Expert Group on

Internet of Things (IoT) / Cyber-physical Systems (CPS)

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ICT Policy, Research and Innovation for a Smart Society

www.picasso-project.eu

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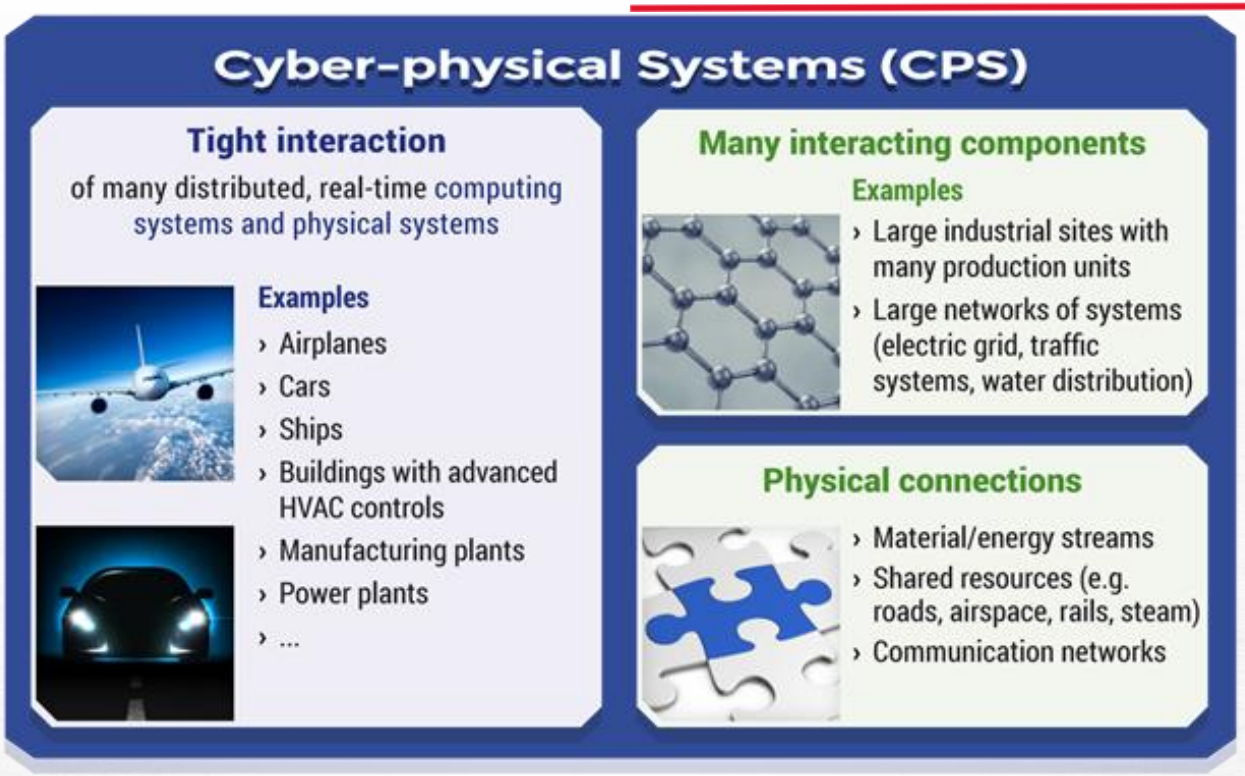
Internet of Things (IoT)

- Internet of Things (IoT) – Paradigm based on the convergence of:
  - Low-cost sensing and computation
  - Ubiquitous connectivity and mobile apps
  - Cloud analytics and big data
- IoT annual global economic potential: Between **$1.4 trillion** to **$14.4 trillion** by 2020 – big hype
- IoT initiatives, alliances, and clusters
  - **US:** Several alliances with international membership
  - **European IoT Research and Innovation Cluster** with over 40 European projects
  - **EU Alliance for Internet of Things Innovation (AIOTI)**

Cyber-physical Systems (CPS)



- An area of European strength
  - € 410 billion market
  - 4 million jobs worldwide, of which one quarter are in Europe

Convergence of IoT and CPS

- Focus of current research and development in IoT
  - Low-cost sensors / computing
  - Provision of connectivity, middleware
  - Enormous amounts of data can be collected
- How to make it useful (and a business) is sometimes not so clear
  - What benefits can be gained from the data?
  - Challenge: From sensing to actuation, closing the loop

→ **IoT/CPS**

- Cyber-physical systems are often embedded in large systems consisting of many coupled components with partial autonomy → Cyber-physical Systems of Systems (CPSoS)

What are Cyber-physical Systems of Systems?

Large, complex, often spatially distributed Cyber-physical Systems that exhibit the features of Systems of Systems

Cyber-physical Systems (CPS)

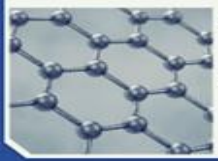
Tight interaction

of many distributed, real-time computing systems and physical systems

Examples

- Airplanes
- Cars
- Ships
- Buildings with advanced HVAC controls
- Manufacturing plants
- Power plants
- ...

Many interacting components



Examples

- Large industrial sites with many production units
- Large networks of systems (electric grid, traffic systems, water distribution)

Physical connections

- Material/energy streams
- Shared resources (e.g. roads, airspace, rails, steam)
- Communication networks

Systems of Systems (SoS)

Dynamic reconfiguration

Components may...

- be switched on and off (as in living cells)
- enter or leave (e.g. in air traffic control)

Continuous evolution

Continuous addition, removal, and modification of hardware and software over the complete life cycle (often many years)

Partial autonomy

Local actors with local authority and priorities

Autonomous systems ...

- ... cannot be fully controlled on the SoS level
- ... need incentives towards global SoS goals

Examples

- Local energy generation companies
- Process units of a large chemical site

Emerging behavior

The overall SoS shows behaviours that do not result from simple interactions of subsystems

Usually not desired in technical systems, may lead to reduced performance or shut-downs

Examples

- Power oscillations in the European power grid
- Oscillations in supply chains

Examples of Cyber-physical Systems of Systems

Integrated large production complexes

- Major source of employment and income in Europe
- Major consumer of energy and raw materials
- Many interconnected production plants that are operated mostly autonomously with distributed management structures

Transportation networks (road, rail, air, maritime, ...)

- Vital to the mobility of EU citizens and the movements of goods
- Large integrated infrastructures with complex interactions, also across national borders
- Involve multiple organizational and political structures

Many more examples, e.g. smart (energy, water, gas, ...) networks, supply chains, or manufacturing

CPSoS

- CPSoS are a key element in the ARTEMIS Strategic Research Agenda
- „IoT = Systems of Systems“

  → IoT that involve physical systems = CPSoS („Internet of Energy“)

Expert Group on IoT/CPS

- **Scope** of the Expert Group: **The intersection of IoT and CPS**
- **IoT related to applications that involve physical systems**
  - Smart Cities
  - Smart Energy
  - Smart Transport
  - Smart Production
- Beyond connectivity:
  - How can the data be transformed into useful knowledge and actions?
  - Large scale systems (CPSoS) with multiple / multiscale feedback loops, local autonomy
  - Strong involvement of humans
  - But also strong need for support of humans (“Cognitive Systems”)

Expert Group Members

Name	Organization Position	Background
Sebastian Engell (Chair)	TU Dortmund, Germany Professor	Automation and Control / Systems Management / CPS
Tariq Samad (Co-chair)	Technological Leadership Institute (TLI), University of Minnesota, US Professor	Industrial Automation
Massoud Amin	TLI, University of Minnesota, US Director / Professor	Infrastructures / Smart Grid
Chris Greer	NIST, US Associate Director for Programs	Computing / CPS
Paul Nielsen	Software Engineering Institute, CMU, US Director / CEO	Software development / CPS / Cyber-security
Haydn Thompson	THHINK, UK Director	Wireless sensors / Transportation / Manufacturing / Smart Cities / CPS / IoT
O. Sinan Tumer	SAP Co-Innovation Lab, US Senior Director	Co-Innovation / Research Commercialization
Hubertus Tummescheit	Modelon CEO	Modeling / Simulation
Ovidiu Vermesan	SINTEF ICT, Norway Chief Scientist, Chair WG01 AIOTI	Internet of Things

Some Facets of the Discussion (1)

- Different understanding of the concepts („semantics“) – clarification is needed
- US: Two views of IoT
  - IoT meaning connectivity/middleware
  - Broader understanding: IoT = physical + computing + virtual + human „worlds“
- CPS has the connotation of being rigorous, whereas IoT is „quick and dirty“
- IoT comprises CPS vs. CPS make use of IoT

Some Facets of the Discussion (2)

- Dependability, security, trustworthyness …
  - Vulnerability of IoT-connected devices is worrying, many systems were never meant to be connected to the internet
  - Several examples of cyber attacks in energy/production in the last years
  - To which extent is regulation needed?
  - Applications come to the market quickly → de-facto architectures, how can they migrate to better defined, more reliable and secure and extensible ones
  - Localization and expiration of data

Some Facets of the Discussion (3)

- Autonomy means that systems are not confined, deep „world-knowledge“ is needed
- Full autonomy not likely in the near future
- Important role of humans in semi-autonomous systems
- Deeper understanding of cognition, situation awareness, … needed

Some Facets of the Discussion (4)

- Several competing IoT reference models – unification/reduction/interfacing
- How to connect different platforms e.g. in smart cities

- Many options for transatlantic collaboration
- What kinds of topics are appealing for funding agencies
  - Fundamental: Autonomy, human in the loop, …
  - Applied: Address world-wide challenges, beyond US and EU
- Discussion who could be US partner for joint calls

- IoT/CPS/CPSoS need 5G and Big Data technology

Proposals to the EU side

„One-stop shopping for EU funding“ (?)

„Simplified rules and regulations“ (?)

SUMMARY

- … the discussion helped both sides to understand better the initiatives, the players, and their focus on the other side

Next: Opportunity Report

- **Start from "Panorama Report"**
- **Analytical work by the Expert Group**
  - Investigate current research priorities and the focus of on-going projects
  - Analyse gaps and new opportunities
- **Interviews** with leading representatives of industry and academia on challenges, opportunities, and technology and policy gaps
- **Discussions** with funding bodies (e.g. NSF, EU)
- **Synthesis:** Key challenges, proposals for strategic initiatives
- Posting and discussion