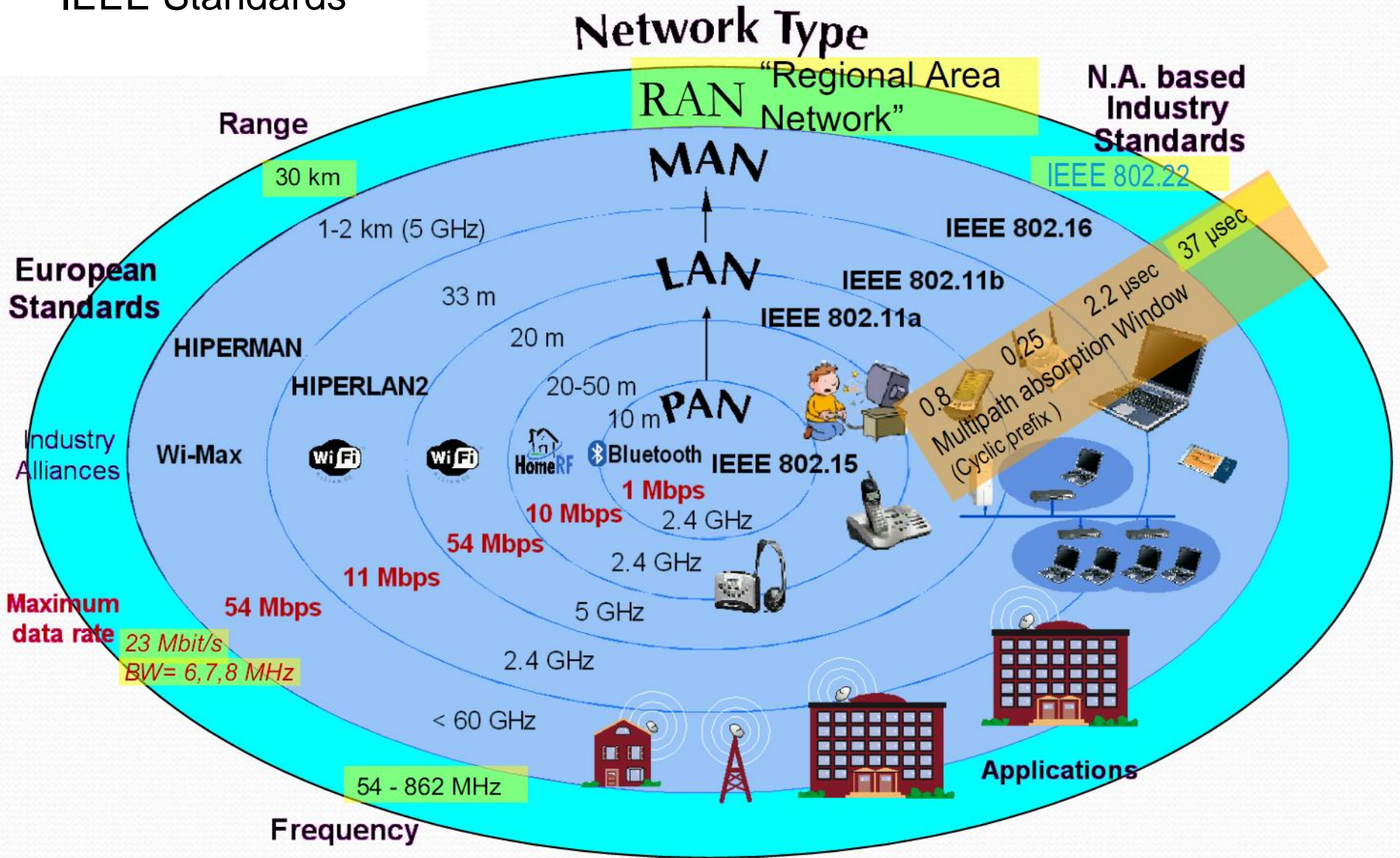
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# Outline

- Telecommunications ecosystem
  - What builds complexity?
- Adaptive techniques in wireless communications systems.  
A critical perspective
  - Limitations of current adaptive approaches
  - Adaptability vicious cycle
- Unified approach to adaptability in communications systems – a proposal
  - Cognitive radio technologies
- Illustrative model – a cognitive antenna system

# IEEE Standards



# Telecommunications ecosystem

## What builds complexity?

- Context – convergence of the great three: telecom, media, and IT
- Increasing number of **users, systems, technologies, applications,** and **services,**
- Their **development** and **accelerated dynamics,**
- Their **heterogeneity.**
  
- **Adaptation<sup>\*)</sup>** – a key feature of a communications system
- Manual configuration – impossible
- Cognitive radio technologies – enabler for **complexity management** in communications systems.

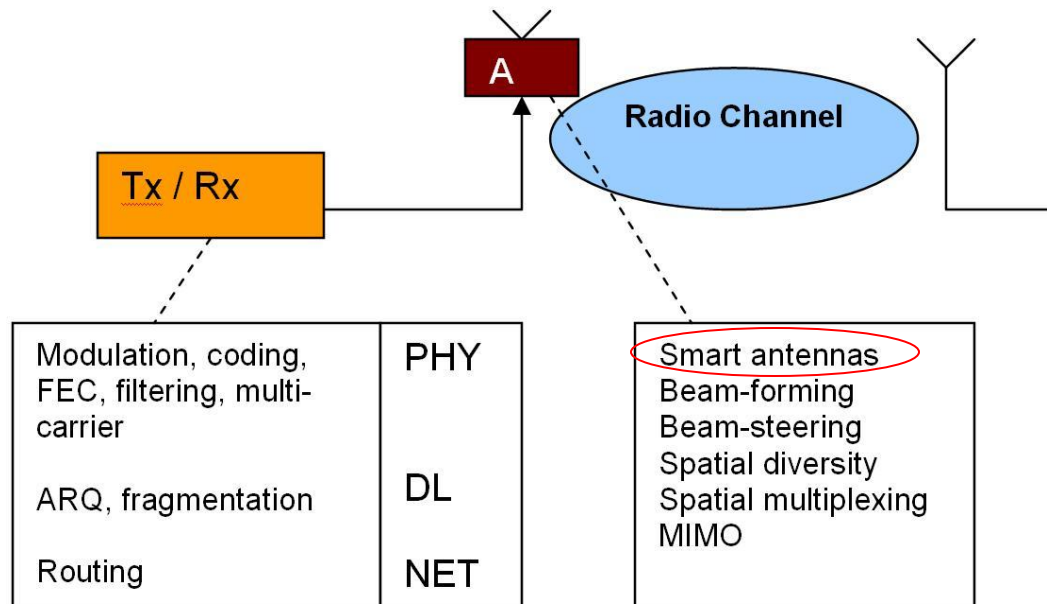
# The need for adaptive techniques

- The **dynamic development** of communications systems generates a degree of complexity that may impair on the functioning of the informational ecosystem.
- The **heterogeneous infrastructure, user requirements, and the constantly changing environment** in which communications systems operate **require the existence of flexible radio interfaces capable of managing such dynamics.**

# Adaptive Radio Techniques

- An adaptive technique involves:
  - **Dynamic change of system parameters** in order to compensate variations in the operation environment
  - **Goal:** to ensure **performance** – link availability and capacity, spectral efficiency, coverage
  - **Criteria:** SNR or QoS maximization, BER or PER minimization, etc.
  - **Controlled Parameters:** signal power, modulation&coding scheme, combining technique, equalizing method, antenna geometry/configuration, etc.

# Adaptive techniques at different levels of the wireless Tx – Rx chain



Tx - Transmitter

Rx - Receiver

PHY - Physical Layer

DL – Data Link Layer

NET – Network Layer

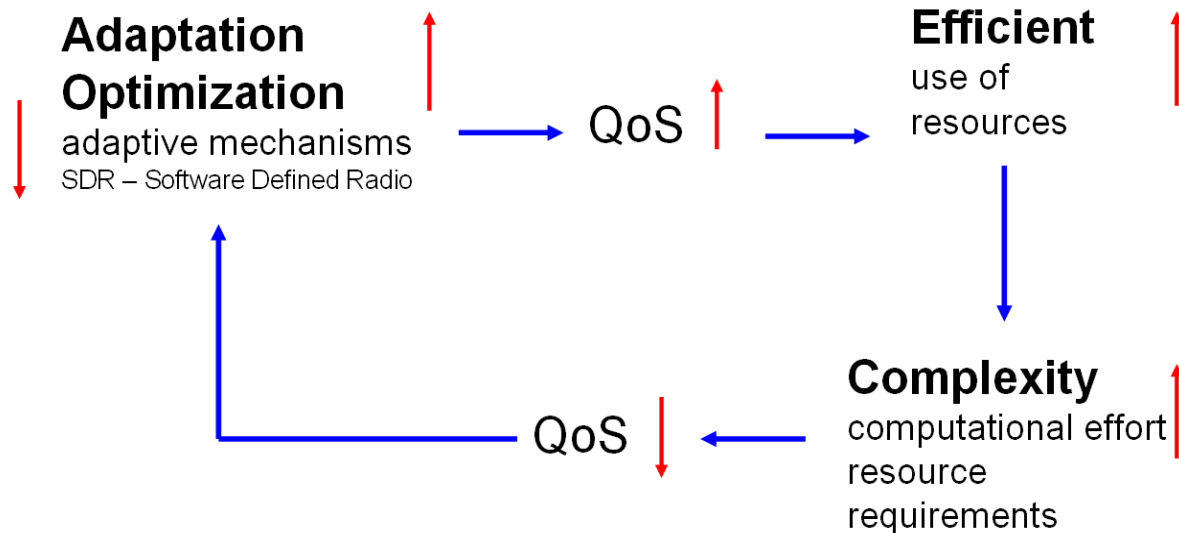
# Adaptive radio techniques - limitations

- they have more or less independent approaches,
- their joint operation is not much studied.
  
- are usually specific, **short-term solutions**, having a **local effect**.
- **lack of correlation** (in order to assess the **global effect**).
  
- most of them are hard-coded and therefore **not able to evolve, not sustainable**.
- processing that considers time and frequency variability of the channel exploits only partially the spatial component information.



# Adaptability vicious cycle

Focusing on short-term adaptation solutions led to the formation of a vicious cycle of adaptation



\*) Adaptation builds complexity.

# Unified approach to adaptability in communications systems

- Design of **sustainable adaptation solutions** requires extended time, effort, and sometimes leads to greater complexity.
- A unitary yet flexible approach is needed, so that **local problems may be solved locally and global ones globally**, while considering the effects of a local action at global level, and vice versa.
- Such an approach of adaptation solutions in nowadays wireless systems may be conceived by taking **the model of living organisms' cognition mechanisms**.

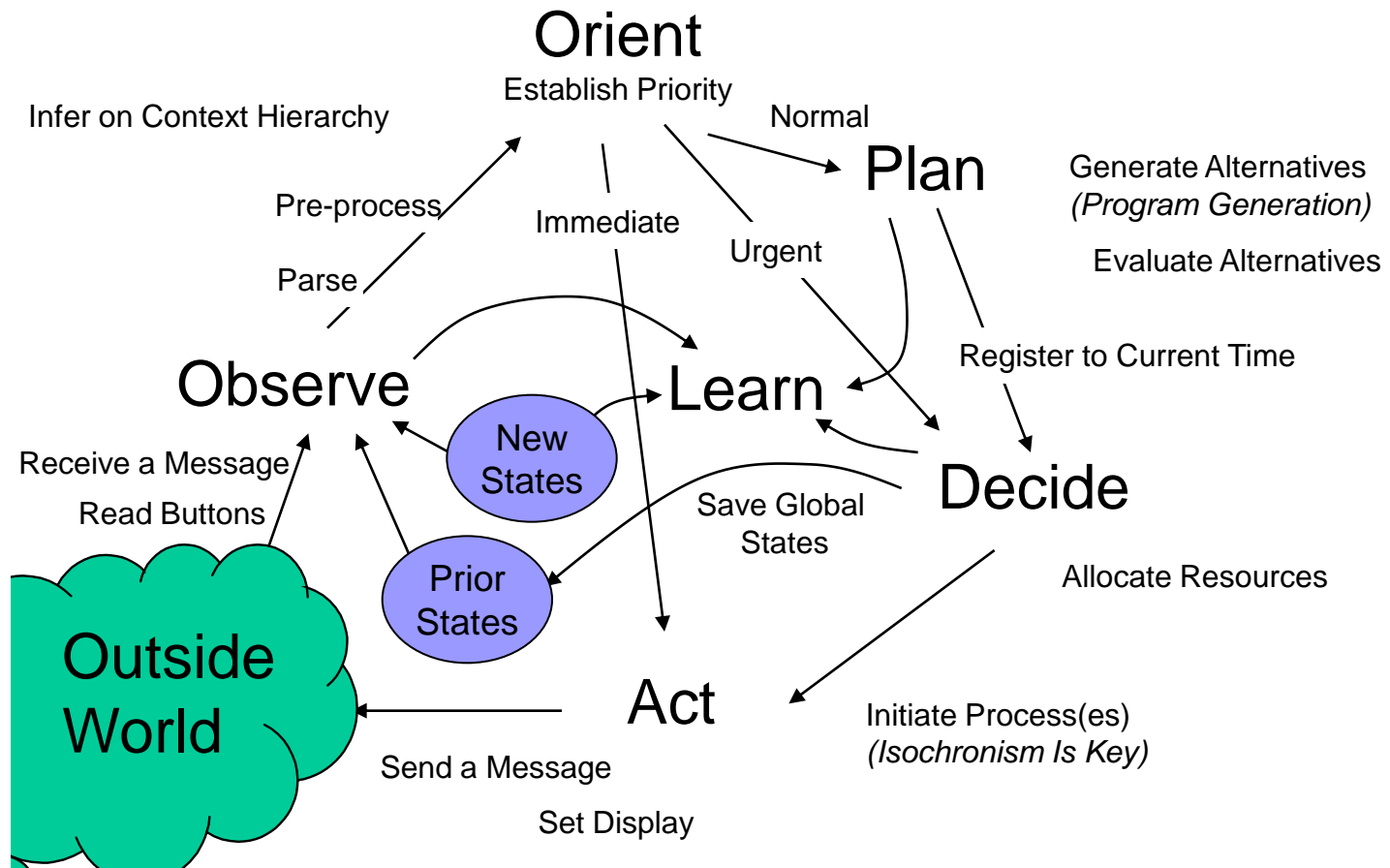
# Holistic approach

- A holistic approach to adaptation in communications systems is proposed.
- An illustrating model is presented – the Cognitive Antenna System.
- Essential to this model are:
  - (i) integration of **cognitive mechanisms** (perception, reasoning, learning, action), and
  - (ii) **natural computing metaheuristics** for **optimizing processes** and **decision making**.

# Cognitive radio technologies

- Enabler for **complexity management** in communications systems
- Transferring **cognitive mechanisms** to telecom systems
- **Interdisciplinary approach** – telecom, AI, economics.

# The Cognition Cycle (J. Mitola, 2000)



# Illustrative model

## Cognitive Antenna System

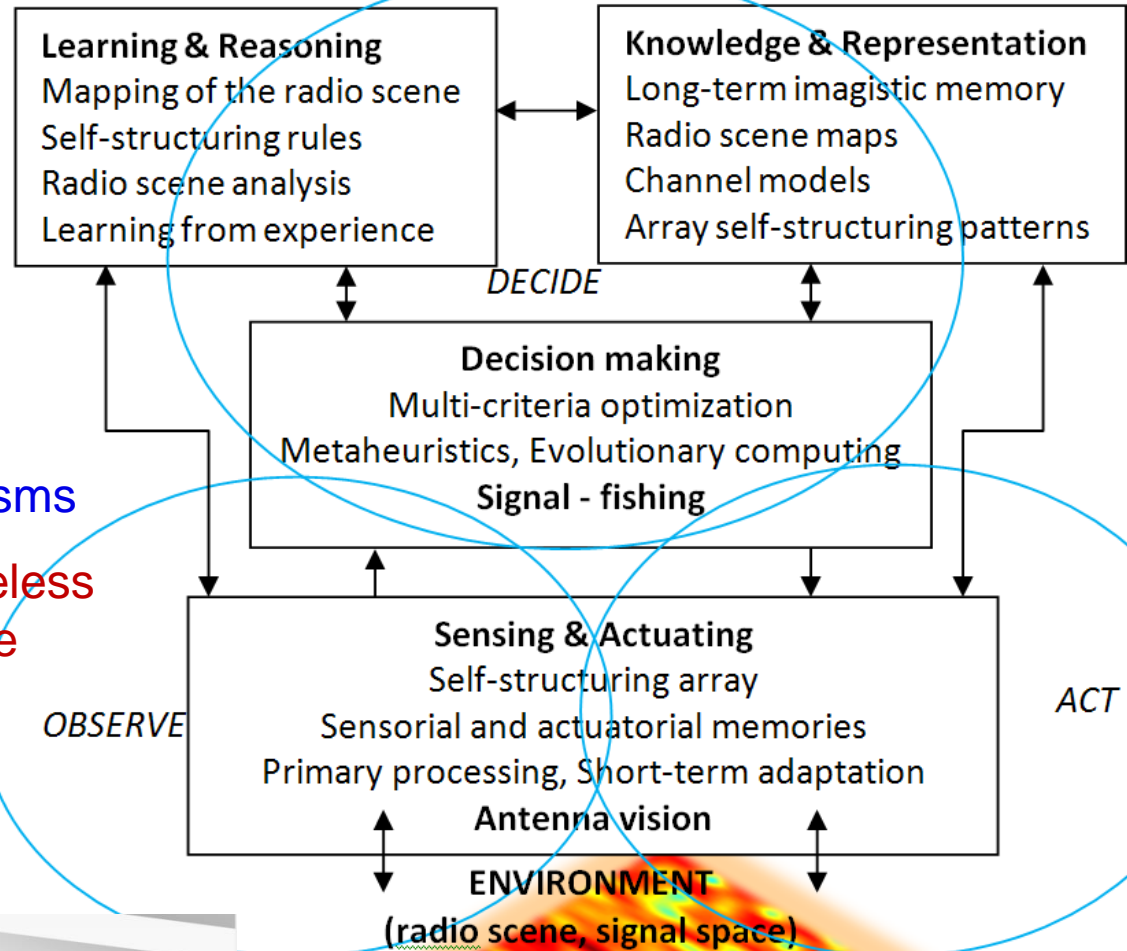
- Long-term dynamic adaptation for wireless receiver chains
- **The antenna** – a pivotal element in determining and assessing quality in wireless communication systems.
- The antenna takes an active role in **characterizing and learning** the operation environment (wireless propagation channel).
- **Proactive reception**
- **Radio scene analysis** (analyzing the signal space in terms of space, time, frequency, code and location)
- **Advantages:** higher received SNR, no additional noise, higher AoA estimation accuracy.

# Cognitive Antenna System – proposed conceptual model

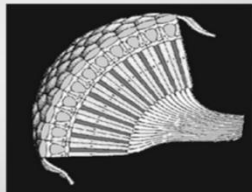
Bio-inspired model

Integrates cognitive mechanisms

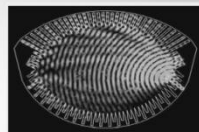
Improves reliability of the wireless link by performing radio scene analysis and responding to changes in the RF signal environment.



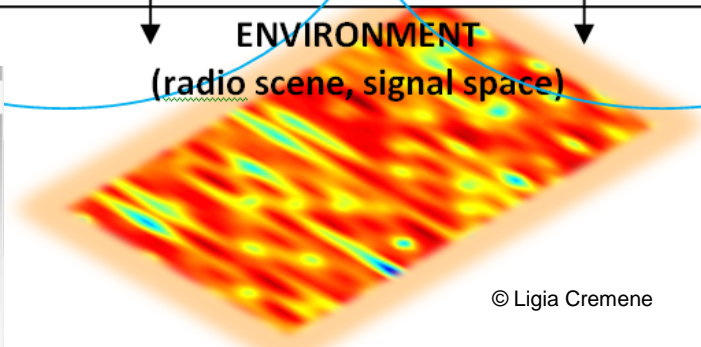
Compound-eye-like array structure



Compound eye section  
thousands of ommatidia



Modified Rotman  
lens control



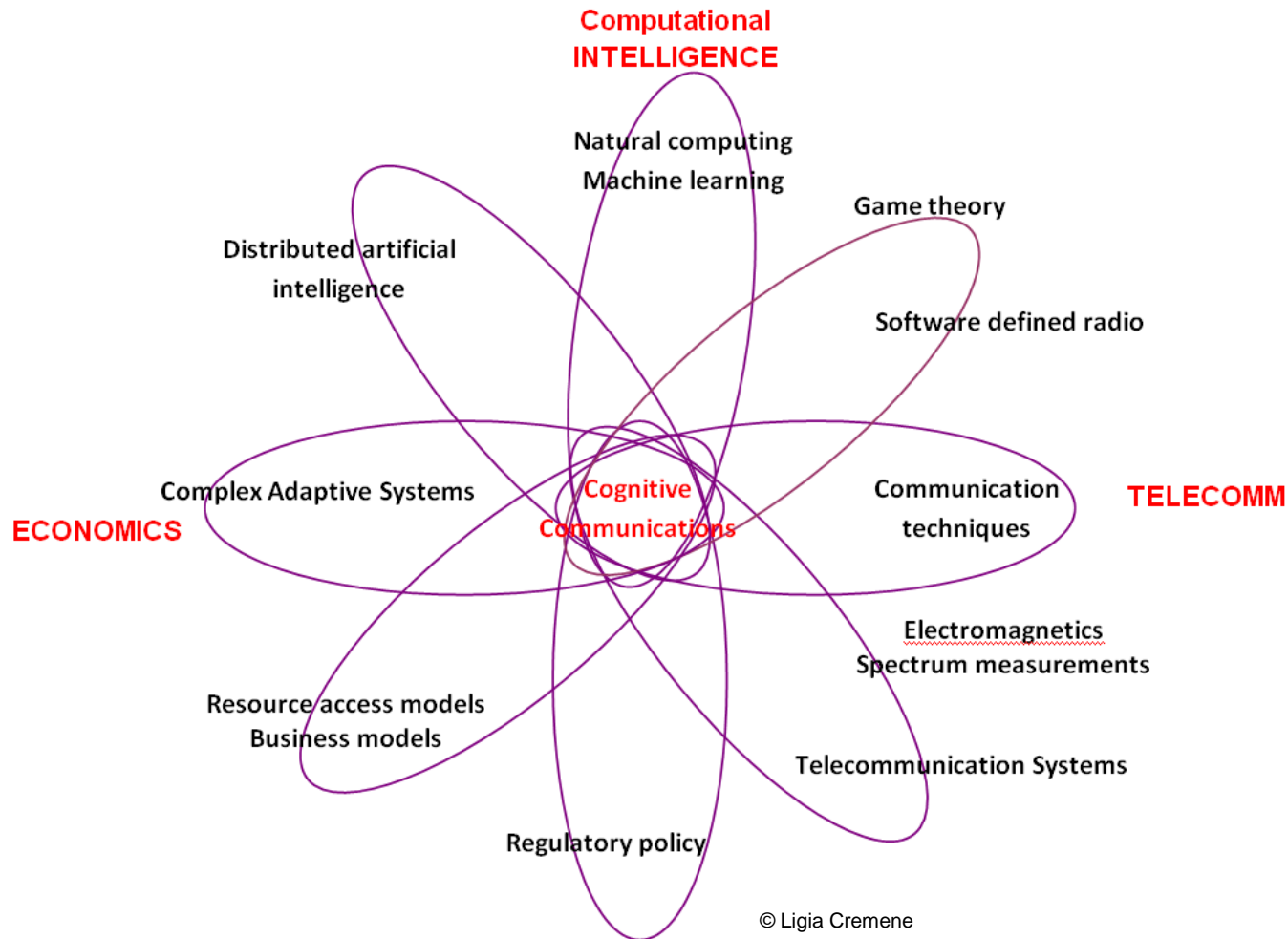
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# Conclusions

- Future communications systems are imagined as sufficiently flexible to cope with complexity generated by emerging services and applications, unforeseen needs and technologies.
- In order to manage the complexity and dynamics of current telecommunication systems **a holistic approach** is required to their design, **centred on the human user**.
- Integrate the operating restrictions of resources and cost components in order to optimize the solutions.
- Integration can be achieved by applying computational intelligence techniques, still underused in the telecommunications sector.



Hopefully, the proposed model will contribute to materializing the emerging paradigm of **Cognitive Communications**.



# Acknowledgment

- This paper was supported by CNCSIS–UEFISCDI of Romania, PD, project number 637/2010.
- This presentation was supported by the project *"Develop and support multidisciplinary postdoctoral programs in primordial technical areas of national strategy of the research - development - innovation 4D-POSTDOC"*, contract nr. POSDRU/89/1.5/S/52603, project co-funded from European Social Fund through Sectorial Operational Program Human Resources 2007-2013, Romania.

*Thank you for your attention.*



*No problem can be solved from the same level of consciousness that created it.*

*A. Einstein*