Systems of Systems (SoS)/Complex Systems

an

Introduction

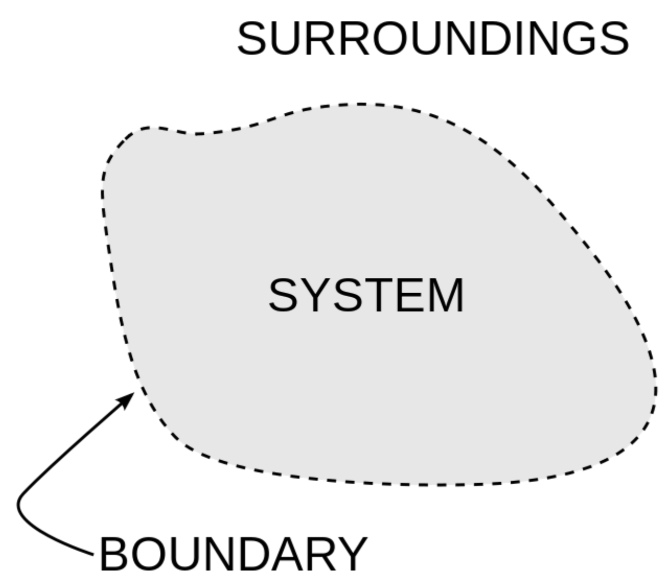
System

- Etymology:

  The term is from the Latin word *systēma*, in turn from Greek *σύστημα* systēma, "whole compounded of several parts or members, system", literary "composition"[1]

System boundaries

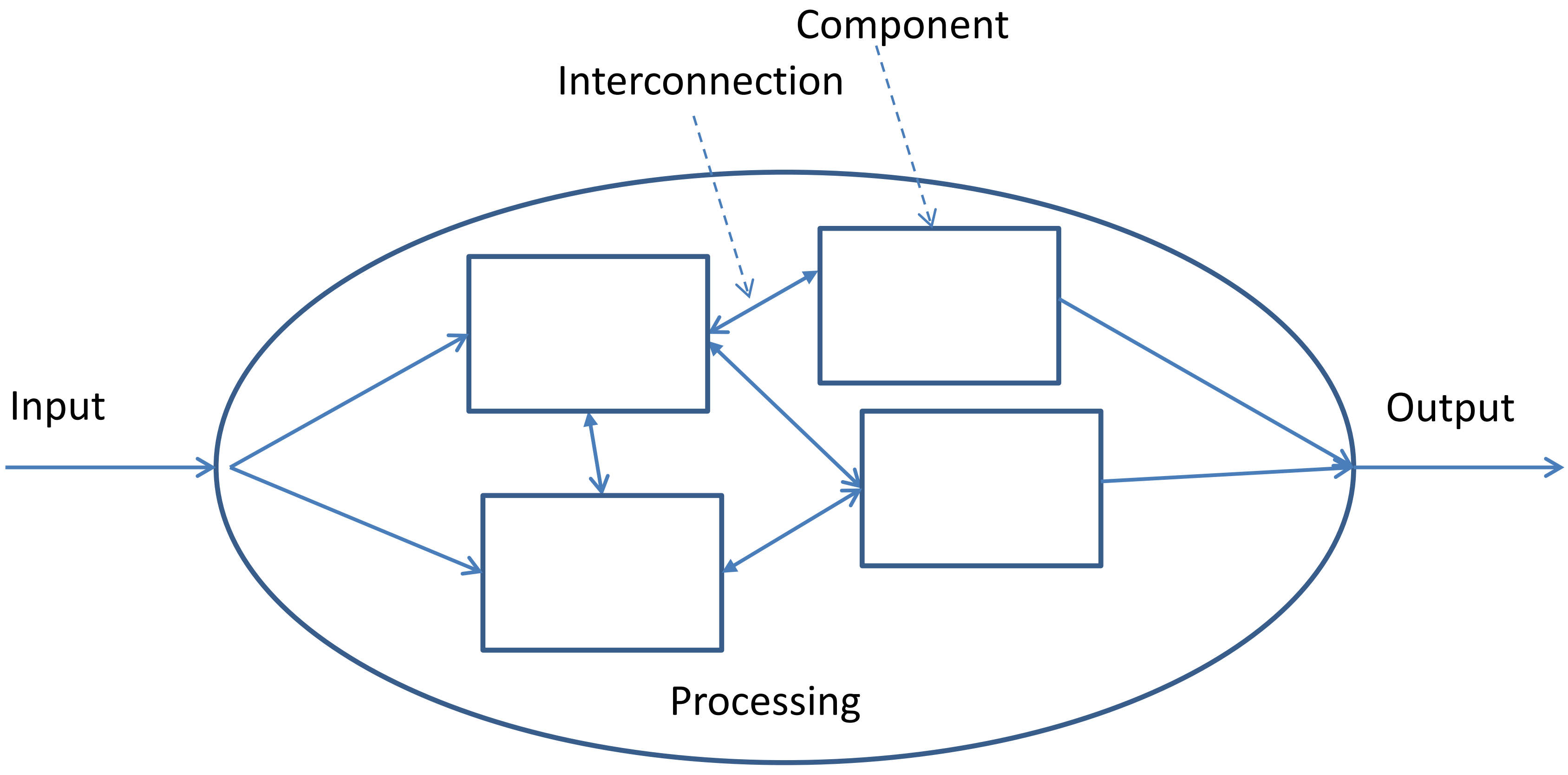
- Systems theory views the world as a complex system of interconnected parts. We scope a system by defining its **boundary**; this means choosing which entities are **inside** the system and which are **outside**.



System

- Systems have structure, defined by components/elements and their composition;
- Systems have behavior, which involves inputs, processing and outputs of material, energy, information, or data;
- Systems have interconnectivity: the various parts of a system have functional as well as structural relationships to each other.

System structure



Example: Car

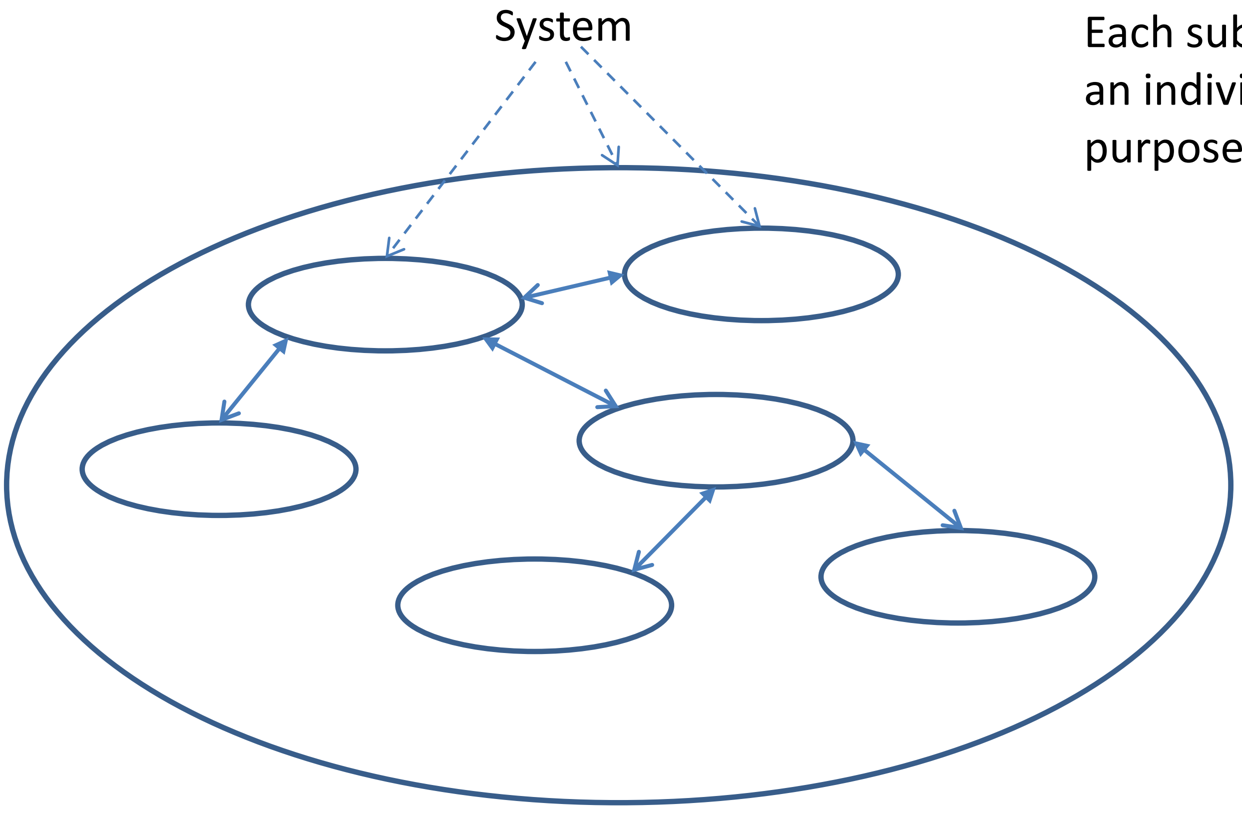
- Components:
  - wheels
  - engine
  - gas tank
  - chassis
  - body
  - lights
  - battery
  - steering wheel
  - seats

Definition of SoS

M.Maier 1998

- **Operational Independence** of the Elements: If the system-of-systems is disassembled into its component systems the component systems must be able **to usefully operate independently**. The system-of-systems is composed of systems which are independent and **useful in their own right**.
- **Managerial Independence** of the Elements: The component systems **not only *can*** operate independently, **they *do* operate independently**. The component systems are separately acquired and integrated but maintain a continuing operational existence independent of the system-of-systems.
- **Evolutionary Development**: The system-of-systems does not appear fully formed. Its development and existence is evolutionary with functions and purposes added, removed, and modified with experience.
- **Emergent Behavior:** The system performs functions and carries out purposes that do not reside in any component system. These behaviors are emergent properties of the entire system-of-systems and cannot be localized to any component system. The principal purposes of the systems-of-systems are fulfilled by these behaviors.
- **Geographic Distribution:** The geographic extent of the component systems is large. Large is a nebulous and relative concept as communication capabilities increase, but at a minimum it means that the components **can readily exchange only information and not substantial quantities of mass or energy.**

System of Systems



Components are systems in their own right.
Each subsystem ser an individual purpose

Complex Systems

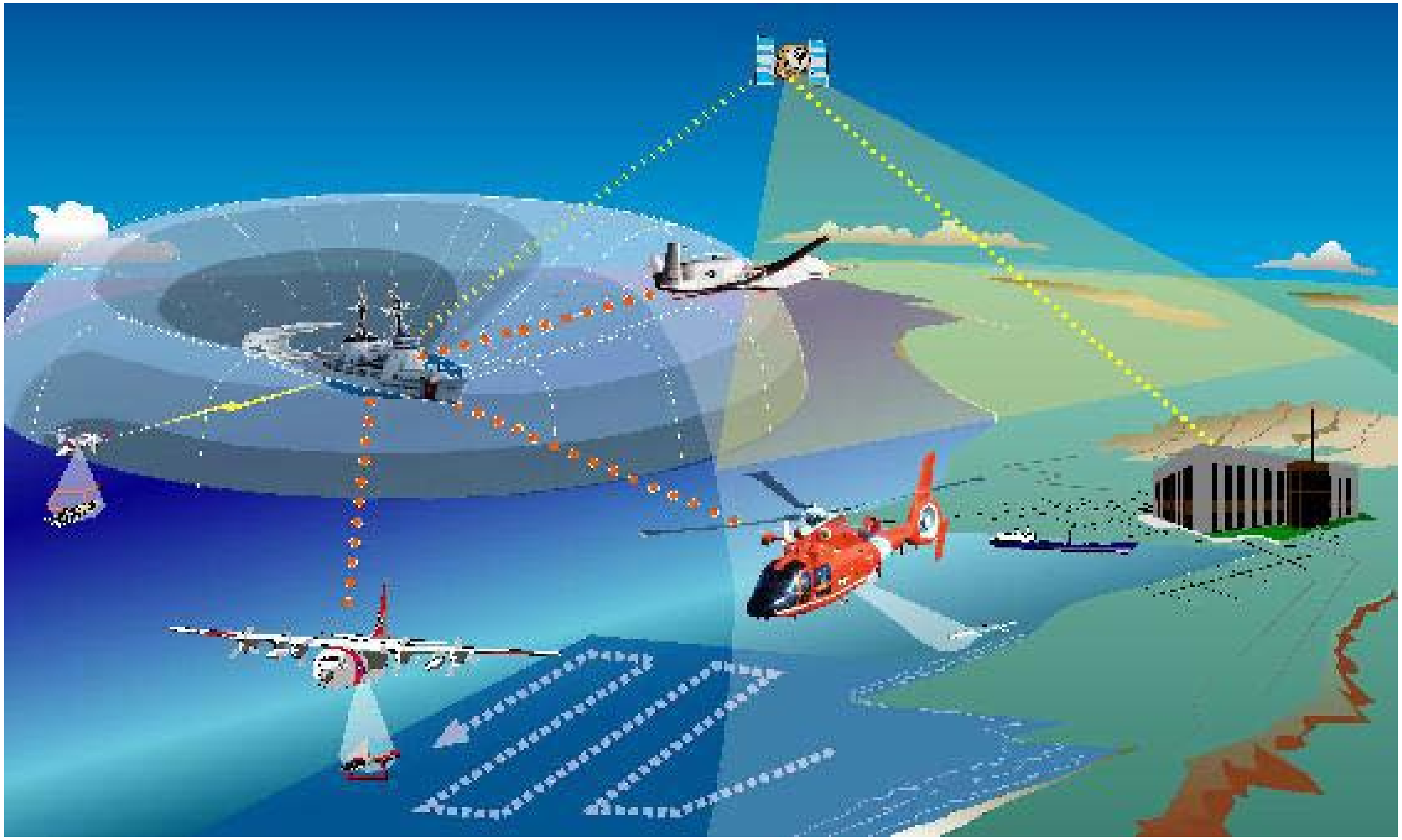
- Sarah A. Sheard 2006

Complex systems are systems that **do not have a centralizing authority** and are not designed from a known specification, but instead involve **disparate stakeholders** creating systems that are **functional for other purposes and** are only brought together in the complex system because the individual "agents" of the system see such **cooperation as being beneficial** for them.

Differences to traditional systems engineering

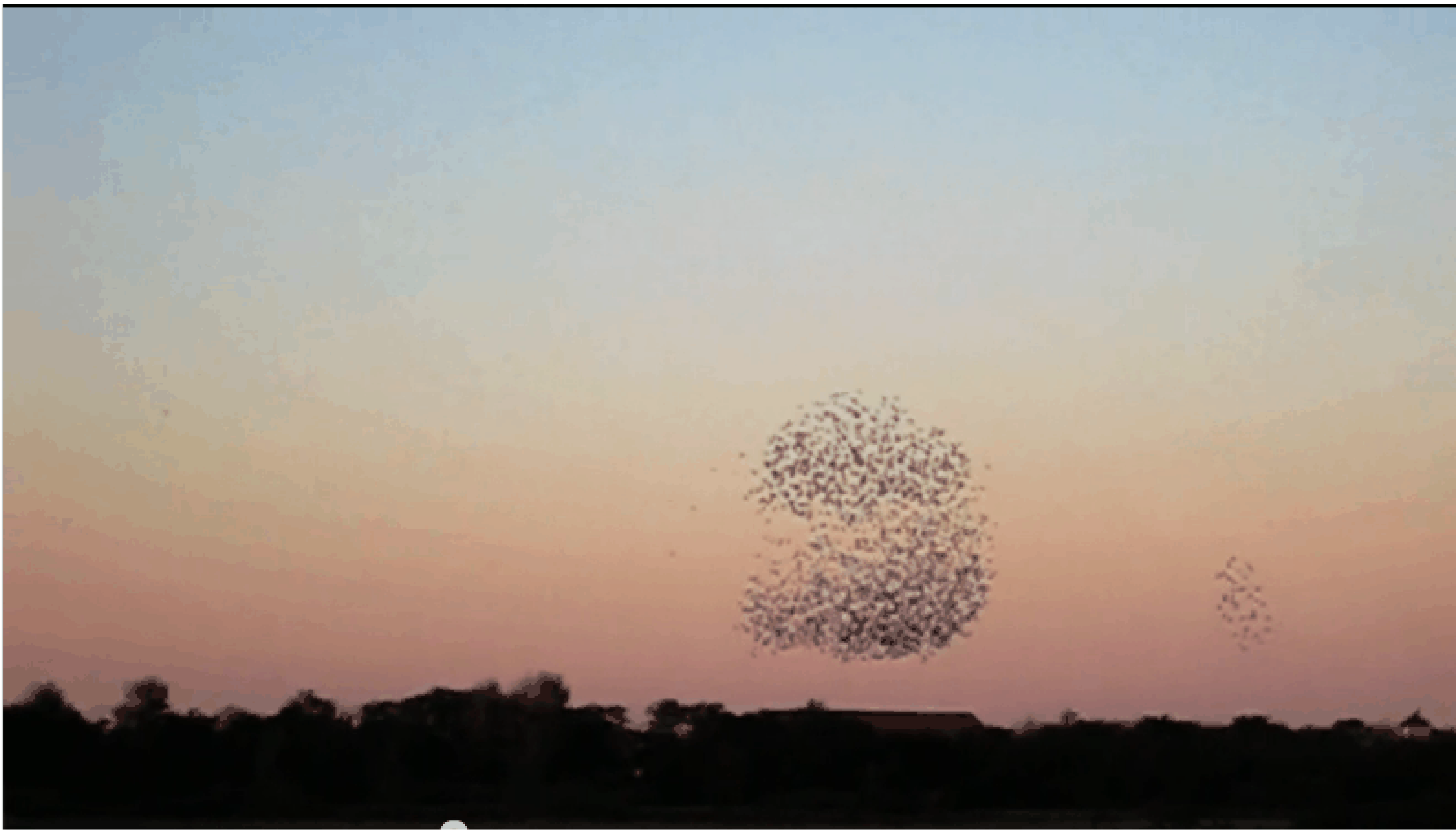
- Integration of independently operational component systems that were built for other purposes;
- Rapid evolution of both user needs and system technologies, which precludes stable requirements;
- Multiple disparate stakeholders with conflicting needs and a lack of incentives to participate in the system of systems;
- Distributed development and its consequent communication problems;
- Dependence on an integrated computing infrastructure that has extremely high and increasing complexity and therefore possibilities of unintended consequences.

US coast guard



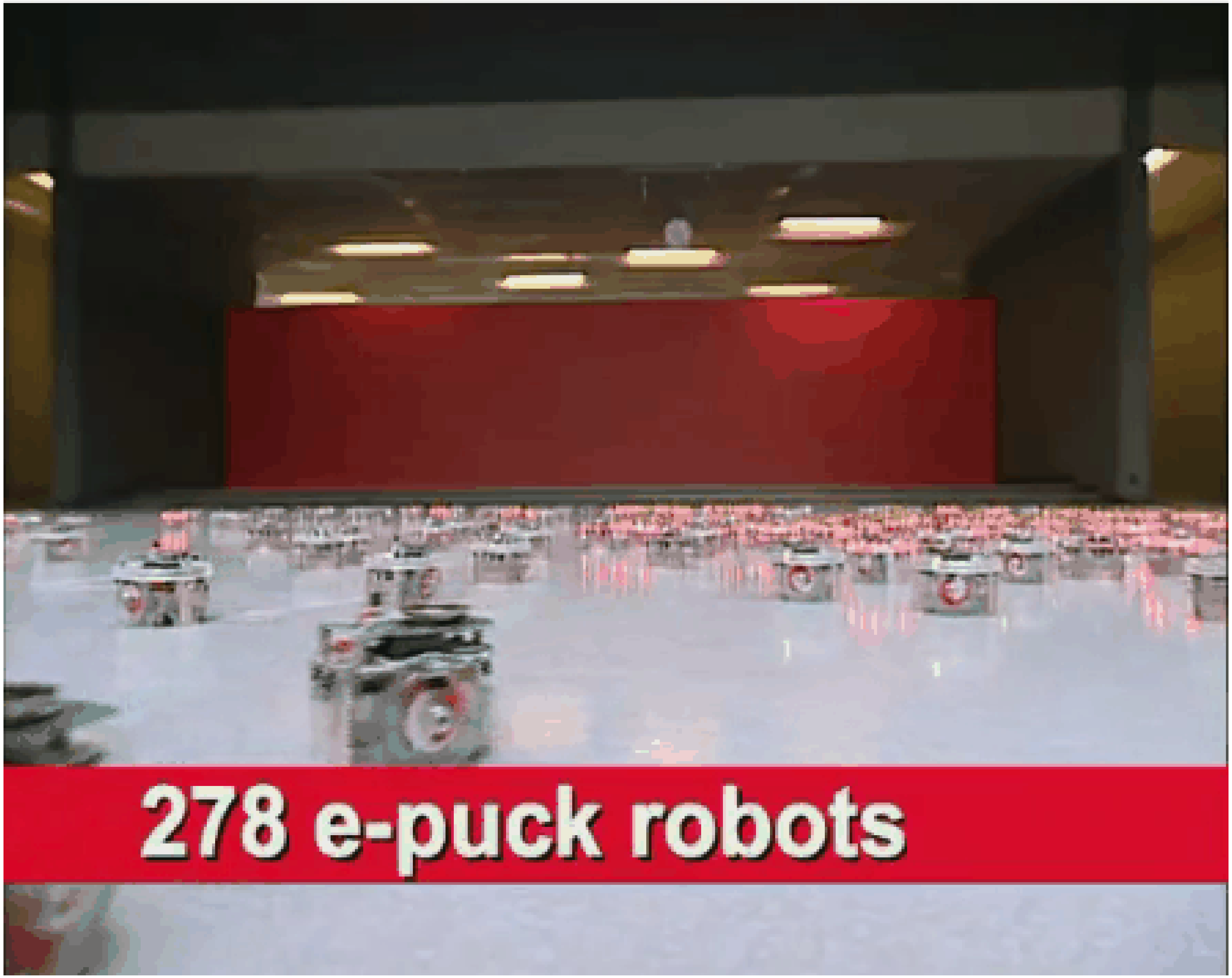
The US Coast Guard Integrated Deepwater System concept involving multiple, independent systems. [Crossley 2003]

Black Sun



Slime mold

Robotic Swarms



Other examples

- Stock brokers
- Electricity producers
- Electricity consumers
- Wind turbines in farm with decentralized control
- TCP clients
- Appl. Layer network clients (Diff. Prizing)
- Clients in wireless social network
- Cars in Intelligent Transportation System (ITS)

The power grid

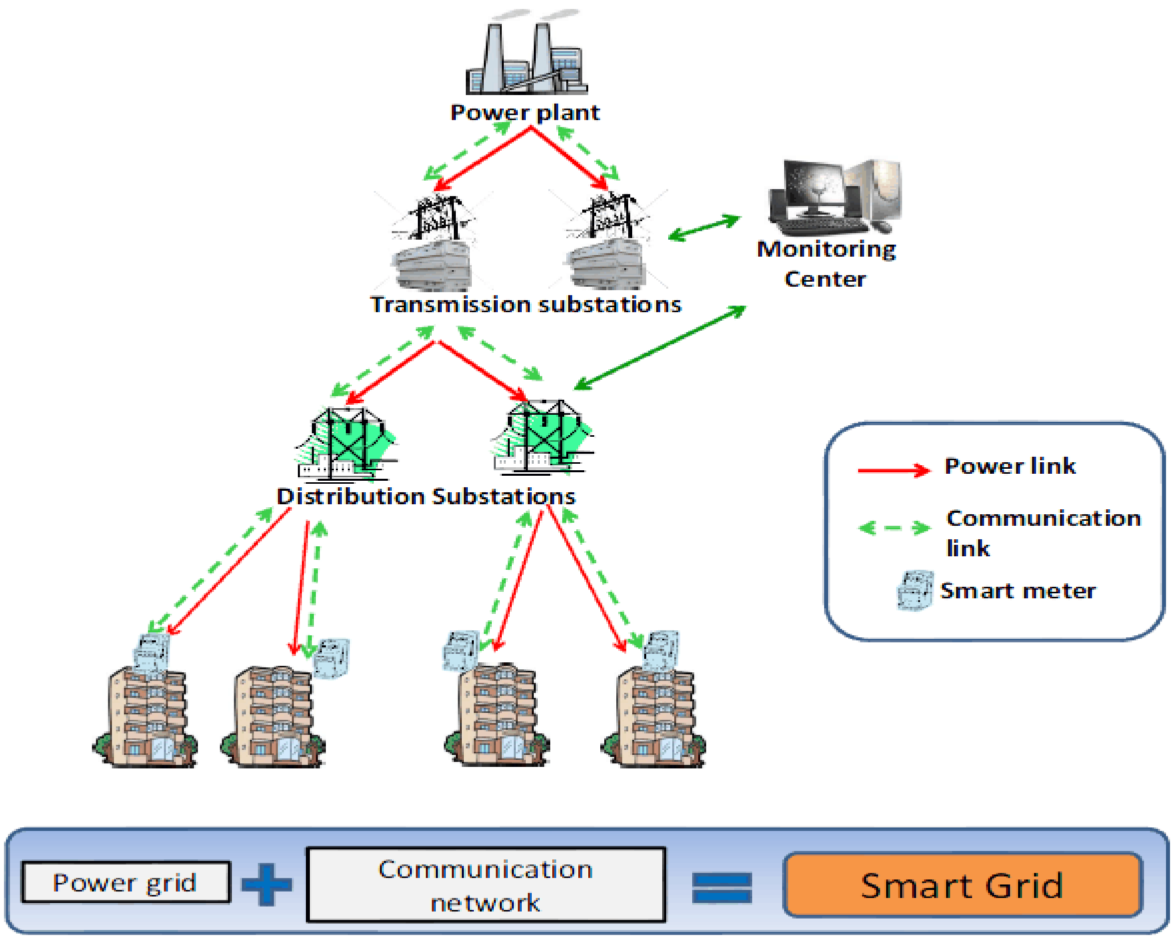


Fig. 1. Considered smart grid communications framework.

The smart grid

A **smart grid** is a modernized electrical grid that uses analogue[1] or digital information and communications technology to gather and act on information, such as information about the behaviours of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity.[2]

New actors in the grid

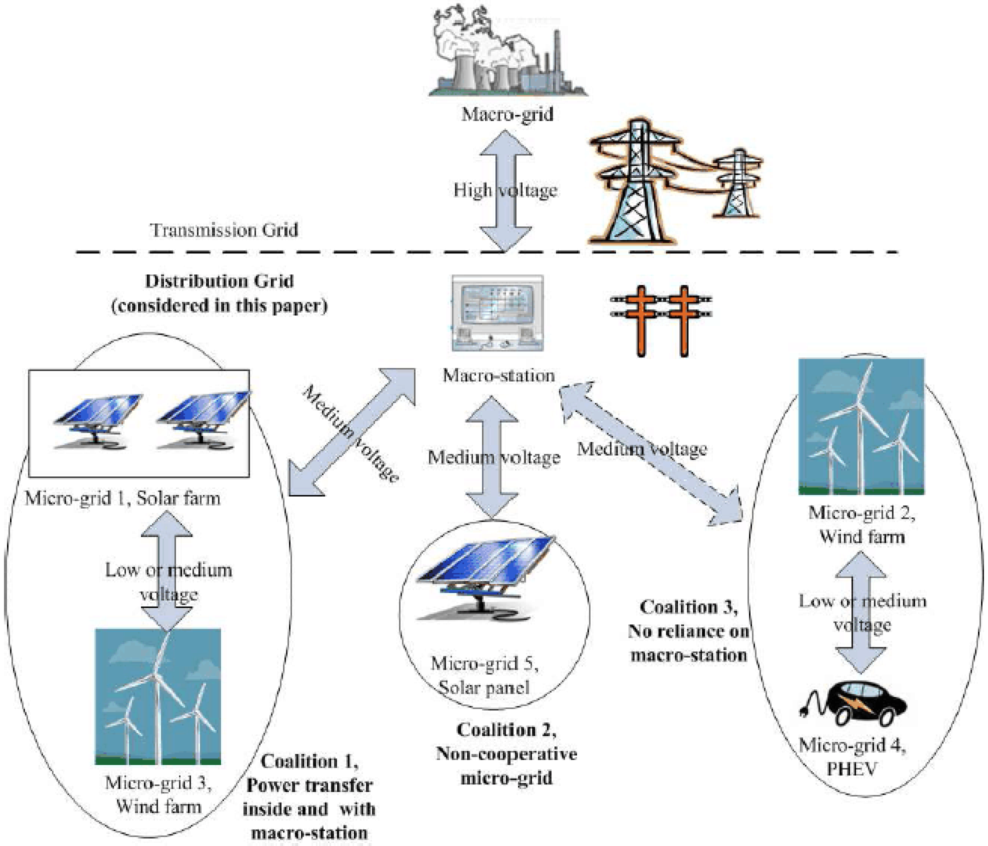


Fig. 1. An illustration of a cooperative micro-grid model.

Elements and actors of the power grid

- Large scale generators
- Transmission lines
- RTO, TSO (transmission and coordination - utility - energinet.dk)
- Distribution stations
- Distribution lines (bottlenecks)
- DSO
- Power brokers
- Consumers
  - Industrial (cooling)
  - Domestic (heatpumps)
- Renewables
  - Windturbines
  - Solar
- HEV

Power Grid Commodidities

- Active electrical power
- Reactive electrical power
- Active power at a time
- Voltage stability
- Frequency stability
- Availability
- Reliability

Virtues of the smart grid

- Reliability
- Flexibility (bidirectional, elasticity)
- Efficiency
  - Demand response
  - Peak curtailment
- Market enabling (liberalization)

Battles of the power grid

- Producers want higher prices (high demand)
- Consumers want lower prices (low demand)
- Producers battle to earn orders
- Consumers battle to have power (energy)
- Demands are timely correlated
- Multiple objectives / multiple players

Skills

- Optimization (Multiobjective)
- Game theory
- Decentralized control
- Probabilistic modelling
- Mobility models (individual/group)
- Swarm models
- Epidemic models

Multi Objective Optimization

- Where a large collection of subsystems meet a number of different objectives are defined.
- Some are contradictive, i.e.

  Optimization variable: x
  Objectives: $f_1(x), f_2(x),.., f_N(x)$
  $\{\min_x f_i(x)\}$

  or

  $x=(x_1,..,x_M)$
  $\{\min_{xi} f_i(x)\}$ (game theory)

Decentralized control

$d/dt\ x = f(x, u_1, .., u_N)$

$x = (x_1, .., x_N)$

$u_i = g(x_i)$ (sometimes optimal -> gaming)

Probabilistic Modelling

- System state is high dimensional
- Dynamics are nonlinear - > chaotic
- Dynamics are random
- State evolution is non-reproducible
- Statistics may be stable -> ergodicity

Mobility models

- Mobility characteristics may impact system performance significantly (mobile ad-hoc networks, mobile robot systems)
- Individual models: agents move independently
- Group models: agents move dependently
- Brownian motion
- Ornstein-Uhlenbeck
- Less Drunk
- Gauss Markov
- Swarm models

Epidemic models

- When in proximity, (non-positional) state of one agent may impact another agent.
- Example: information/disease spread
- Example: decentralized clock synchronization
- Example: robotic trophollaxis (energy sharing)