

Highly-Complex and Networked Control Systems

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Concept and objectives

Main idea 1

The analysis and design of control algorithms is an essential technology for **improving robustness, safety, performance, predictability and cost** of large-scale networked systems (increasingly distributed & immersed in hostile environments)

Main idea 2

The **new discipline** merging the disciplines of control, computer, communication with physical or biological systems is facing new very interesting challenges. A considerable focused research effort by the best complementary teams is needed

Main idea 3

Research on **Highly-Complex and Networked Control Systems** has major strategic relevance for the European industry and society and is essential to ensuring a leading position for Europe in numerous key industrial sectors and in the biological and medical world. This is well-recognized in the ICT FP7 priorities.

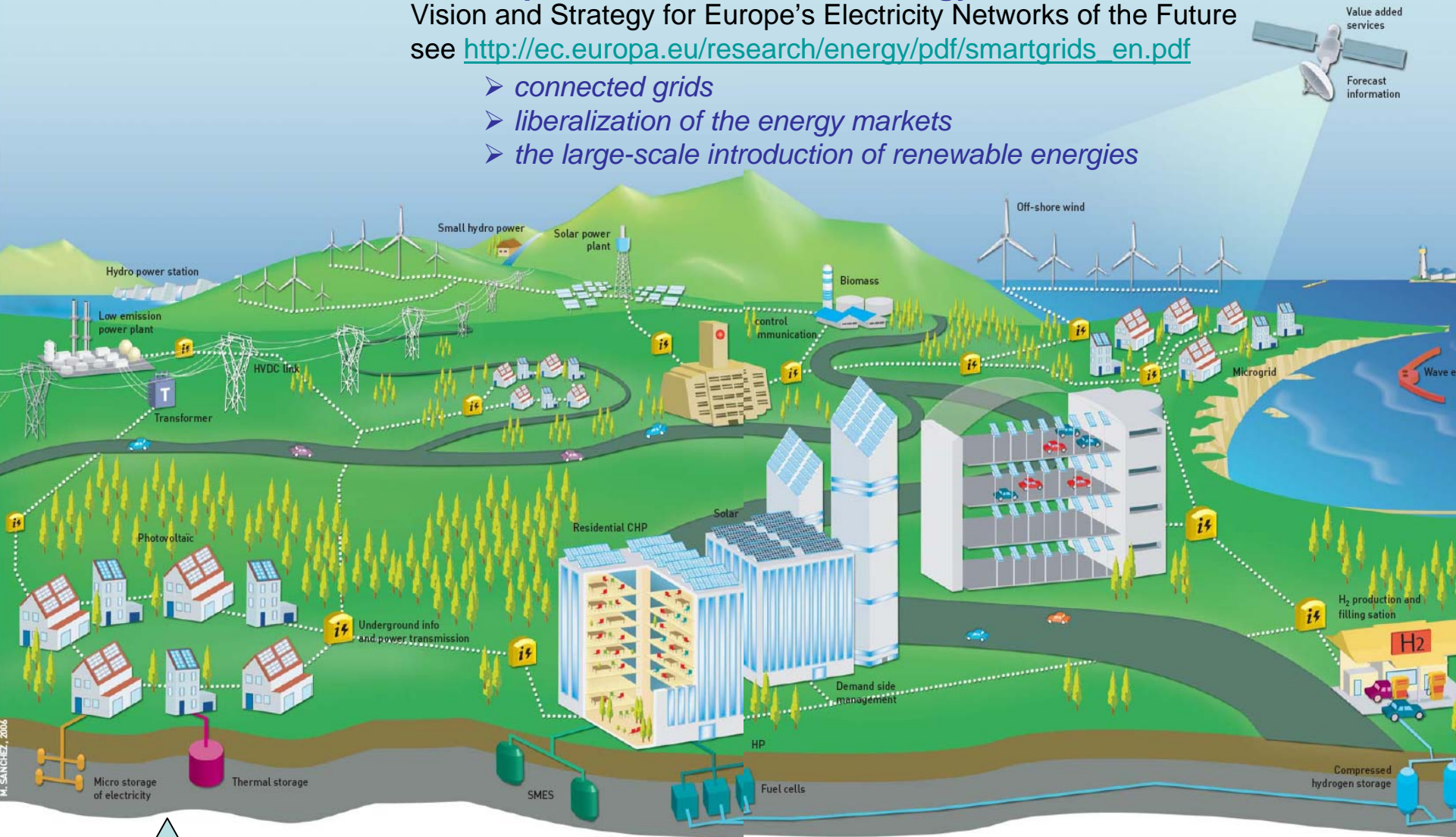
Main idea 4 - from HYCON to HYCON2

Extension on two fronts: foundations and application domains

European SmartGrids Technology Platform

Vision and Strategy for Europe's Electricity Networks of the Future
see http://ec.europa.eu/research/energy/pdf/smartgrids_en.pdf

- *connected grids*
- *liberalization of the energy markets*
- *the large-scale introduction of renewable energies*

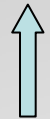


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- 3) HIGHER LAYER - overall network security, mitigation of large disturbances
 - 2) INTERMEDIATE LAYER - balancing produced and consumed power
 - 1) LOWER LAYER - **electro-technical devices** for ensuring local distribution

Highly-Complex and Networked Control Systems SPECIFICITY:

Different layers: each layer has its own “life” (size and time scales) but it is strongly connected to the other layers.

Ex1: Energy management



- 3) overall network security, mitigation of large disturbances
- 2) balancing produced and consumed power
- 1) **electro-technical devices** for ensuring local distribution

Ex2: Transportation



- 3) traffic flow
- 2) interactions between electronic devices
- 1) **electronic devices** for making vehicles cleaner or safer

Ex3: Molecular processes



- 3) networks of interactions (transcription networks)
- 2) interactions between molecular species
- 1) **microfluidic devices** to control the cellular environment

other Application Domains



- 3) networks of interactions
- 2) interactions between systems
- 1) **devices** to control

HYCON2 spirit

Motivation,
definition of
new
problems

- **Control & Systems theory**

- abstract mathematical representations
- general solutions to theoretical problems
- general methods for analysis and design

- **Applications**

- specific performance requirements
- specific modeling needs
- specific hw/sw implementation constraints
- tailored solutions to complex problems

Modeling
and control
design tools

HYCON2 scope

HYCON2 will **develop novel abstractions and methods** or will **adapt and extend existing techniques** (*i.e. Multi-agent or Hierarchical MPC, Relaxed dynamic programming, Control by interconnection*). **Five thematic areas (TA)** have been distinguished:

- **TA1 - Analysis of complex systems**
- **TA2 - Networked control**
- **TA3 - System-wide coordination and control**
- **TA4 - Self-organizing systems and control**

The HYCON2 common TA fundamental studies are essential in particular for **not rediscovering methods** from one application domain to another, and **for using (and adapting) methods and tools** from one application domain to another.

HYCON2 scope

HYCON2 will focus on three application domains (AD).

In order to contribute in helping European industries stand the pressure of market competition (especially acute now because of the global economical crisis) and the steadily more stringent environmental regulations enforced by public authorities, HYCON2 will focus on:

- **AD1 – Transportation**
- **AD2 - Energy**
- **AD3 - Biological and medical systems**

HYCON2 research activities

International Scientific Council (ISC)

TA1 – Analysis of complex systems

TA2 – Networked control

TA3 - System-wide coordination and control

TA4 – Self-organizing systems and control

AD1 – Transportation

AD2 - Energy

AD3 - Biological and medical systems

Transversal integration

Industrial Advisory Board (IAB)

Modeling large-scale and complex systems and **understanding their behaviour** is an essential first step for the development of advanced control methods to improve their performance. **Novel analysis and modeling methods are needed.**

Challenges include:

- *Compositional and hierarchical modeling and analysis*; needed to develop models at different levels of abstraction and moving seamlessly from one to the other (ex. Behavioural approach).
- *Emergent behaviour*; understanding how the overall behaviour emerges out of the local interactions is a challenging task that cannot be addressed by state of the art methods; understanding the impact that the control commands will have on the emergent behaviour of the system is essential for the successful implementation of control policies.
- *Networking effects*; understanding how the network topology interacts with the primarily continuous dynamics of the underlying system. The problem is further complicated by the fact that the networking structure is often not itself fixed, but subject to change depending on the evolution of the system.

This TA deals with systems that result from the composition of a relevant number of **components (sensors, controllers, actuators) that interact in a networked context**. Two different aspects deserve investigation:

- *Control of networks* is about developing strategies for the automatic control of network functionalities (not only communication networks).
- *Control over networks* is typically concerned with the interactions between a set of components and their communication infrastructure (with limitations, but also opportunities with a great amount of new communication technologies).

For instance: control loops

CAN – Controller Area Network in automobiles

AGC – Automatic Generation Control in power distribution



Challenge: introducing modelling and control in the design of networks, from the prediction of the behaviour of the network to the analysis of stability, and the design of adaptive rules for the control of the network.

The interaction of multiple elements that are efficient, safe and robust when taken individually thanks to a good design at the lower levels, *has to be analysed to avoid performance deterioration and vulnerability with respect to disturbances and model errors.*

Example: Efficient resource utilization and rapid adaptation to market demands require **flexible production systems** where the available resources and the operating modes of the units are flexibly reconfigured to match the demands with lowest possible cost. Optimal scheduling reduces the cost and the energy consumption.



This layer needs **new model strategies** that can be used for instance to produce a simulation tool. This new tool could then be coupled with optimization algorithms in order to produce a complete scheme for modeling, optimizing and simulate.

The convergence of communication, computing, and control is providing the technological opportunity **to create large systems of many autonomous “objects”, which have capabilities of not only sensing, but also acting in and on the environment.** These systems of many sensors, actuators, and computational units, interconnected wirelessly or over wires, raise several research challenges of different nature, as to what concerns e.g. their deployment, coordination and communication.

How can an ensemble of individually autonomous agents act in a coordinated way to achieve a common goal?

Particular focus: a scenario in which a group of objects (robotic vehicles) move autonomously in a shared environment, each vehicle being assigned a specific task to accomplish on its own or in collaboration, such as dispatching items in an automated warehouse, monitoring the environment, reconstructing a map, searching for an object, or detecting hazards or intruders. Agents - typically heterogeneous, unmanned vehicles - can join or leave the group dynamically.



Crucial issues: coordination, safety, scalability, and security of the distributed system

Modern control design problems involve **different and interacting layers of control, from regulatory loops to supervisory functions** for the optimized management of a vehicle, up to the coordination of multiple vehicles. HYCON2 envisions directions of research for new control theories and tools.

- New control designs including embedding optimization procedures are needed to make ground vehicles cleaner (for instance by further reducing emissions through better control of exhaust gas composition), and safer (for instance for improved stability of vehicle dynamics).
- At a higher layer of control new control paradigms will be developed for coordinating the functions of multiple control units. (in CAN, optimally manage real-time different power sources in hybrid electrical vehicles to reduce consumptions and emissions).
- By developing new models / (predictive) controls and new tools for coordinating the motion of entire collections of vehicles at the highest layer of control, including traffic flows (ground transportation) and air traffic management (air transportation).

Water networks, fuel cells, combined heating-power, energy-efficient heating and ventilation, use of solar energy for heating and cooling, power networks

Many control schemes of present power systems have been formulated in the past and were based on national and monopolistic operated power systems with considerable spare capacity. This situation is not realistic anymore. The major changes are:

- connected grids
- liberalization of the energy markets
- large-scale introduction of renewable energies

Our modern, industrialized society **requires a reliable and efficient electric power system**. Most industries, transport, communication, Internet organisations but also citizens completely rely on the continuous availability of sufficient electric energy at affordable prices.

- *better use of Flexible Alternating Current Transmission System* in order to provide new control inputs in the power grid in the first, and to be able to better deal with the new consumer/producer status of individual costumers.
- *new model tools in order to better understand the interconnection mechanisms of the grid*, and in particular the problem of the inclusion of renewable energy production including intermediate energy storage.

Analysis and control of networks of cells:

1) Bio-medical applications

(DBS-Electrical stimulation of some cerebral zones)

The ability to handle complex networks of dynamical systems finds immediate applications in the medical world. A representative example is given by **the analysis and control of synchronization processes in networks of interconnected oscillators**: this formalism allows for a tight analysis of the phenomena involved in the symptoms of neurodegenerative illnesses, such as Parkinson disease.

2) Molecular biology

While the past research in molecular biology focused on modeling and analysis of phenomena within the cell, research is rapidly shifting towards the goal of **controlling the behavior of cell populations**. This is made now possible by the availability of experimental techniques such as **microfluidic devices** that allow one to measure gene expression in single cells while controlling precisely the cellular environment.

Progresses of such networked systems will greatly contribute to: i) help design feedback control schemes acting on the environment for guaranteeing population-level coordinated behaviors (e.g. synchronization); ii) equip single cells with distributed regulators mapped into biochemical systems for realizing the desired behaviors in a robust fashion with respect to non-idealities (time-delays in communications) of the network.



- **Management: European Embedded Control Institute**
Research institute born as a permanent result of HYCON, aiming at becoming a European focal point in embedded and networked control.
- **Level 1 actors: ~20 universities and research centres in Europe**
Direct involvement, workpackage leaders, training event organizers, ...
- **Level 2 actors:**
Partner universities, research centres and private companies wishing to cooperate, share knowledge and participate in the activities.
- **Funded EU projects on related scientific topics:**
HYCON2 aims intensifying collaboration with and between existing initiatives such as STREP projects. EU project leaders will be active partners.

Jointly-executed program of activities

HYCON2 JPA: 15 Workpackages

Integration

4 WPs

IN1 – Research coordination

IN2 – Benchmarks

IN3 – Tools

IN4 – International Curriculum Option

Research

5 WPs

TA1 – Analysis of complex systems

TA2 – Networked control

TA3 - System-wide coordination and control

TA4 – Self-organizing systems and control

Dissemination

3 WPs

DI1 – Training

DI2 – Outreach and industrial advisory board

Management

3 WPs

MA1 – Financial management

MA2 – Project management

MA3 – Communication
Newsletter
Web portal

Long term integration

Highly-complex and networked control systems is a multidisciplinary area requiring competences from control theory, signal processing, computer sciences, mechanical – electrical – electro-technical – information – chemical – hardware -software engineering, life science.

The HYCON2 NoE gathers together leading European teams from all these areas and insures:

➤ **Critical Mass**

It was essential to gather a sufficient number of partners, to achieve a fair coverage of the main topics in the area, as well as to have the capacity to impact the European research landscape. Nonetheless, to ensure efficiency, we have limited the number of partners.

➤ **Excellence**

The HYCON2 partnership includes the main European leading teams, as attested by their leadership in their respective areas, as well as their strong involvement in national and European or international projects. They are also very active in the IFAC or IEEE CSS Technical Committees.

➤ **Commitment**

Most of the HYCON2 partners have demonstrated during HYCON life a high degree of investment and professionalism to achieve the work programme objectives. Most of them were also strongly involved in the creation and definition of EECl

From HYCON to HYCON2 via EECI

... a European and international recognition

This is visible and attested through:

➤ **Dissemination activities:**

major publications (surveys, special international journal issues, handbook), organization of major conferences and workshops, strong individual national and regional involvements, international collaborations (seminars, IFAC, IEEE CSS)

➤ **International (now worldly renowned) training activities (EECI Graduate School on Control)**

➤ **EECI is an ARTEMISIA B Chamber Member**

EECI offers a **legal and perennial** (with a **physical space**, 300 m² in the heart of a new Campus Plateau de Saclay plus Lab in Univ. L'Aquila) structure making the European control community a reality. The HYCON NoE has been a very beneficial instrument for initiating and triggering this necessary integration. Considerable research efforts have been also deployed. Let us remind here that the resources needed have been far larger than financial contribution granted by EC (only for integration). **HYCON2 would allow to increase yet more the impact of the research activities of the HYCON NoE and would allow to push forward in the most efficient way, extremely important new foundations for the control of complex systems in accordance with the Physics or Biology reality.**

www.ist-hycon.org and www.eeci-institute.eu

