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SOME CONSIDERATIONS ON DEPENDABILITY ISSUES AND CYBER-SECURITY OF CYBER-PHYSICAL SYSTEMS

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Convergence between IT and cyber-physical systems

US Black-out, 2003

Industrial Control Systems (ICS)

Smart grids

Cyber attack ukrainian power network, Dec. 2015

- Integrity of the information and communication infrastructure

→ Challenge: DEPENDABILITY (RAMS Reliability, Availability, Security & Safety, Maintainability)

Drones
Autonomous vehicles
Connected Objects

Maroochy shire, Stuxnet, CrashOverride

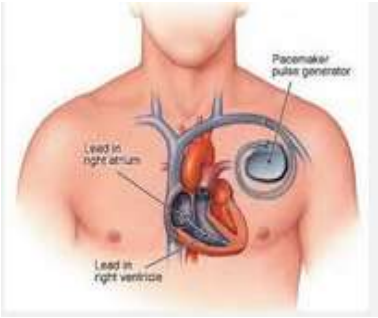
Cyber-physical systems

Remote-control and autonomous Vehicles

- Embedded circuits
- Smart devices
- Embedded networks
- Wireless networks
- Internet of things
- Ubiquitous networks
- Ambient intelligence
- Smart grids
- Health
- …

Sensor and actuators networks

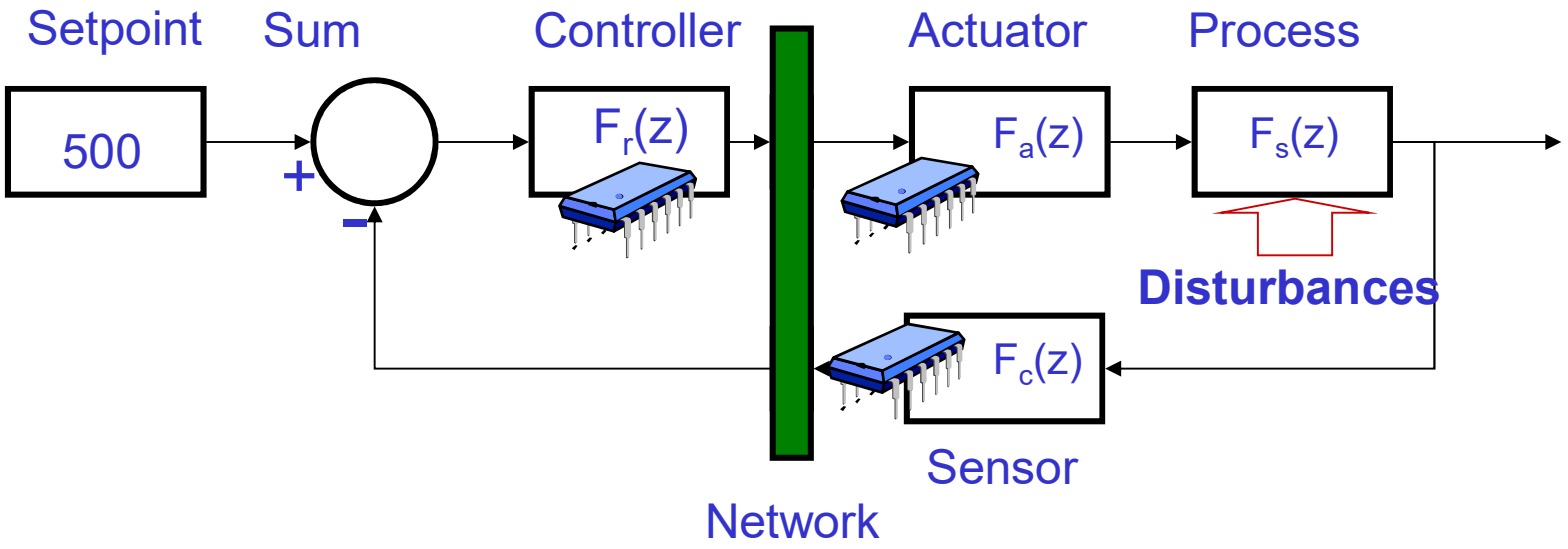
Embedded systems, Internet of things



Overview

1. **Problematics and vocabulary**
2. Dependability, safety, functional safety, security (RAMSS)
3. Risk analysis
4. Some considerations on networks, Safety networks
5. Dependability of networks and networked control systems
6. Cyber-security
7. Applications to cyber-physical systems
8. Discussions & Conclusions

Networked Control Systems (NCS)

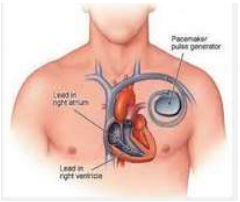


1. Continuous/sampled Components → Hybrid System
2. Discrete events-components
3. Network influence → Time Delay system
   1. Delays
   2. Jig
   3. Packet loss

Quality of Service and Quality of Control for Safer Networked Control Systems (SafeNCS)

Communication networks are more and more used in control-based applications with real-time and/or critical constraints.
Communication and Control aspects need so to be seen from a global point of view. Communication (networks) is shared between various applications, and some aspects such as wireless communication and mobility needs to be taken into account in the design of SafeNCSs. Two examples of SafeNCS can be:

A drone with very strict real-time constraints => control-oriented,
A pacemaker which is remote-supervised from time to time, the infrastructure should protect strongly the integrity of supervision => security-oriented



Cyber-security of industrial systems is now a crucial issue => impact of cyber-security to the safety of networks
In both cases, focusing on control and/or on security aims at guaranteeing **safety**

Quality of Service and Quality of Control for Safer Networked Control Systems (SafeNCS)

Quality of service aims at guaranteeing the best communication aspects, focusing mainly on:

- security aspects: to protect the communication, in order to protect confidentiality of exchanges, integrity of data and control, authentication of actors of the SafeNCS.
- availability of the network, for the considered control application, by allowing the network to control the distribution of throughput as a function of the requirements of the applications (priorities of applications). For that, we can study the network protocols and mechanisms as well as the infrastructure.

Quality of control deals with the need of "automatic control" from the point of view of control, diagnosis, supervision...

- stability which means to guaranty the controllability of the system, despite the potential unavailability of the network
- performance which should be the best as possible in a varying environment, taking account of minimal levels of security, stability and safety.

The presentation will present the problems, propose some approaches and results, and orientations concerning the study of Safe Networked Control Systems

Synthesis on the concepts

1. Dependability : Confidence in the system to ensure its mission without risk (or with a risk management)
   => Co-design approach (Network QoS ⇔ System QoC)
2. Functional safety: part of the overall safety that depends on a system or equipment operating correctly in response to its inputs [IEC]
3. Cyber-security: Cyber security is the protection of systems, networks and data in cyberspace [www.itgovernance.co.uk]
4. Networked Control Systems: Control System closed through a network
5. Complex systems, infrastructure, distributed systems
6. Embedded system, autonomous system, connected objects, IoT
7. ICS : Industrial Control Systems
8. Cyber-physical systems (CPS): Marrying physicality and computation [persyval-lab.org]
9. Our interest: To analyse CPS from the point of view of the potential impact of the system in the physical world (dependability point of view) due to a cyber-attack (attack in the digital world) and define the ways to protect it

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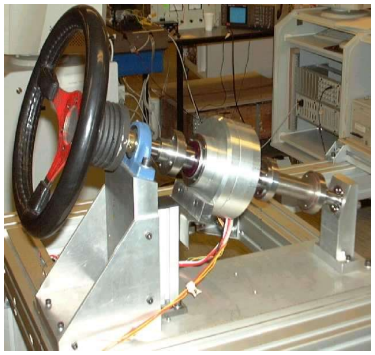
Safety/Dependability level (RAMS) of a networked based system, wired networks

- Steering by wire
  - Probability that the vehicle doesn't turn, when it is requested
  - Probability that the vehicle turns unexpectedly
- Difficult evaluation
  - Network more complex than a set of point-to-point links
  - Network more complex than a delayed system
  - Network-system Interaction

Drive shaft



X by wire, steering by wire

Dependability of networked-based systems (Wireless Network)

1st vehicle (controlled)

X by wire, brake by wire

2nd vehicle (following the 1st one)

Automated driving (virtual train)

- Braking Function
  - First vehicle
    - Probability that the vehicle does not brake when it is asked for
    - Probability the vehicle brakes without any request
  - Second vehicle
    - Probability that it receives a braking information from the 1st vehicle, if everything is correct for the first vehicle
    - …
- Existing system

  Verification model (formal approach, Monte-Carlo simulations)
- Non existing system

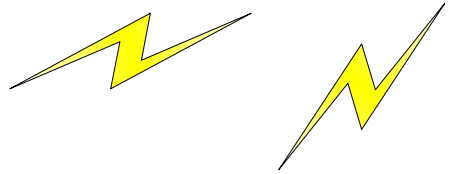
  Design model: « ideal » model + dependability constraints

Embedded system (Embedded wired network + Remote wireless communication) with strong dynamics

Drone-helicopter

Definition of the mission

- Weak dynamics (normal displacement straight ahead)
- Strong dynamics (ex : slaloms between trees)
- Disturbed communication environment (e.m. disturbances, trees…)



Quality of service of the network

- High in critical situation
- High in strong dynamic situations (if remote-control)
- Lower other time

Dependability

RAMS : Reliability, Availability, Maintainability, Safety

Fiabilité

RELIABILITY
Capacity to remain infallible throughout the task

Disponibilité

AVAILABILITY
Capacity to ensure the complete task

Maintenabilité

MAINTAINABILITY
Capacity to remain in or return to the original state

Sûreté de fonctionnement

DEPENDABILITY
Confidence in the system to ensure its mission without risk

- Accidental risks (design error, operational errors…)
- Cyber-security vulnerabilities

Sécurité …

SECURITY
Aptitude of a system to achieve its function… under the normal conditions specified in the instruction manual

SAFETY
Capacity to avoid risk (to people, to property, to the environment)

Dependability Parameters

MTTF: *Mean Time To Failure,* durée moyenne de fonctionnement avant défaillance, espérance mathématique de la durée de fonctionnement avant défaillance.

MTBF: *Mean Time Between Failures,* moyenne des temps de bon fonctionnement, espérance mathématique de la durée de bon fonctionnement

MTTR*: Mean Time To Repair (Recovery , Restoration),* durée moyenne de panne ou moyenne des temps pour la remise en état de fonctionnement, espérance mathématique de la durée de panne

MDT: *Mean Down Time,* espérance mathématique de la durée d'indisponibilité

$$MTTF = \int_0^{\infty} R(t)dt \qquad MTTR = \int_0^{\infty} [1 - M(t)]dt$$

R(t) : probability that the system stays in the operating state without failure over the entire time interval (0,t>.

M(t) : probability that the system will be restored within a specified period of time *t*.

Safety = the Science of Failures

Failure: interruption of the capacity of an entity to carry out a necessary function

- The function concerned should be defined

  ex 1: to ensure communication between two sites

  ex 2: **to ensure the accessibility of data** (locally and remotely)

- The criterion of interruption of this function must be specified

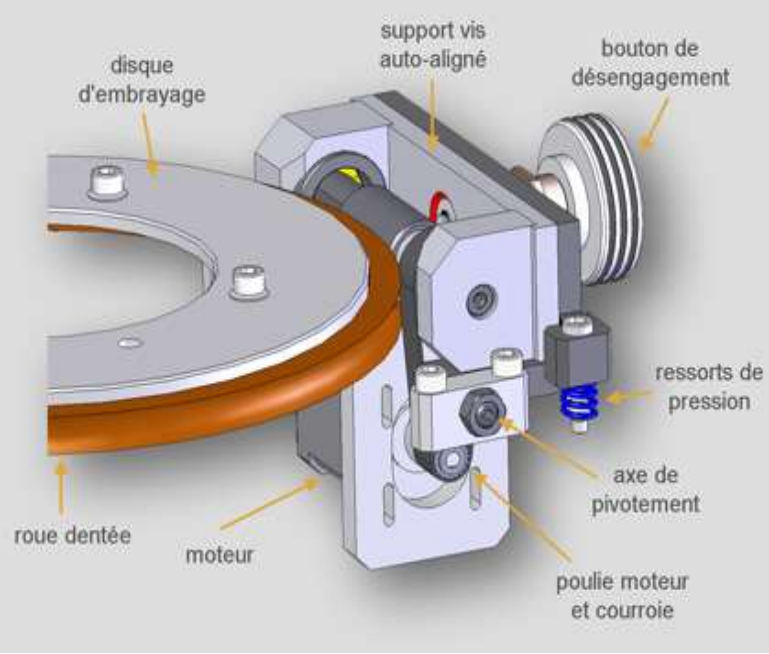
  ex 1: the flow is ≤ a certain %age of a reference value

  ex 2: the loss, or irremediable destruction of strategic data for the company

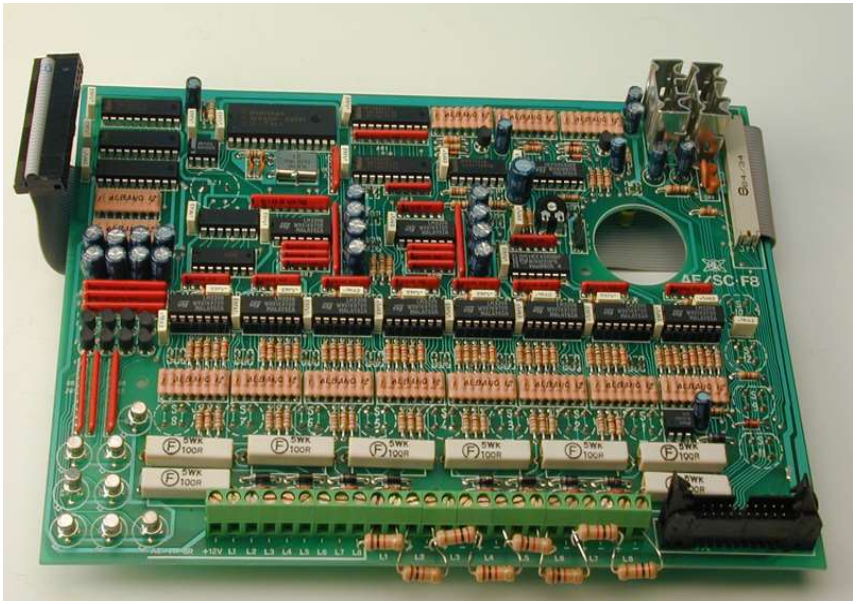
Dependability of classical Components

- System wear-out
- Topology (architecture) of the system
- « Average » use
- Permanent failures

Mechanical systems

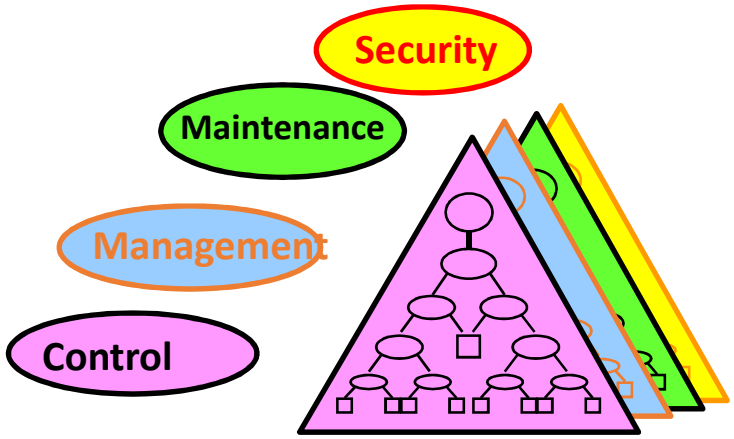


- Electronic systems



Context: Automation system evolution

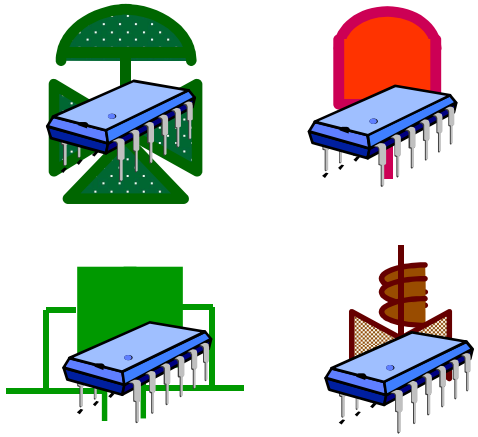
Needs:



Increased number of services

More complex architectures

Components :

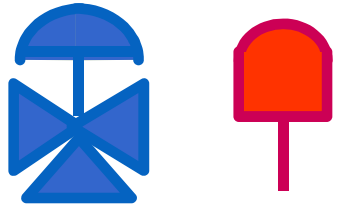


Various capacities and functionalities availability

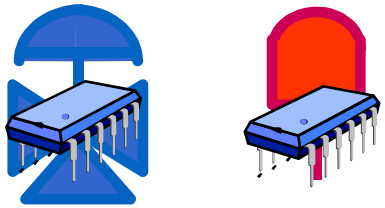
Dependability hard to evaluate and to qualify

From analog to digital and from smart to intelligent…

- Analog sensors and actuators
  - Hardware and analytical Redundancies
  - « Classiques" studies of dependability



- Digital sensors and actuators
  - A/D Interfaces, processing units, delays…
  - Software, implementation



- « Smart » sensors and actuators
  - Embedded intelligence, local decision
- « Intelligents » sensors and actuators
  - Communicating Interface
  - Diagnosic, monitoring, checking, embedded decision
  - Instrument contributing of the global « intelligence » of the system
- Intelligence vs. Complexity => consequences on Dependability ?

Functional safety: Safety Integrated Level (SIL)

- Generic standard IEC-**61508**/IEC-61511

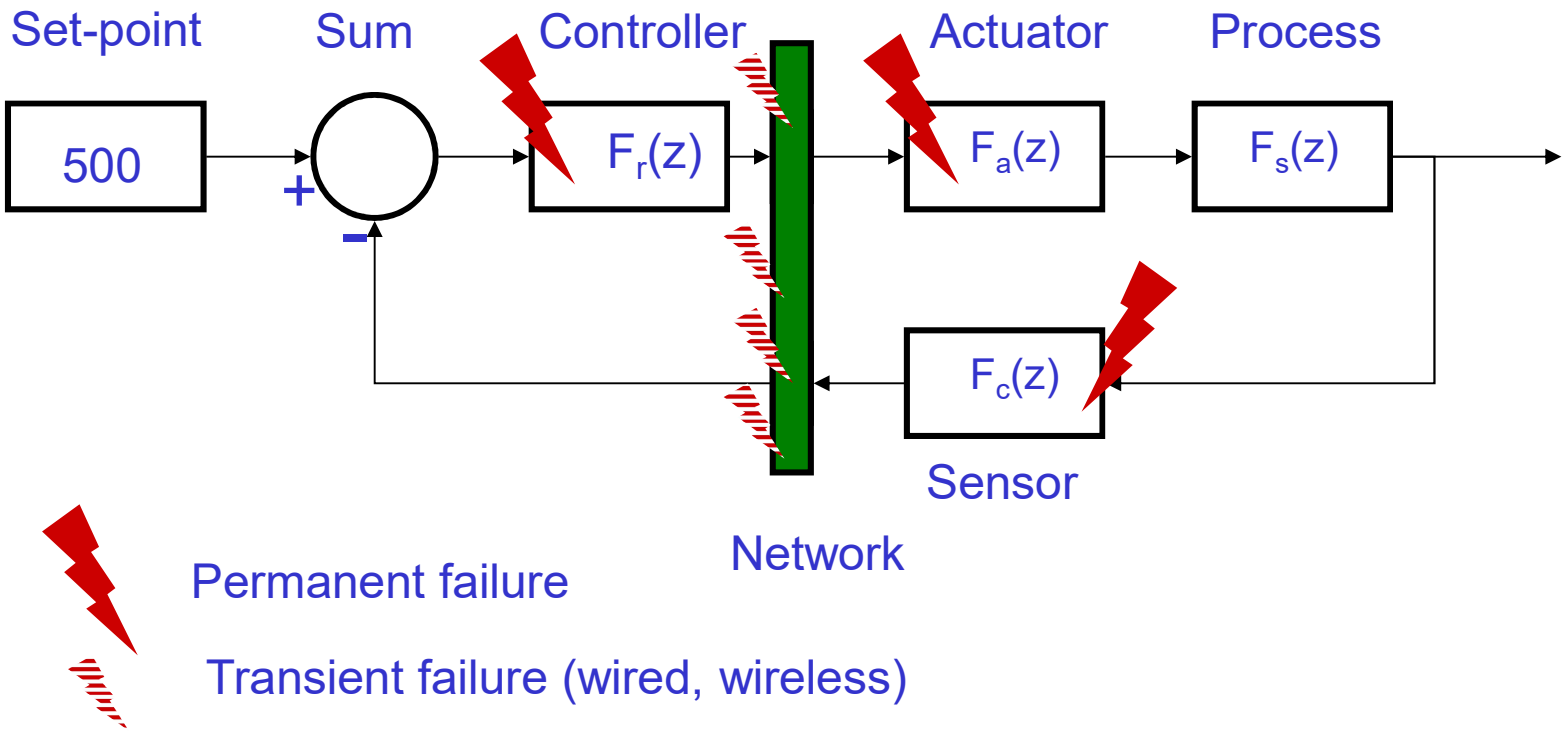
  Functional safety of electrical/electronic/programmable electronic safety-related systems

- SIL (*Safety Integrated Level*)

Problems:
- SIL of a component
- SIL of physical architecture
- SIL of a functional architecture
- SIL of a computer and network-based architecture

Prescriptions of a security system and corresponding SIL levels		
SIL	Demand operation Average **probability of failure on demand (PFD)** Failure rate per year	Continuous operation λ Failure rate per hour
SIL4	$10^{-4} < PFDavg < 10^{-5}$	$10^{-8} < \lambda < 10^{-9}$
SIL3	$10^{-3} < PFDavg < 10^{-4}$	$10^{-7} < \lambda < 10^{-8}$
SIL2	$10^{-2} < PFDavg < 10^{-3}$	$10^{-6} < \lambda < 10^{-7}$
SIL1	$10^{-1} < PFDavg < 10^{-2}$	$10^{-5} < \lambda < 10^{-6}$

Failures integration



Failure Modes

- Continuous/sampled
- Discrete events

Time scales

-Speed (modulation rate, throughput) of the networks
-System time constant
-Time between failures

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Safety = RISKS ANALYSIS => Risk Management

To Identify failures in a more exhaustive manner

- Crashing of hardware disks
- Burning down, or flooding of premises containing backups
- Open ports on a network

To evaluate the severity of each failure (level of risk)

To envisage the failures (use of evolution models)

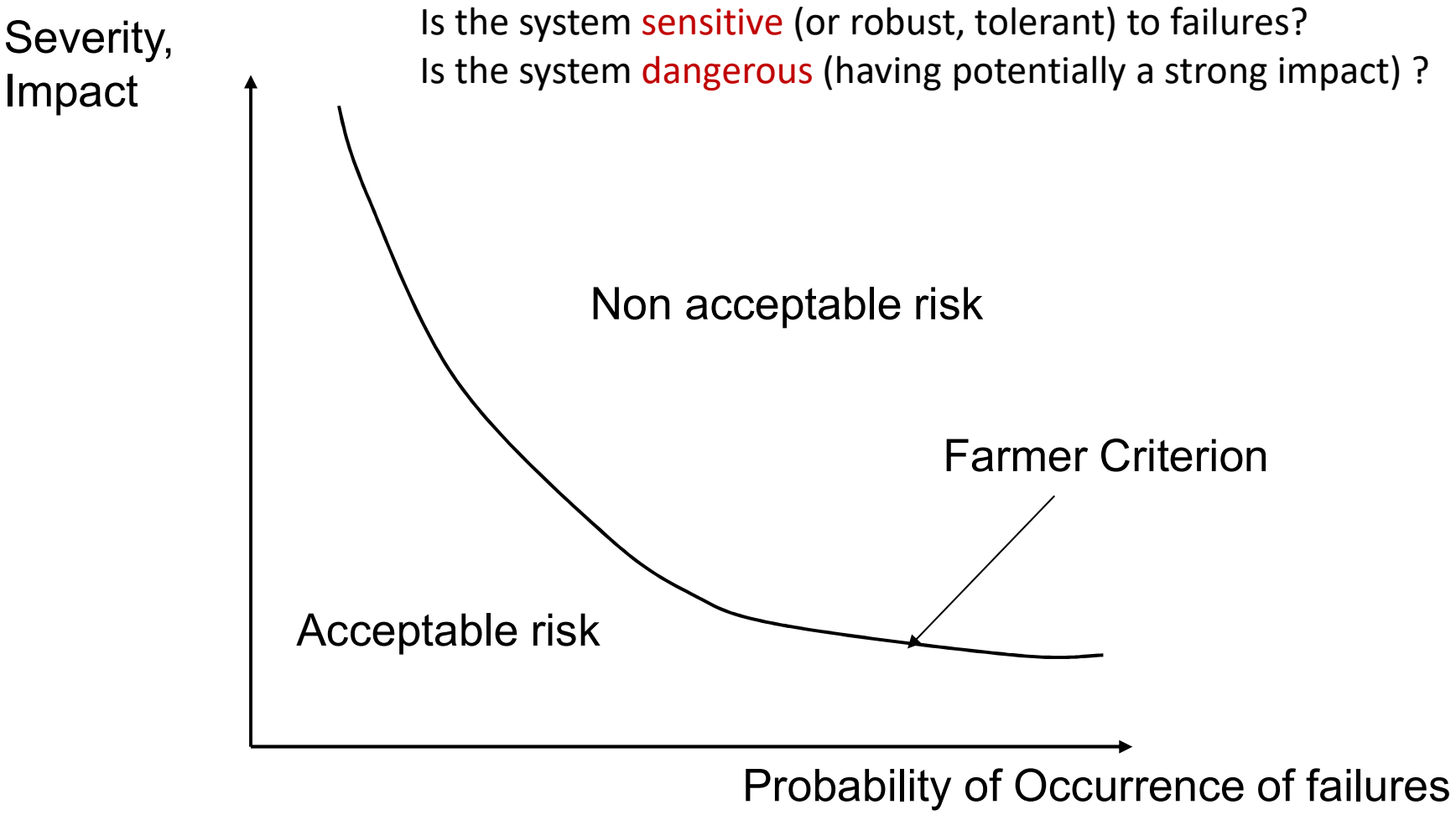
- 'Outdatedness' of the data-processing components
- Probability of attacks by third parties on vulnerable ports

At each **observation** of a failure, we should associate the appropriate **measurement** (statistical) => to improve the forecasting models

To control the failures

- Reduction of their frequency
- Preventive measures against the consequences (reduction of the impact)
- Tolerance

Risk analysis: Severity-probability



Elements of risks (asset, threat, vulnerability)

Asset (*actif*)

- Represented by monetary value
- Anything of worth that can be damaged, compromised, or destroyed by an accidental or deliberate action
- A asset's worth is generally far more than the simple costs of replacement (image, legal issues…)

Elements of risks (asset, threat, vulnerability)

Threat (*menace*)

- Potential event that, if realized, would cause an undesirable impact
- Two factors plays in the severity of a threat: degree of loss and likelihood of occurrence

Exposure factor: degree of loss (percentage of asset loss if a threat is realized) – ex: if we estimate that a fire will cause a 70 % loss of asset values if it occurs, the exposure factor is 70 % or 0.7

Annual rate of occurrence: likelihood that that a given threat would be realized in a single year in the event of a complete absence of control – ex : if we stimate that a fire will occur every three years, the annual rate of occurrence will be 33 %, or 0.33

=> A threat can be calculated as a percentage by multiplying the exposure factor by the annual rate of occurrence. Ex : 0.7*0.33 = 0.231 or 23,1 %

Elements of risks (asset, threat, vulnerability)

Vulnerability (*vulnérabilité*)

- Absence or weakness of cumulative controls protection in a particular asset

Estimated as percentages based on the level of control weakness

Control Deficiency (cd) is calculated by subtracting the effectiveness of the control by 100% - ex : if we estimate that our industrial espionage controls are 70 % effective, so 100 % - 70 % = 30 % (CD)

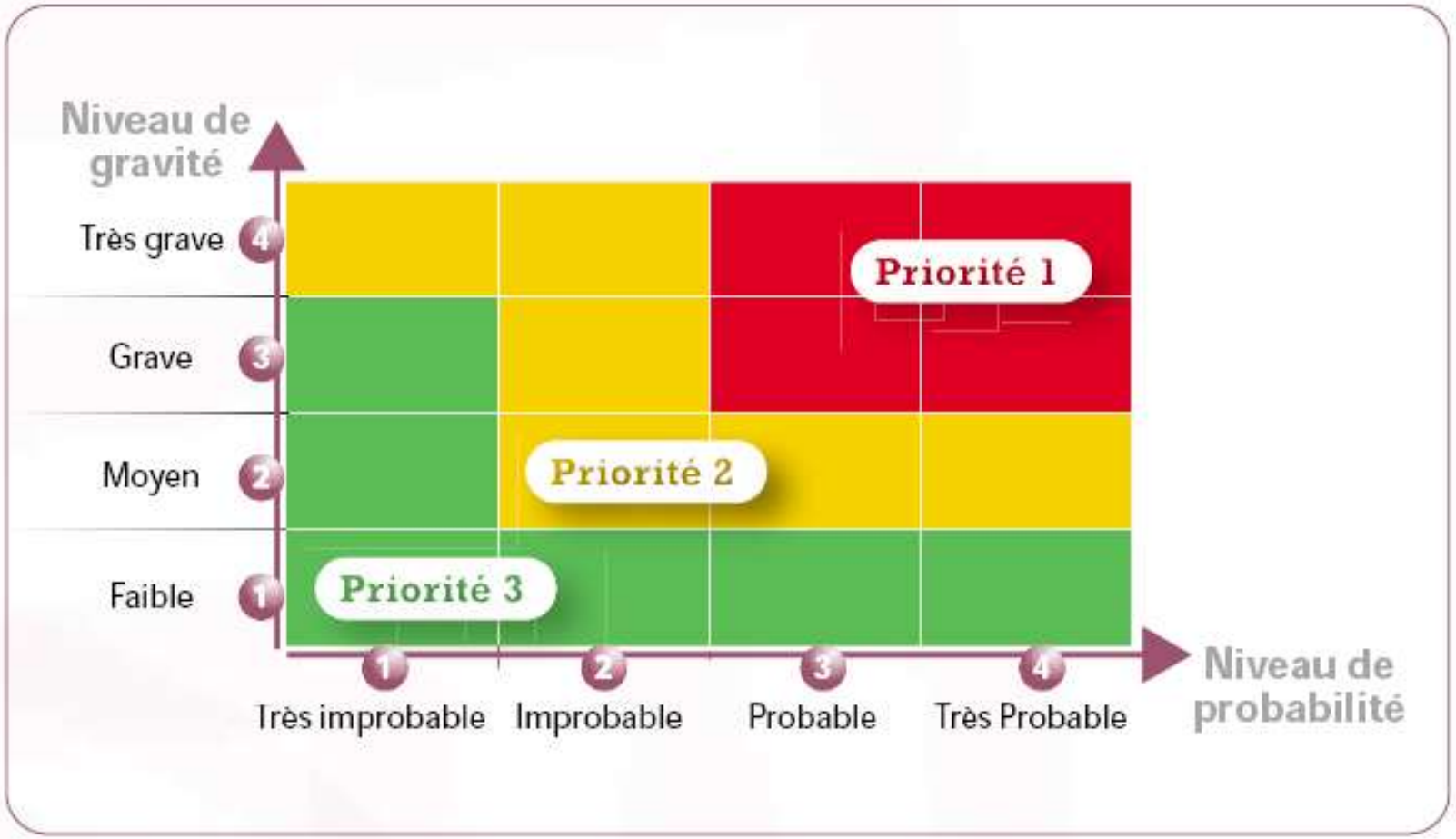
- Most of the time, more than one control is employed to protect an asset.

Ex : the threat is an employee stealing trade secrets and selling them to the competitio

To counter this threat, we may

- implement an information classification policy,
- monitor outgoing e-mail,
- prohibit the use of portable storage devices
- …

Risks evaluation, evaluation of the severity



Example

Danger (cause)	Dange-rous situa-tion	Dange-rous event	Risk of…	Conse-quence	Severi-ty	Proba-bility	Priori-ties	Obser-vations
Explo-sion of a tyre	Car sliding	Screw in the tyre	Acci-dent	Killing people in the car	4 (high)	1 (low)	1 (low)	Having a spare wheel…

Prescriptions, Methods for risk analysis

Methods

1. FMEA (Failure Mode and Effect Analysis)/AMDE
2. HAZOP (Hazard and Operability Study)
3. Preliminary Hazard Analysis
4. MEHARI (Method for Harmonized Analysis of Risk) (FR, CLUSIF)
5. EBIOS (Expression des Besoins et Identification des Objectifs de Sécurité, FR, ANSSI)
6. OCTAVE (Operationally Critical Threat, Asset and Vulnerability Evaluation, US-CERT)
7. CRAMM (CCTA Risk Analysis and Management Method, UK CCTA (Central Communication and Telecommunication Agency))

Prescriptions

1. US standard NERC-CIP-002-3 Critical Cyber Asset Identification
2. US standard NIST.IR 7628 Guidelines for smart gris security
3. ISA/IEC 62443 Security for Industriel Automation and Control Systems
4. EU efforts about smart grid security
5. ANSSI Classification method and key measures

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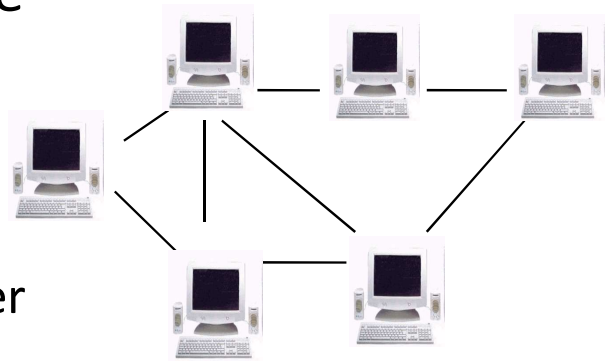
Access mode: Random Access

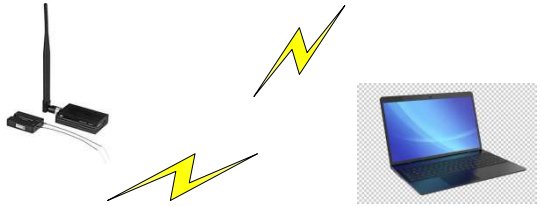
CSMA/CD (Carrier Sense Multiple Access /Collision Detection)

- Carrier Sense
- Multiple Access : Several hosts can access simultaneously: collision risks
- When a collision occurs:
  1. transmission of a jamming sequence
  2. after a delay: new attempt
  3. abandon after too many failures
- Collision Detection and processing (probabilist protocol, no priority)
  - Ex: Ethernet, each host can transmit whenever



Non determinist

Access mode: Random Access



CSMA/CA (*Carrier Sense Multiple Access / Collision Avoidance*)

For wireless networks, CSMA/CD not possible

It is not possible from a host to have a view on all the other hosts (transmission range)

Transmitter host listening to the network

If free during a certain time (*DIFS : Distributed Inter Frame Space*),

the host send a RTS frame (*Request to Send*, information about the size of data to be transmitted and the speed required)

The receiver (or the access point) acknowledges with a CTS (Clear To Send) frame

to allow the transmission (authorization)

The transmitter then send the data to be transmitted

When all the data are received, the receiver send an ACK (*Acknowledgement*) frame

The other hosts wait during a certain time (estimated time from the known data size and transmission speed)

Collision Avoidance (ex : Wi-Fi 802.11, 802.15.4 6LowPAN)

Non determinist

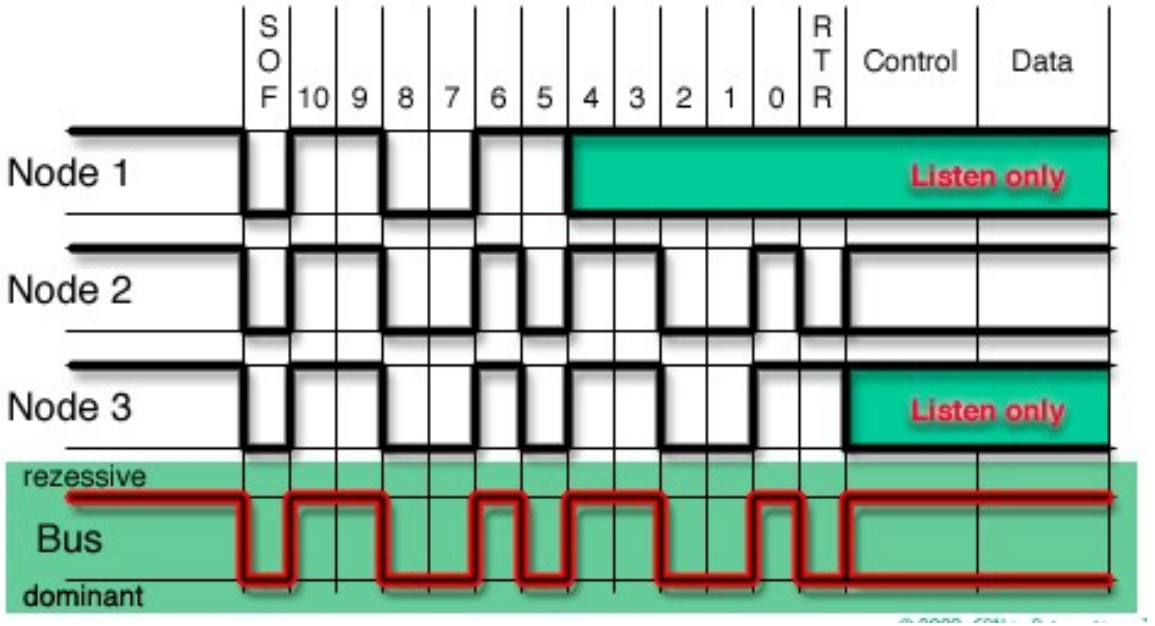
Access mode: CSMA/AMP
Arbitration by Message Priority

Ex. of Fieldbus networks

Scheduling of messages as a function of priorities

(ex : CAN network, Controller Area Network),

Partially determinist (configuration strategy)



Access Mode: Controlled access

Waiting until having the right to transmit (avoid any conflict)

centralised management:
1 host controlling accesses

decentralised management:
many hosts controlling accesses

Centralised access by "polling" :

Each station can transmit in turn according to a predefined schedule.

Need:
1. of an access controller
2. a scrutation table

Ex : WorldFIP network

Determinist (for determinist traffic)

Decentralised access (ex : Token Ring)

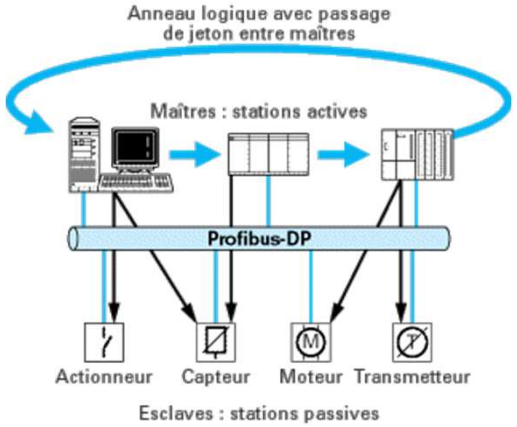
A token running in a logical ring

Right to transmit and access control held by the token owner

time-limited possession of the token

Ex : ProfiBUS network

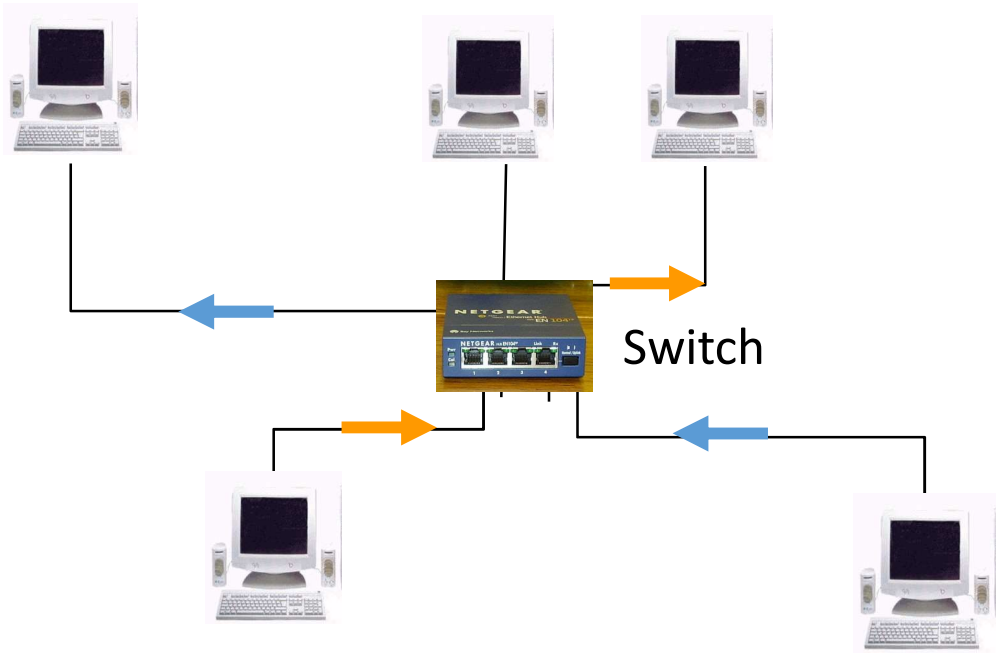
Partially determinist (configuration strategy)



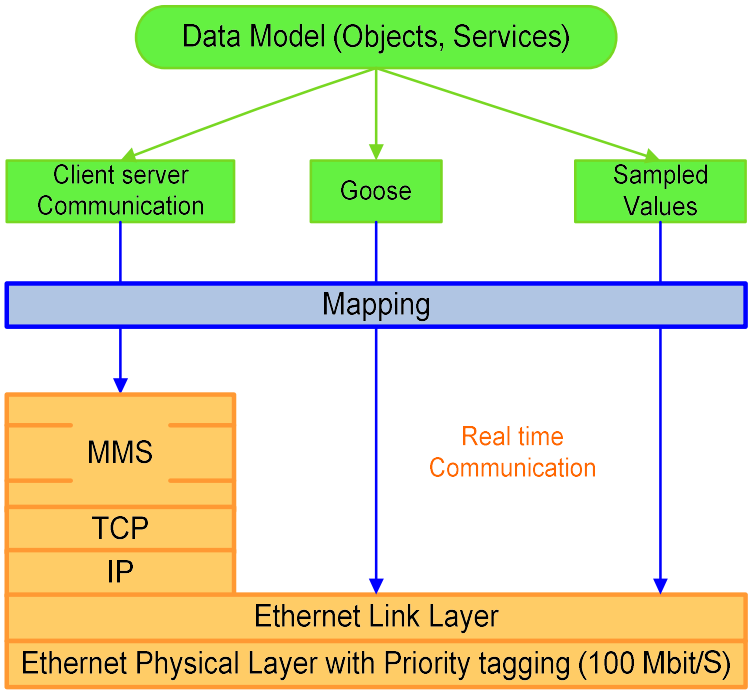
Switched Ethernet

Ethernet = collisions

Switches: delimitation of « free collisions » zones



IEC 61850
Communications aspects based on Switched Ethernet => for Smart Grids



- Satisfying real time performance by the standard in developing extension cards that can transmit critical real-time signals at serial network level
- Development of a new appliction layer allowing to track the dialogue according to the IEC 61850 standard
- New equipment design playing the role of Ethernet switch/ IEC 61850 converter and data concentrator

Wireless networks

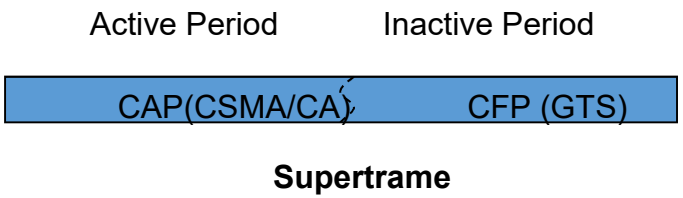
See also 6LowPAN (802.15.4)…

ZigBee	Wi-Fi
IEEE 802.15.4	IEEE 802.11b
2.4-2.4835 GHz (world), 902-928 MHz (USA) and 868-870 MHz (Europe)	2,4 GHz,
from 10 to 75m	46 m indoor, 92 m outdoor
250 kb/s (2.4 GHz), 40 kb/s (915 MHz), and 20 kb/s (868 MHz)	1, 2, 5.5, 11, 54 Mb/s
2^{16}=65536 Number of nodes	32
100-1000+ Batteries life duration	0,5-5
30 ms Time to find a new node in the network	Up to 3s
Reliability, low Power, low Cost	Speed, Flexibility
Home, building, industrial monitoring and control (for small, cheap microprocessors, low rate control networks)	Web, Email, Video. (for PCs, laptops, PDAs)

Real Time (critical time) Wireless network (if the physical layer works!)

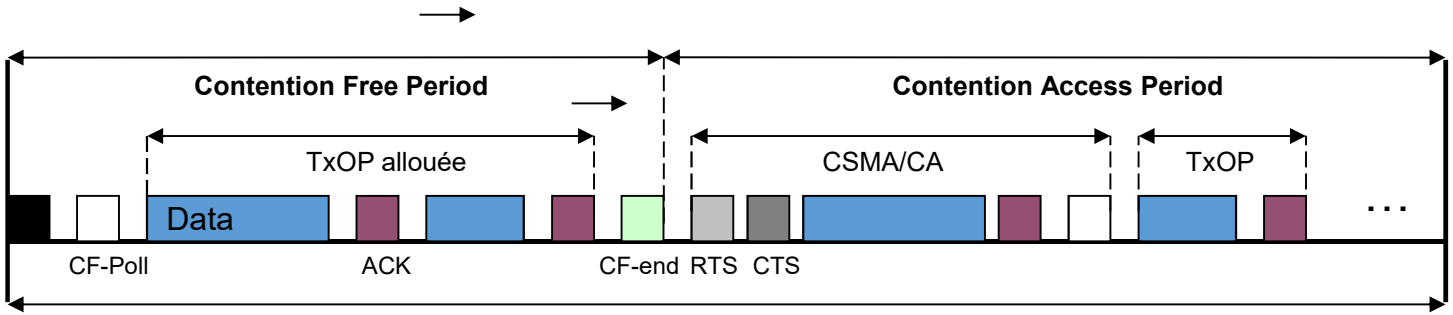
Zig-Bee (on 802.15.4)

– Superframes :



CAP (Contention Access Period) : all the nodes can transmit in a random way respecting the slot duration CSMA/CA
CFP (Contention Free Period) : Allow to garanty an access to a node during a certain amount of time (measured as a number of GTS slots) : **GTS (Guaranteed Time slots)** : Dedicated time slots (the coordinator can allocate one or several slots to a node, in particular for time garanties)

Wi-Fi 802.11e



Superframe

Networks « Defaults »

- Delays: some tolerance (jig)
- Losses: (re-transmission, regeneration, fault tolerances)
  - [Kim]. CSD (control system deadline),
  - [Babak] [Zhang] stability of distributed systems with packet losses
- Alterations
  - Alteration detection thanks to error code detector
  - Error corrections (if corrector code)
  - Fault-tolerant functioning (missing data reconstruction)
- Desynchronisation (clock protocol, external clock)
- Electromagnetic disturbances
- Overload due to the shared network (protocol)

Delays

- Determinist Network (controlled access)
  - Task 1 : every T=0,01 s.
  - Task 2 : every T=0,02 s.
  - Task 3 : every T=0,01 s.
- 1 3 2 1 3 1 3 2 1 3 1 3 2 1 3
  - Task 2 periodic
  - Tasks 1 and 3 are periodic with some « jig »
- Causes of the delays
  - Transfer time
  - Synchronisation policy (time-driven, event-driven,…)
  - Access mode (random, controlled)
- Types of delays
  - Average delay (bounded, not bounded)
  - worst-case delay
- Non determinist network (random access)
  - Priority
  - Re-transmission of tasks following error detection

Wireless networks

- Same problems as wired networks +
- Electromagnetic disturbances (more sensitive)
- Network not always available (normal functioning)
  - Non visibility, delays due to reflections (non direct reception)
  - Not always « on » because of energy consumption (embedded system)
- Disturbances linked to the mobility
  - Transmitter-receiver distance
  - Obstacles between transmitter and receiver
  - Need to have a service traffic (connection, routing…)
- Evolutive topology (mobile stations, communication between a mobile and several ground stations), (hand-over, roaming)

CONSEQUENCES

- Throughput decreasing
- Communication loss (« non negligible » loss of frames)
- Greater sensitivity to hacking

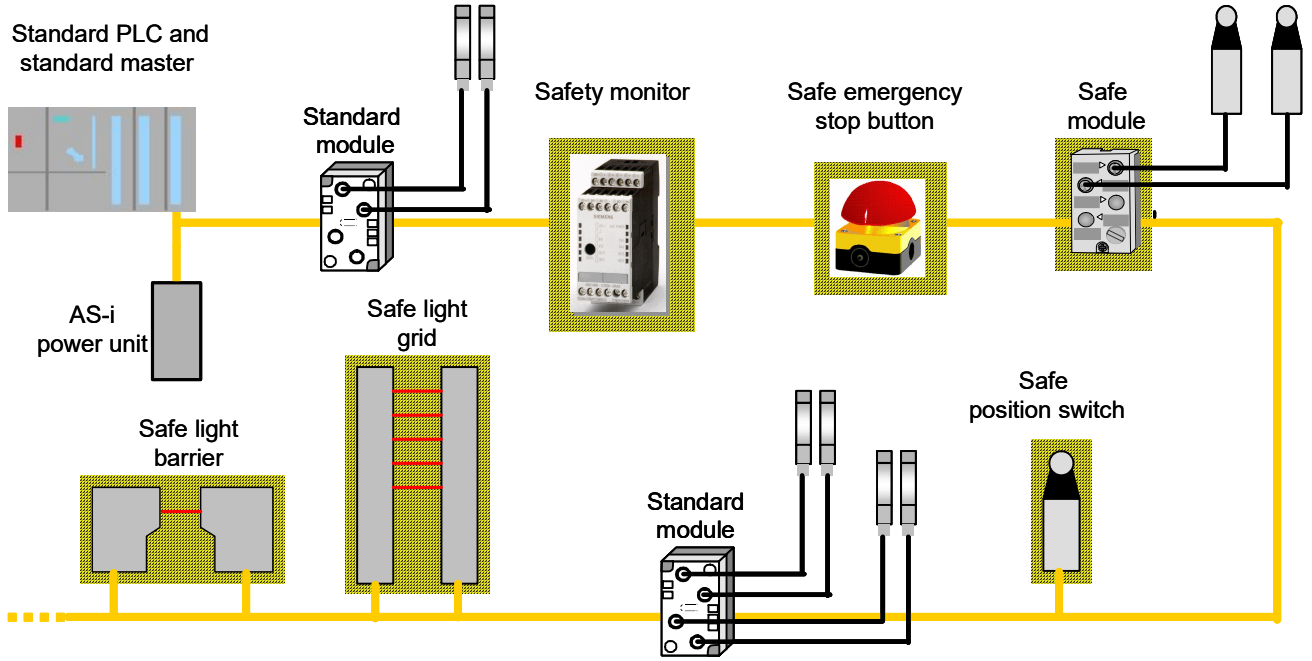
Safety networks

- Safety-Bus p, one of the first network designed for safety
- 2 safety protocols based on the lower CAN layers : **CANopen-Safety** and **TTP** (Time-Triggered Protocol),
- FlexRay, designed for dependable automotive applications,
- ProfiBus who became **ProfiSafe**, thanks to the safety extension,
- ASI Safety at Work, safety extension of the low level ASI network.

- Periodic frames (watch dog)
- Redundancies (wires, redundant transmission, heterogeneous redundancy)
- Safety monitor (ex with ASI) : Passive element detecting suites of 4 consecutive zeros representative of a problem
    A user has triggered a security system and pressed an emergency stop defaults were detected on the communication bus or a component
- Secure communication between safe components (CRC, acknowledgment, verification of transmission time => specific frames for security)

Safety networks: AS-i Safety at Work

Extension to the classical AS-i protocol
A safety monitor added – continuous monitoring
Specific safety code table for each slave
Power supply stop by the monitor (safety relay) (stop, com. interruption, mess. corrupt, response delay)



Advantages

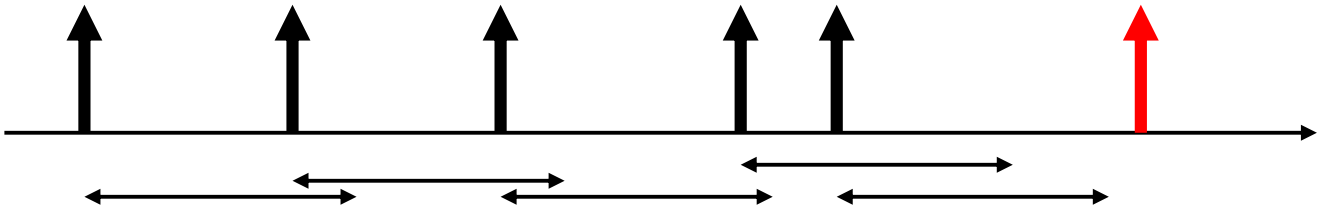
- cabling reduction
- Safety and non-safety on one bus
- Groups of safety signals
- EN 954 – 1 category 4 compliant
- Certified: TUV and BIA
- No AS-i wiring changes needed

Safety networks: CANOpen Safe

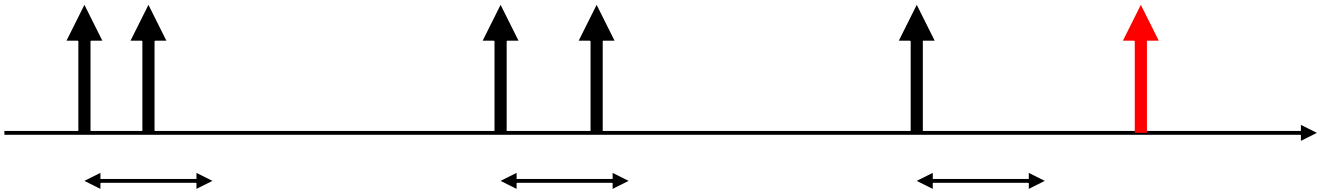
Difficulties due to the non-determinist access,
bus arbitration → maximum delay can be estimated

Use of 2 watch dogs

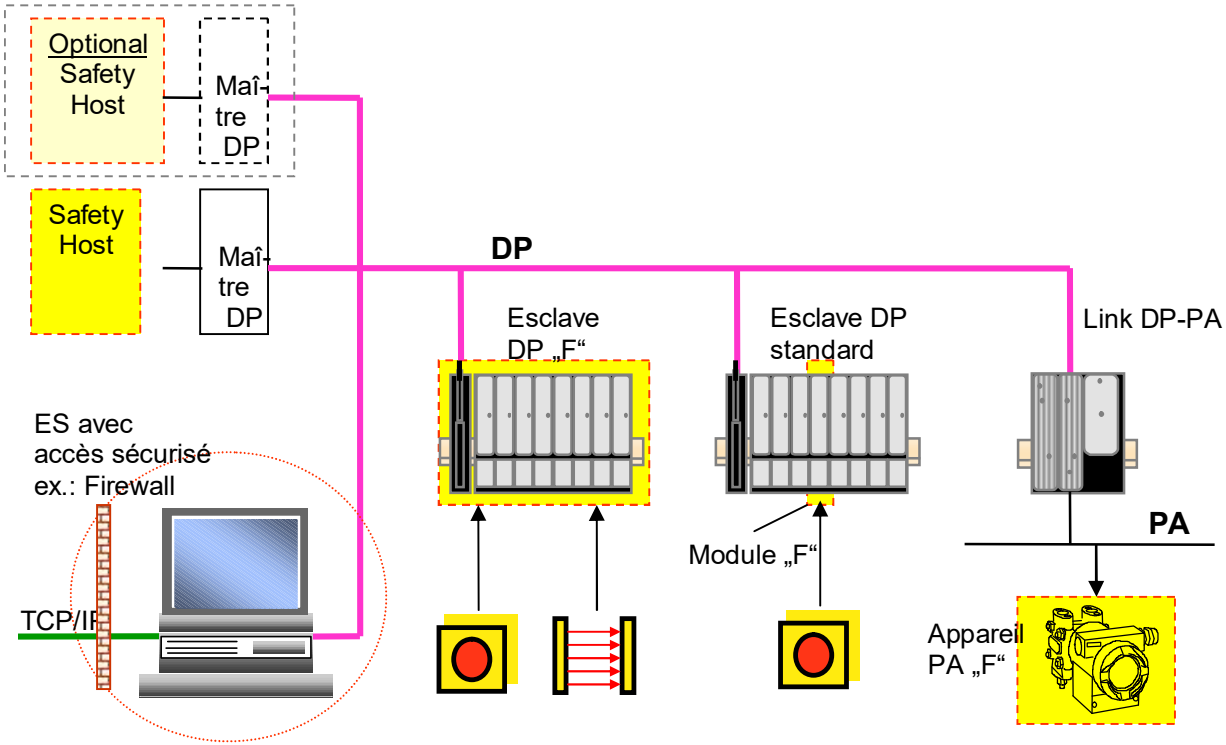
Time window between each trans.



Doubled Emission (redundancy)



Safety networks: Profisafe



Conclusion on Networks

- Protocol quality
  - %age of time to send data
  - Need to retransmit ?
  - Important service traffic…
  - Determinism?
- Determinism
  - Difficult with wireless networks
  - Need of a « closed » network
- « Disturbances » (electro-magnetic dist., loss of connection because of distance, impact of mobility)
  - Negligible for wired networks
  - Important for wireless => need of control applications, robust to the network…
    - Setting of redundancies (multi-bursts, multi-canal, multi-stations…)
- Safety networks

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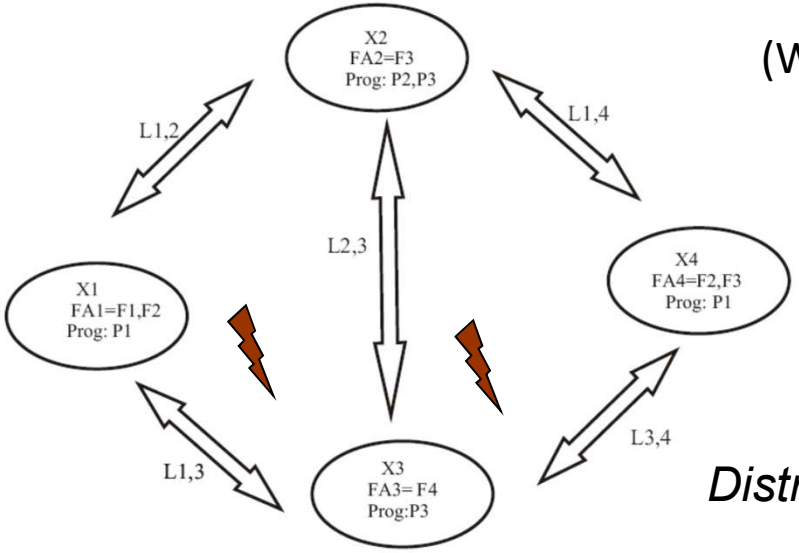
Network dependability

- Evaluation of the network « alone »
  - Quality of service of the communication
  - Sensitivity to disturbance
- Network seen as a simple communication link
- Network seen as several "independent" communication "strands"

Integration of the communication function in the reliability study (distributed system, Independent links)



(Wang et al, 2002) and (Lin et al, en 2001)

$FA_1 = \{F_1, F_2\}$ $PRG_1 = \{P_1\}$ $FN_1 = \{F_1, F_2, F_3\}$

$FA_2 = \{F_3\}$ $PRG_2 = \{P_2, P_3\}$ $FN_2 = \{F_1, F_2, F_4\}$

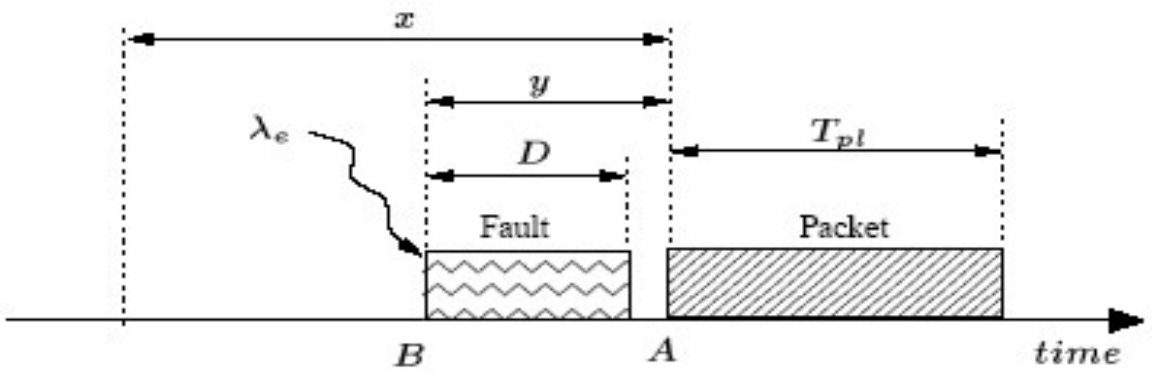
$FA_3 = \{F_4\}$ $PRG_3 = \{P_3\}$ $FN_3 = \{F_1, F_2, F_3, F_4\}$

$FA_4 = \{F_2, F_3\}$ $PRG_4 = \{P_1\}$

Distributed System with 4 nodes and 5 links

- Each link has two states: running state and failure state
- Link failure rates are independent and exponentially distributed
- Link repair rates are independent and exponentially distributed
- During one time unit, only one link can fall down or be repaired

Integration of the communication function in the reliability study (distributed system, Network approach)



- [Tindell] Response time and transient faults
- [Navet et al], [Portugal et al] probability that a message misses its tolerated delay
  One message misses its delay → failure of the communication function
- [Portugal and Carvalho] : Markov chains-based approaches for the evaluation of the unavailability of the communication function (permanent faults)

- **These approaches take into account the communication function but do not take into account the application which lay on this network**

Conclusion Networks and Dependability

- Communication function-oriented approach
- Gives the possibility to measure the Network Quality of Service
- Allow to certify communication (ex : Safety networks)
- Don’t take into account interactions with the system
  - System state
  - Failure succession (ex : component « chatting »)
  - Network load rate as a function of sollicitations
  - Priority level (criticality) of the information to be transmitted as a function of the system state and/or the environment

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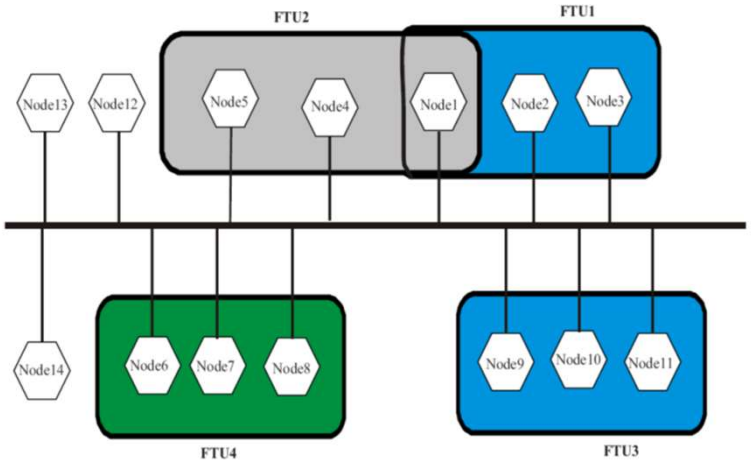
Comparison of Dependability parameters for various architectures of a distributed system



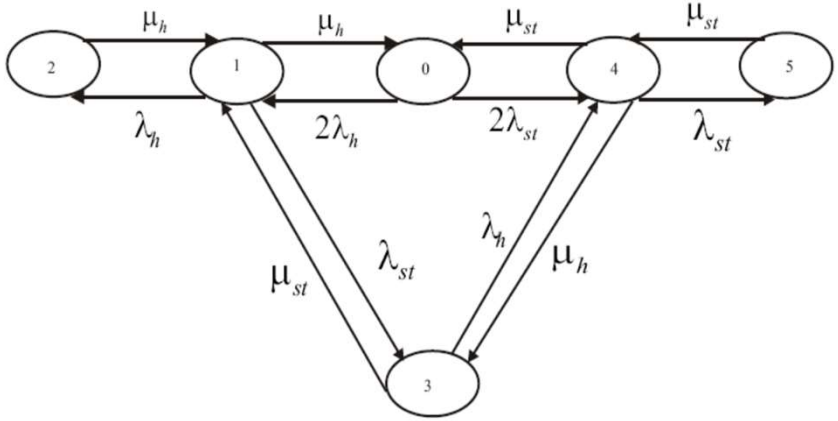
[Pimentel et Salazar]

- Various components (nodes)
- Nodes are grouped within Fault Tolerance Units (FTU)
- One FTU is running if at least one of its node is running
- The system is running if every FTU are running (4 in this example)
- The network is perfect (always running)
- Evaluated parameter: *MTTFF - Mean Time To First Failure*
- Stochastic Petri Nets model + Monte-Carlo simulations

Markov chain-based Approach for the evaluation of availability

[Lai & al, 2002]

- Assumptions :
- Same hardware failure rates (exponential distribution with mean value) for every components
- Idem for software failure rates
- Two possible states (harware and software)
  - (1) operational
  - (2) failed
- Permanent failure
- Repair time including failure detection and repairation
  - Exponential distribution with mean value for hardware and software components
- Independent failures (no common cause failures)
- One site is operational if both associated hardware and software are also in good condition



State 0: initial state, all components are in good condition
State 1: hardware failure, 1 site working
State 2: 2 hardware failures, system failure
State 3: 1 hardware and 1 software failures, system failure
State 4: 1 software failure, 1 site working
State 5: 2 software failures, system failure

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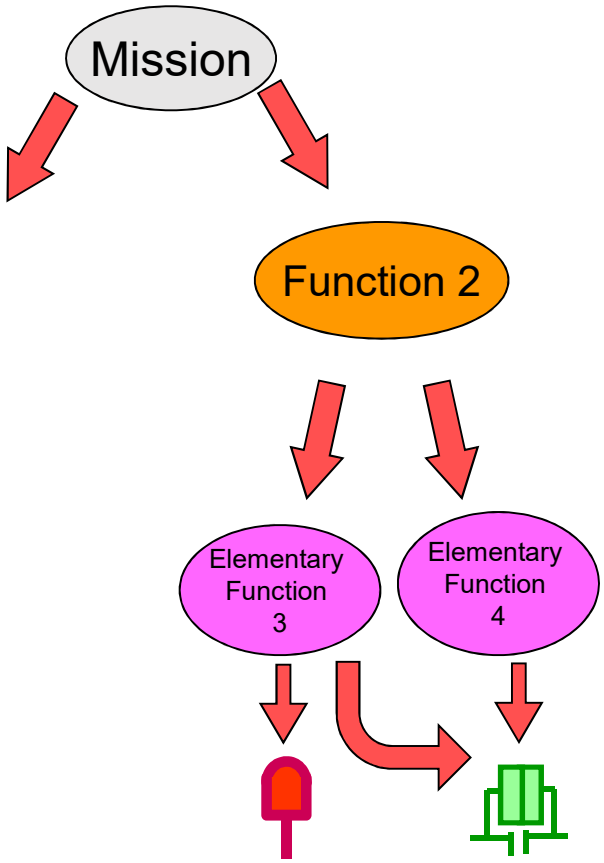
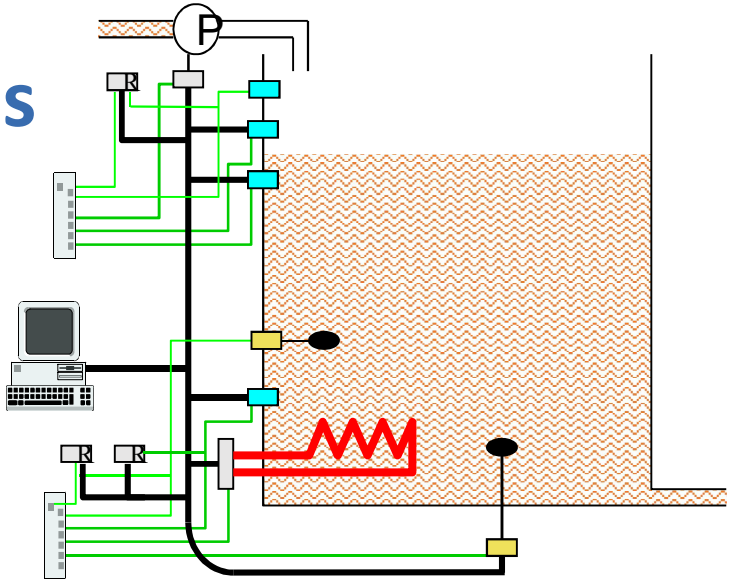
Evaluation of availability and reliability of a networked architecture (design phase)



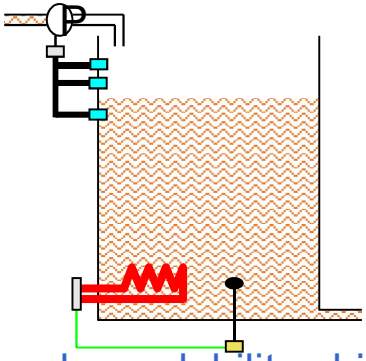
- States => availability
- Failures propagation => reliability
- Use of binary decision diagrams
- ! Common Cause Failures !

[Conrard]

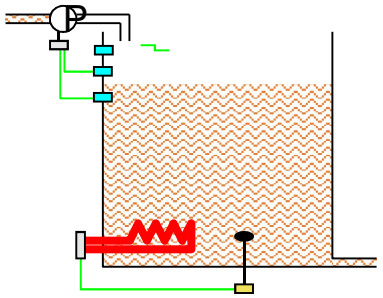
Results



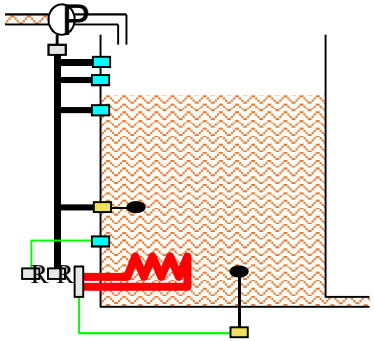
- Preliminary hardware architecture



- Increase dependability objectives
  - Safer solution (networks + intelligents components)



- according to dependability objectives
  - More economic solution



- Increase reliability objectives
  - Even more safer solution

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Dynamic evaluation of dependability

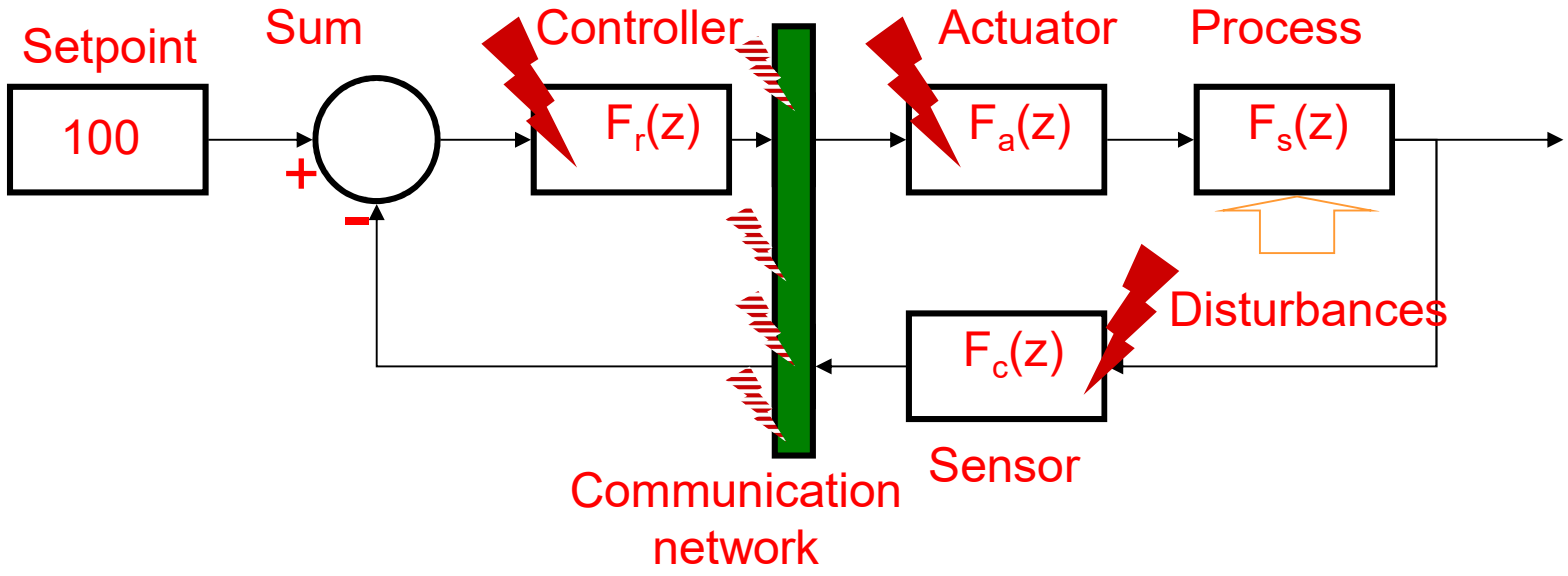
Step - Modelling

Functional model of the components

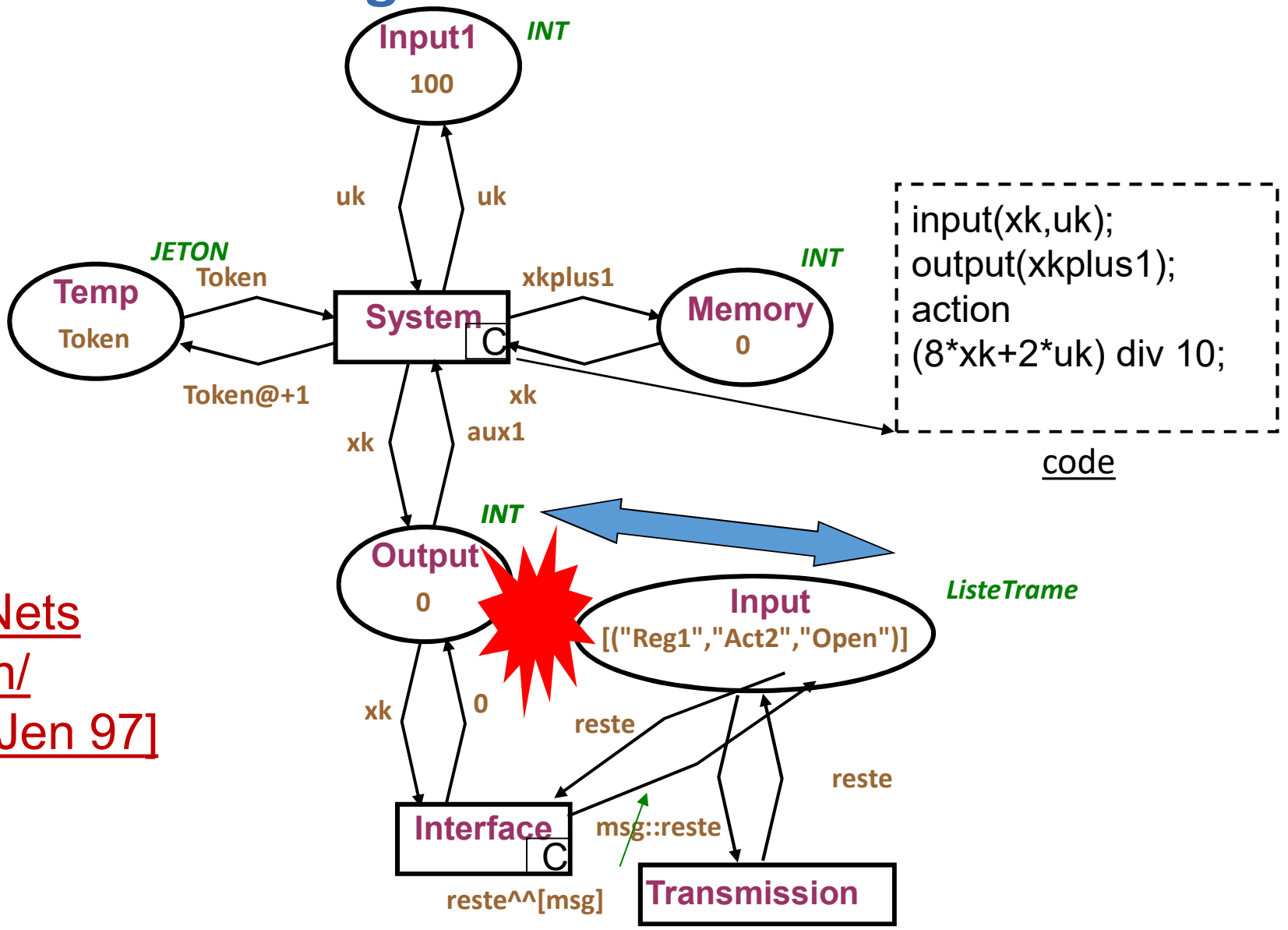
⇒ dysfunctional model of the components

⇒ Unified model of the components

⇒ Interconnection of the components

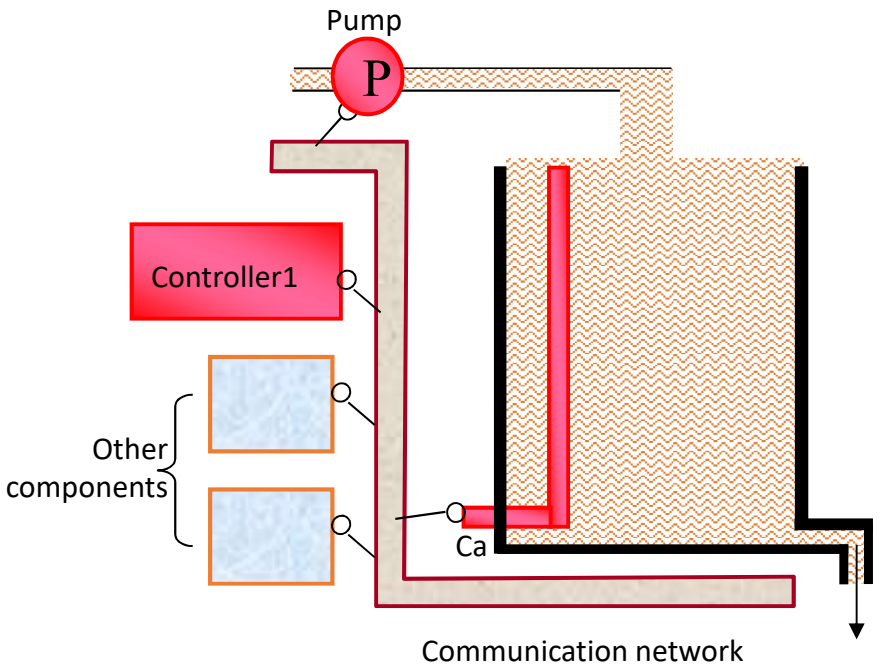


Hierarchical Design

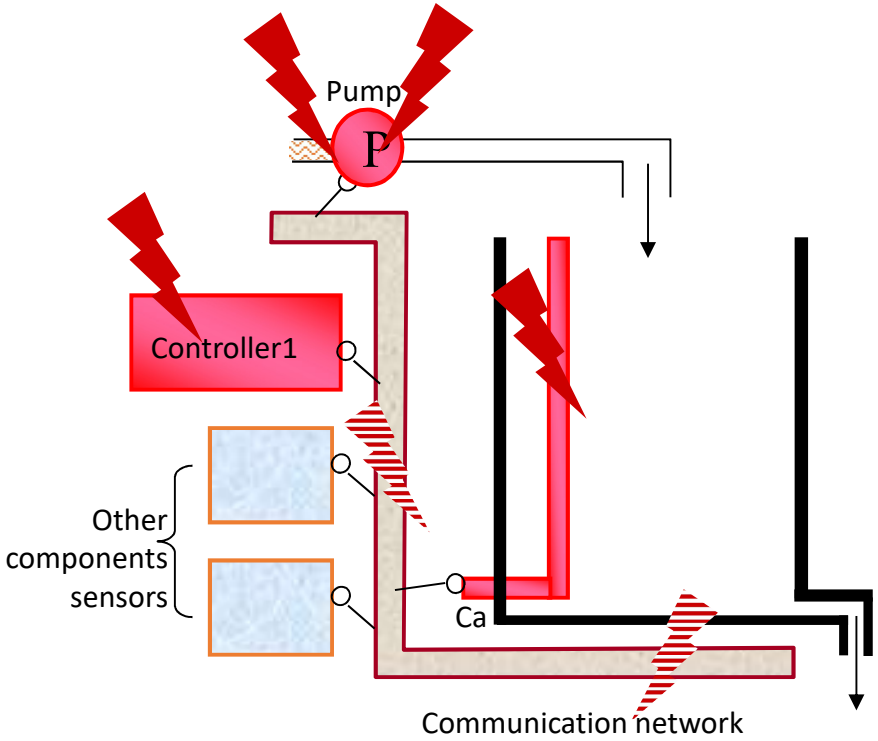


Petri Nets Design/ CPN [Jen 97]

Presentation of a system



Study of failure modes



6 events:

1. Controller failure
2. Sensor failure

Actuator failure

3. Wear-out
4. Blocking

Network errors

5. Loss of a frame
6. Alteration of a frame

[Barger]

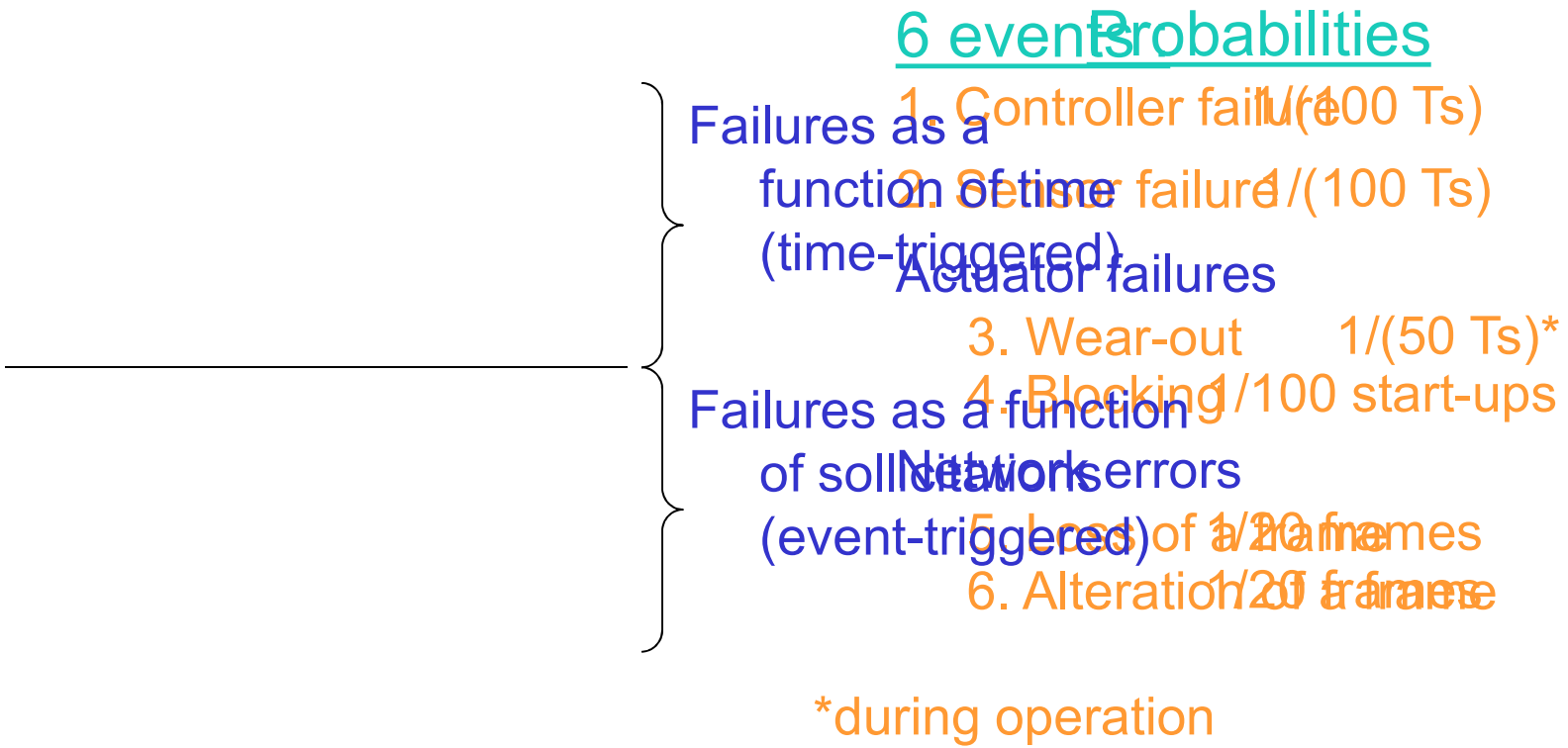
Mission
1. Fill the tank
2. Keep the level

➔ Failure Mode: Do not fill

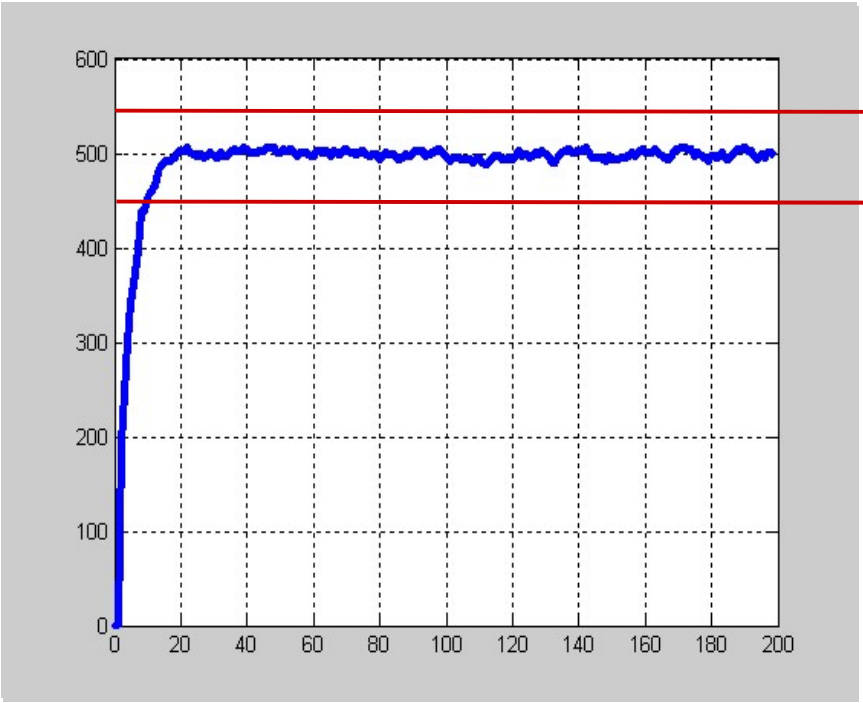
➔ Do not keep

Scenarios

Results of the study of the failure modes



Monte Carlo simulations



11% ***Does not keep the level***

83% ***succeed***

6% ***Does not fill***

Results

Total simulations	Results		
	Does not fill	***Succeed***	***Does not keep the level***
6734	389	5620	725
100%	6%	83%	11%

Conclusions

Networks events and influence are not always important➔ The overflow is generally due to other events

Problem: 50% scenarios leading to an error contains only problems linked with the communication network

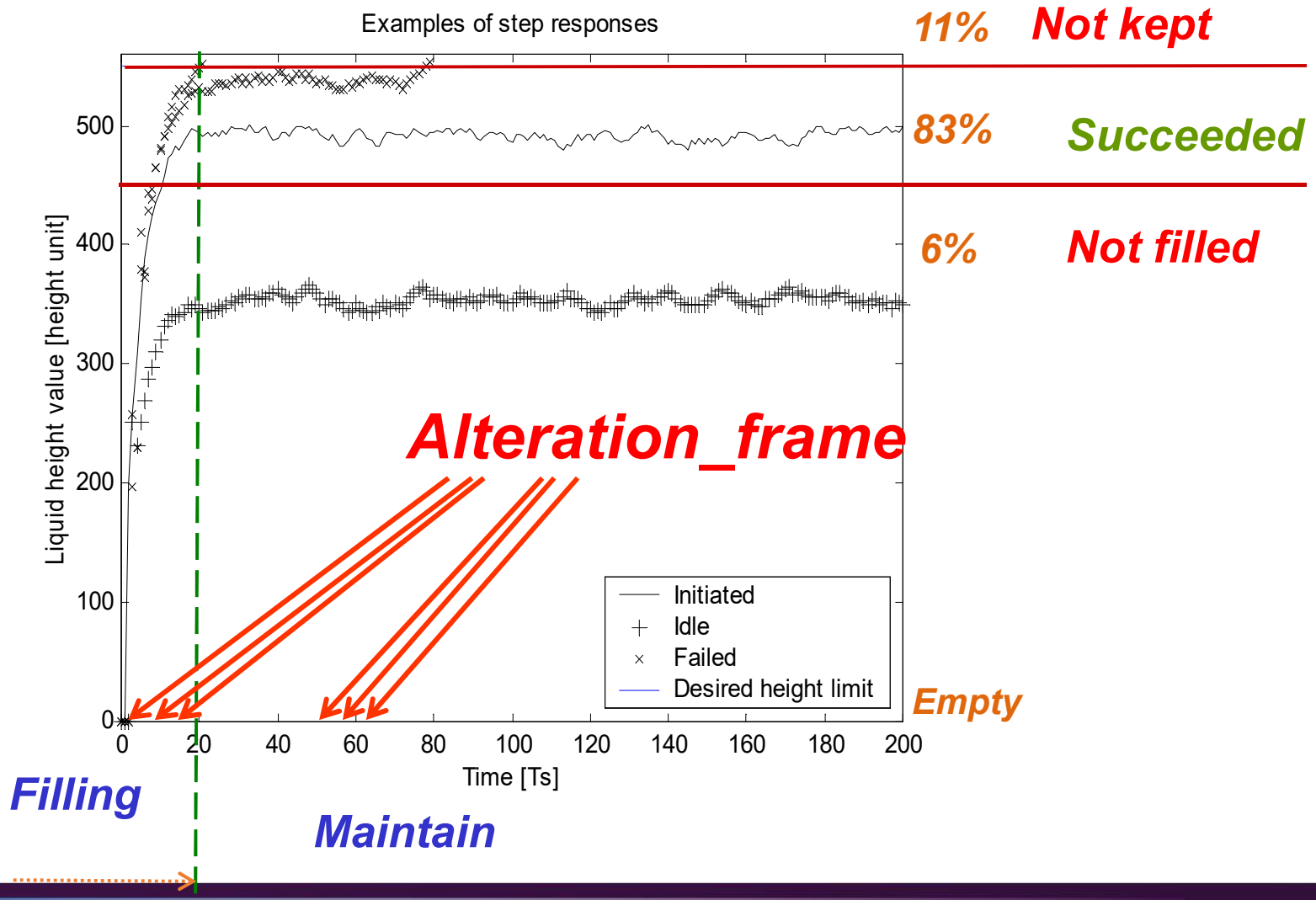
➔Need of another analysis approach:
dynamic analysis

The consequence of a network error depends on the system state

*State in the control meaning (internal variable, level)

Taking account of the history (functional and malfunctional) of the system

Importance of a scenario: Function of the state of the system



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Dependability of NCSs, Tools

- Systems users have ever-increasing nonfunctional requirements on the quality of the systems

  Performance, reliability, availability, etc.

  probability to have a critical failure in one hour< 10^{-8} (IEC 61508/SIL4)

  SIL = Safety Integrated Level

- Difficulties with NCS:

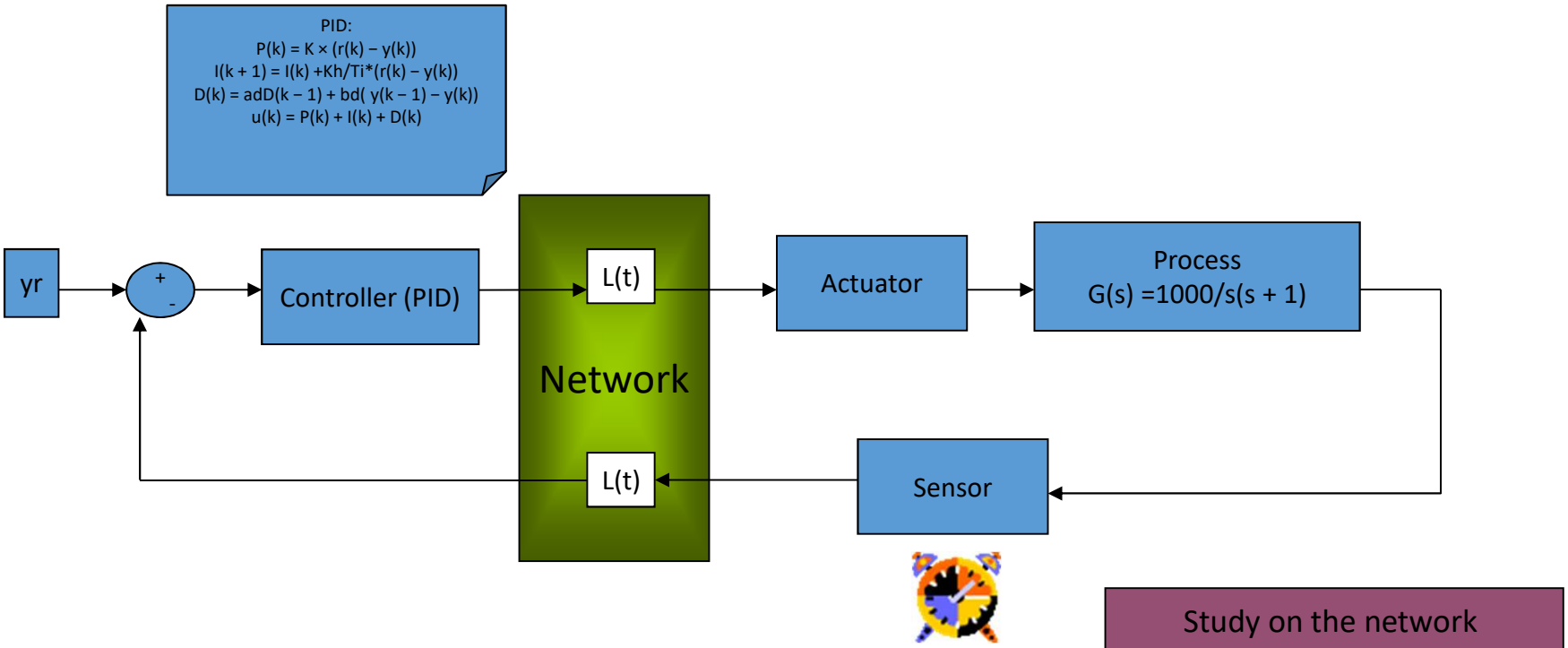
  the system is sequential: depending on the occurrence's order of a given sets of events, the undesirable event may, or may not appear

  it is non coherent: a failure can (at least for a certain time) mask another one, therefore delaying the occurrence of the undesirable event

  components are not "Boolean": they have several failure modes.

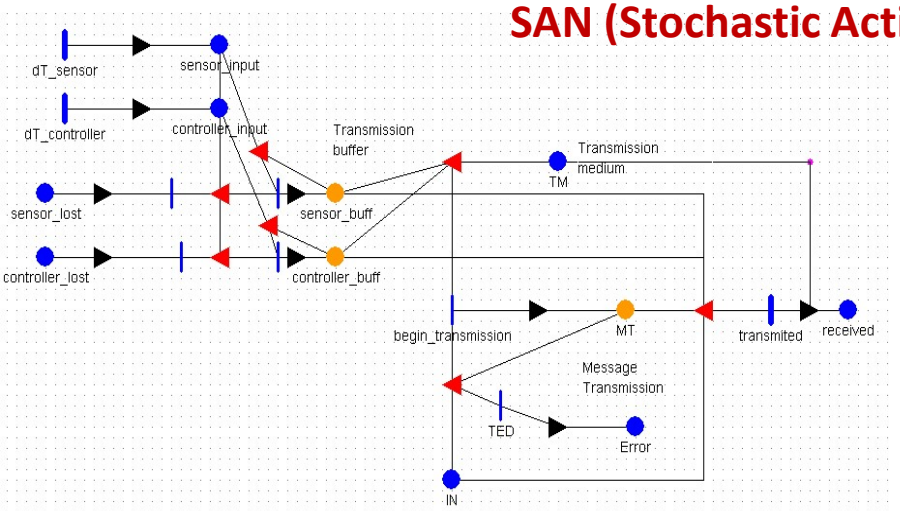
- How to assess dependability parameters for an NCS? (impact of the lost messages on the system reliability)

Proposed approach

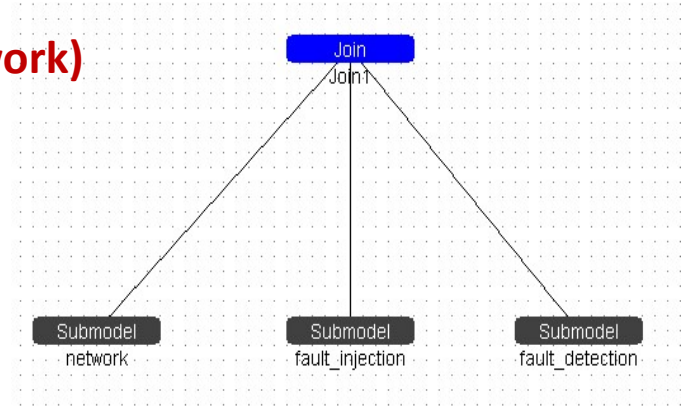


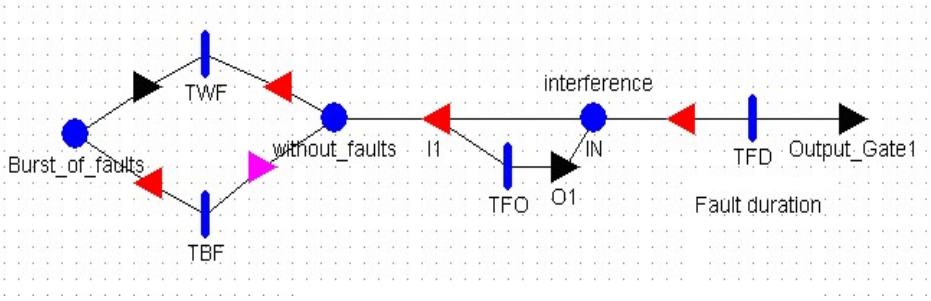
Study on The Network (CAN, Control Area Network)

SAN (Stochastic Activity Network)

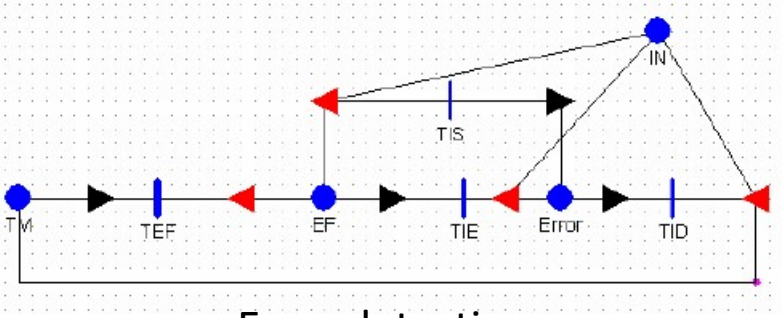


Network





Fault injection (Navet 2000 Portugal)



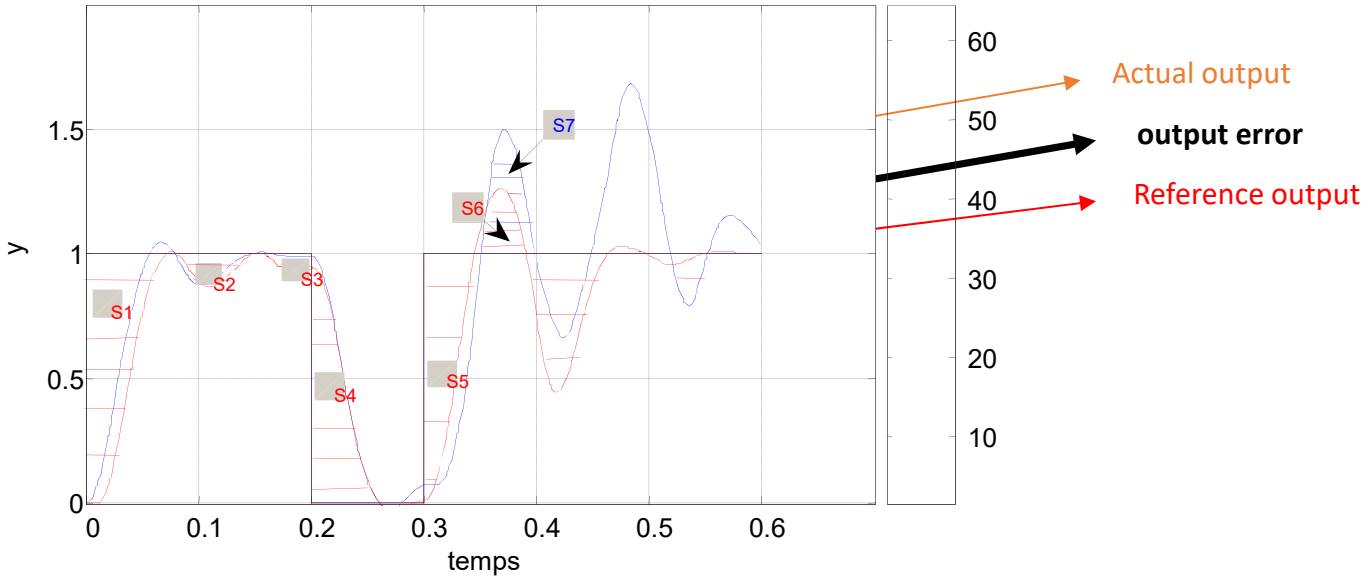
Error detection

Example

Impact of lost messages on the system reliability

- Red, 10 % packet losses
- Blue, 20 % packet losses

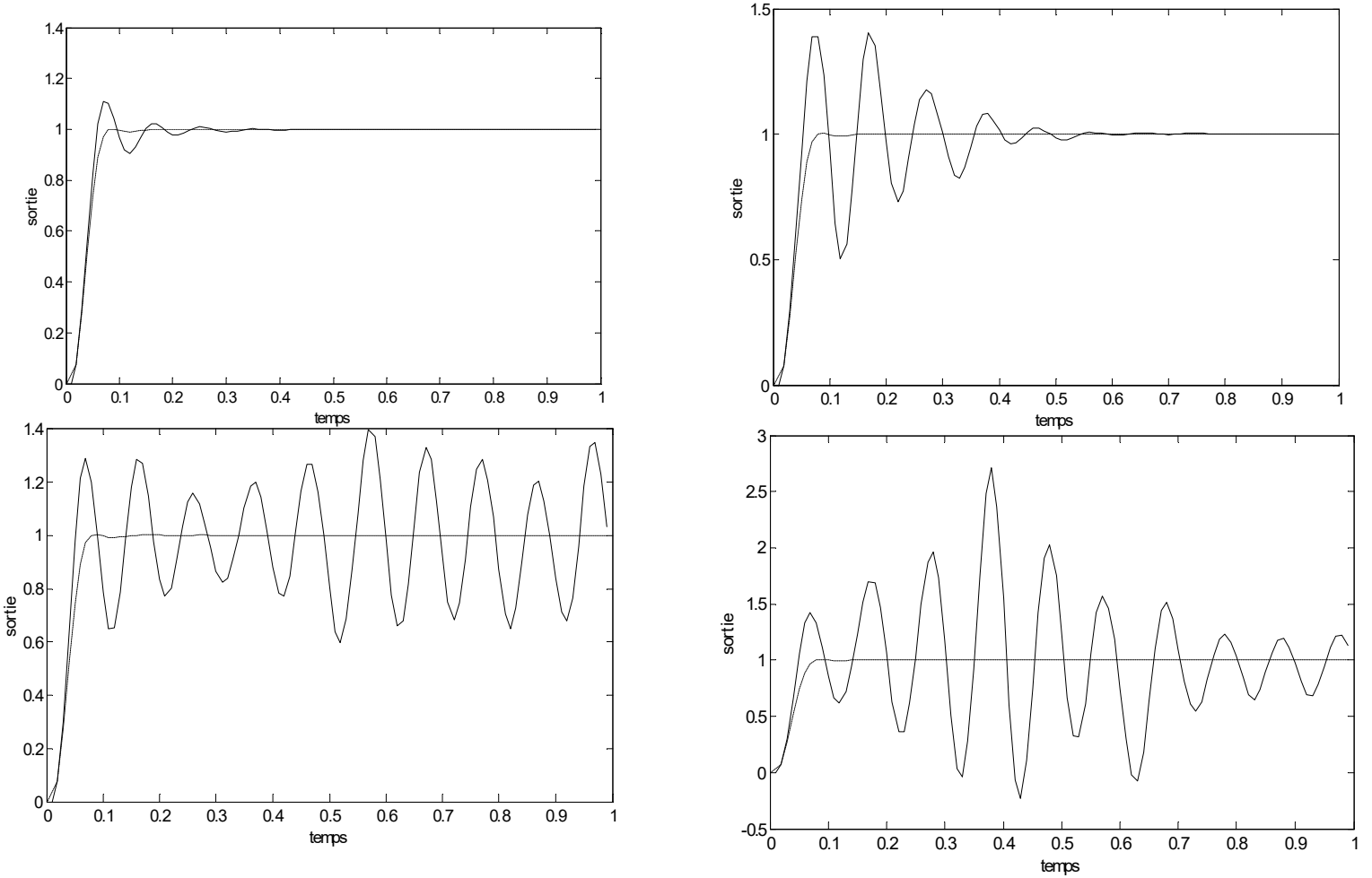
How we detect a failure situation?



Results for a classical NCS

Composed Model

Process=1000/s(s+1) Ts=0.01s
Delays « uniformly » distributed between 0%Ts and 60%Ts



Failure Modes

- Failure per overshoot
- Failure per response time
- Failure per stability

Knowledge about transient faults probabilities (variable delays, message losses)

Probability for the system failure

Conclusions

-Type of network

- Model of the system
- Behaviour of the system
- Continuous time
- Events
- Combination (hybrid) of time-based and event-based properties
- Analysis of the parameters sensitivity

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Safety and security: definitions

- Security: definition (from EN 292 standards)

  Aptitude of a system to achieve its function… under the normal conditions specified in the instruction manual…

- Safety

  Aptitude of an entity to avoid revealing critical or catastrophic events => likely to affect people, equipment, the environment

- **Confidentiality & Integrity**

  Aptitude of one entity to safeguard the confidentiality and the integrity of information

Definitions of terms related to the reliability and the security for applications such like data- processing networks (1/2)

Direct Properties of Security

- Confidentiality (*confidentialité*): preventing the visualization of information by unauthorized persons

- Integrity *(intégrité)*: preventing the non-detection of modifications of information by unauthorized persons

- Authentication *(authentification)*: allowing the identity check of users

Property linked to security

- Availability *(disponibilité)*: *preventing* unauthorized persons access in order to guaranty the use by authorized users

Definitions of terms related to the reliability and the security for applications such like data- processing networks (2/2)

- Authorization *(autorisation)*: preventing access to the system by unauthorized persons

- Auditability *(auditabilité)*: possibility of rebuilding the complete history of the system from recordings of histories

- Non "repudiability" *(non répudiabilité)*: possibility of providing irrefutable proof of the perpetrator of an action on the system

- Protection from third parties: preventing serious damage linked to an attack (pirating) by third parties.

Security principles

- Physical security
  - Energy sources (electricity (power supplies)…)
  - Environmental protection (fire, temperature, moisture/fungi/fungus (humidity)…)
  - Protection of access, traceability of accesses
- Exploitation security
  - Back up plan, recovery plan
  - Emergency help plan
  - Management of the computer park, configurations and updates
  - Management of the incidents and follow-ups until resolution
  - Analysis of accountancy and logging files
  - Management of the maintenance contracts
- Logical security
  - Mechanisms of security by software: Identification, Authentication, Authorization
  - Cryptography mechanisms
  - Effective password management
  - Antivirus
  - Classification of data: Degree of sensitivity (normal, confidential…)
- Applicative security
  - Development Methodology (respect of the development standards suited to the technology employed)
  - Programmed checks, tests
  - security of the software packages (choice of the suppliers, interfaces security)
  - Contracts with subcontractors (responsibility clauses)
  - Migration plan of critical applications
  - Validation and audit of programs

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8. Discussions & Conclusions

Types of targets, types of attacks

Convenient target *(cible opportune)*

-By “chance”: detected by the pirates in the search of least protected machines or servers

-What to do?: update the systems

-To test the system (try to find faults)

Chosen target *(cible de choix)*

-Precise Target: strategic interest of the company …

The types of attacks are classified in two categories:

Passive attacks

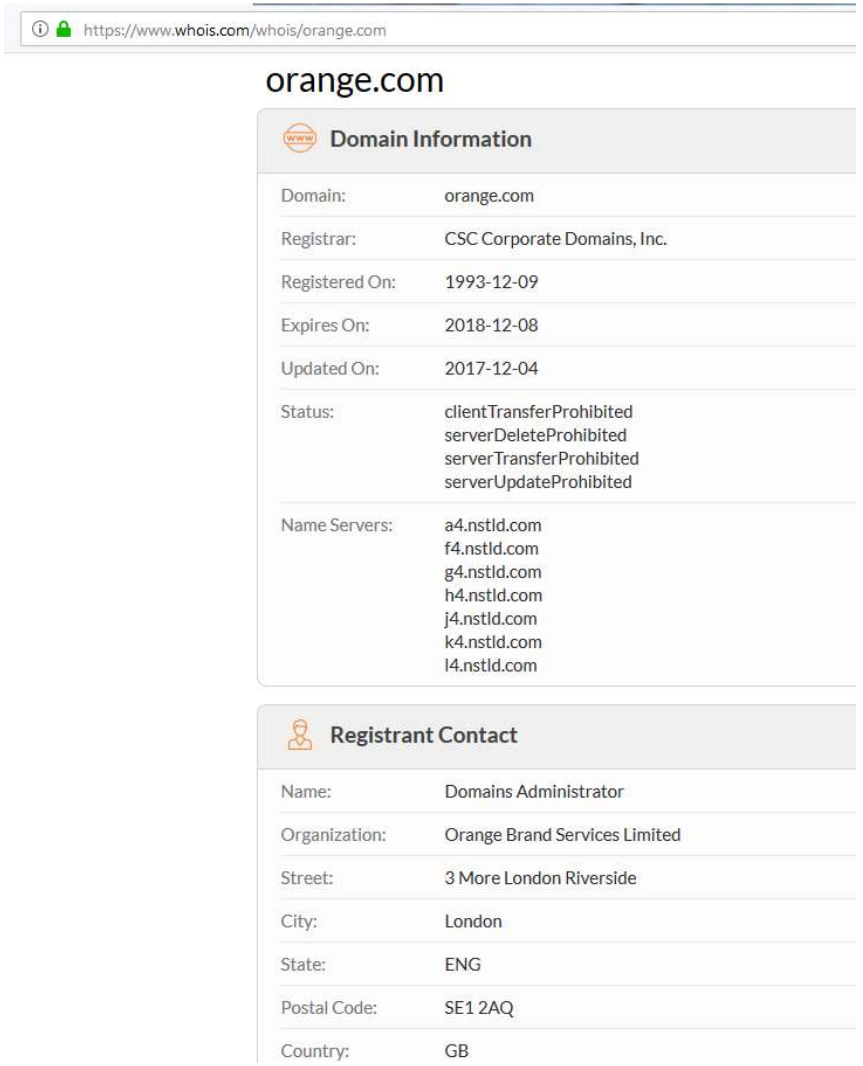
- Interception, listening

Active attacks

- Modification
- Interruption
- Denial of service

Attacks 1/6: Recognition and collection of information

- Domain names, DNS servers, blocks of assigned IP addresses
- IP addresses accessible from outside
- Services presenting a valid target
  - www, ftp, e-mail…
- Types of machines on which the services are carried out
  - Operating systems and number of version => use of the exploitable known faults
- Type of firewall and IDS (Intrusion Detection System)
- User names, groups, routing tables, SNMP information
- Physical location of the equipment and systems
- Used network protocols (IP, IPv6, IPSec, SSL/TLS)
- Cartography of the network
- Type of access connections
  - Traditional access (frame relay, broad band)
  - Wi-Fi Access
- Approach by “social engineering” (consists in questioning people and recovering information by trapping them)
  - Information on the people, their names, telephone numbers, situation in the company, addresses…



Attacks 2/6: Scan of the services and the ports

- Detailed Scan of a target (NMAP = Network Mapper)

Attacks 3/6: Enumeration

- Extraction of information on the valid accounts and the resources
  - Network resources and shared resources
  - Users and groups (as a function of the Operating system)
  - Applications
  - Character strings sent in response by the equipment

Attacks 4/6: Obtaining an access

- Tackle at the operating system level
  - Use of the functionalities of the O.S.
- Tackle at the application level
  - Use of the functionalities of the application
- Attack benefiting from a bad configuration
  - “Opened” system, default configuration (administrator name and password!), many activated functionalities
- Attack using lodged scripts
  - Scripts available on the system and sometimes activated by default (Unix/Linux)
  - Détournement de requêtes SQL lors de l’interrogation d’une base de données via interface web
- Automated Attack (ex: scan of port 80 of a whole C-class block of addresses in order to seek a fault)
- Targeted Attack : much rarer but difficult to detect (experienced pirates)

Attacks 5/6: Extension of the acquired privileges

If the pirate succeeded in entering on the system with a “weak” password => extension of the rights (authorizations)

- To carry out code to obtain privilege
- To seek to decipher other passwords
- To scan for non ciphered passwords
- To seek possible inter-network relations
- To identify badly configured files or shared resources permissions

Attacks 6/6: Cover the traces

To dissimulate to the administrator the fact that one penetrated the system

-Windows: To eliminate the entries (inputs) in the event logs and the registers

-Unix: to empty the file of history (execution of the program *log wiper*)

-! The attacker cleans the log files but does not remove them!

Attacks types

Deny Of Service DOS

Sniffing, to get information

Scanning, to get information

Social engineering

Cracking

Spoofing, to remote-control the process,

Man in the middle

Hijacking

Buffer overflow

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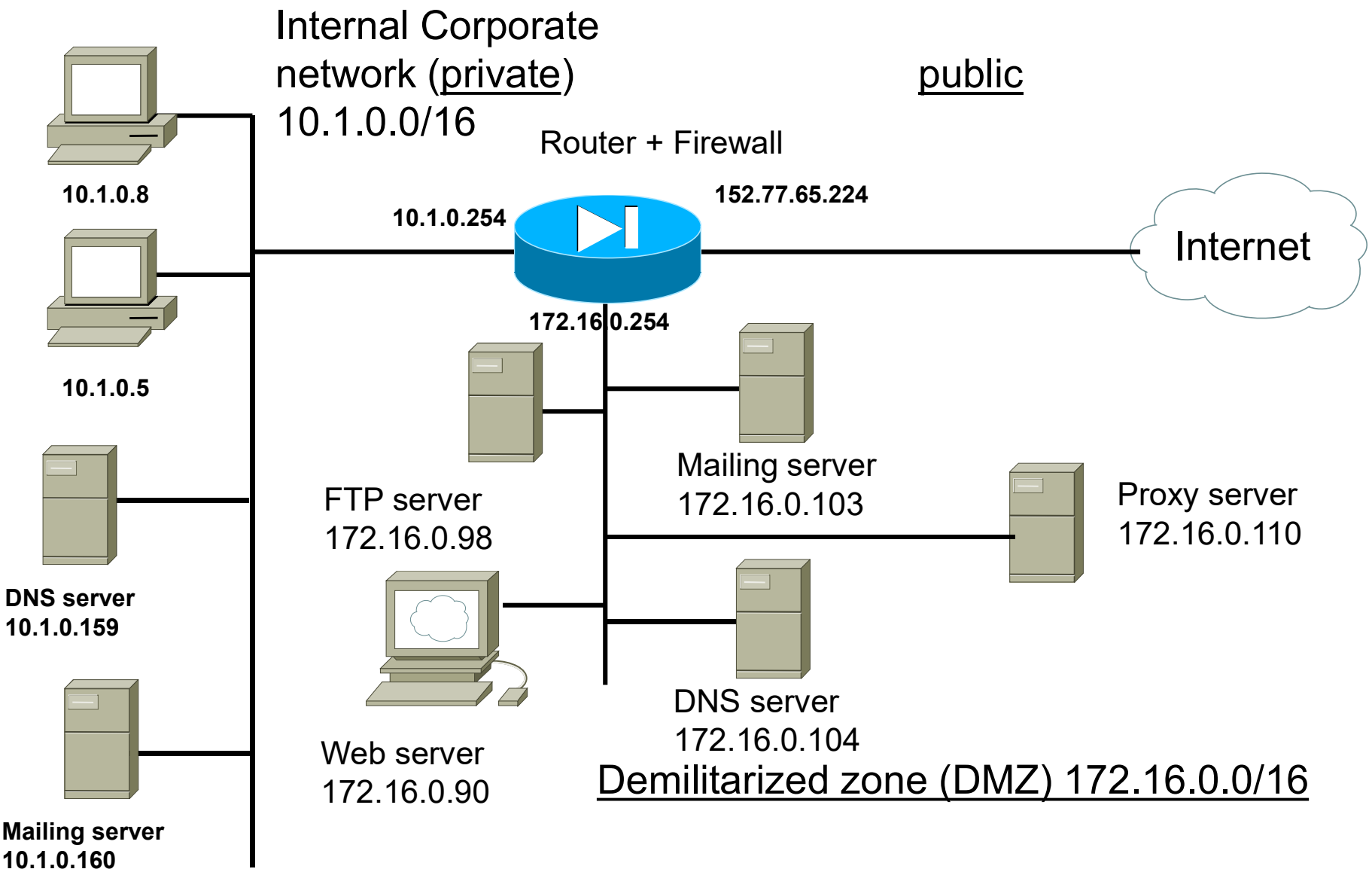
A network…


Internal Corporate
network (private)
10.1.0.0/16
public
Router + Firewall
10.1.0.8
10.1.0.254
152.77.65.224
Internet
10.1.0.5
172.16.0.254
Mailing server
172.16.0.103
FTP server
172.16.0.98
Proxy server
172.16.0.110
DNS server
10.1.0.159
DNS server
172.16.0.104
Web server
172.16.0.90
Demilitarized zone (DMZ) 172.16.0.0/16
Mailing server
10.1.0.160

Stateful firewall: Dynamic Access Control List

- Dynamic filtering
  - **Stateful inspection firewall**: packet filters that take into consideration OSI-layer 4 (TCP, UDP)
  - Dynamic entries for responses to the TCP, UDP, ICMP requests
  - Does not require to keep open the static ports (the ports remain open only during the time of the session)
- Follow-up/monitoring of the TCP sequence numbers
  - Monitoring of the sequence numbers of the input and output packets to follow-up communication flows
  - Protection against “man in the middle” attacks and session hackings

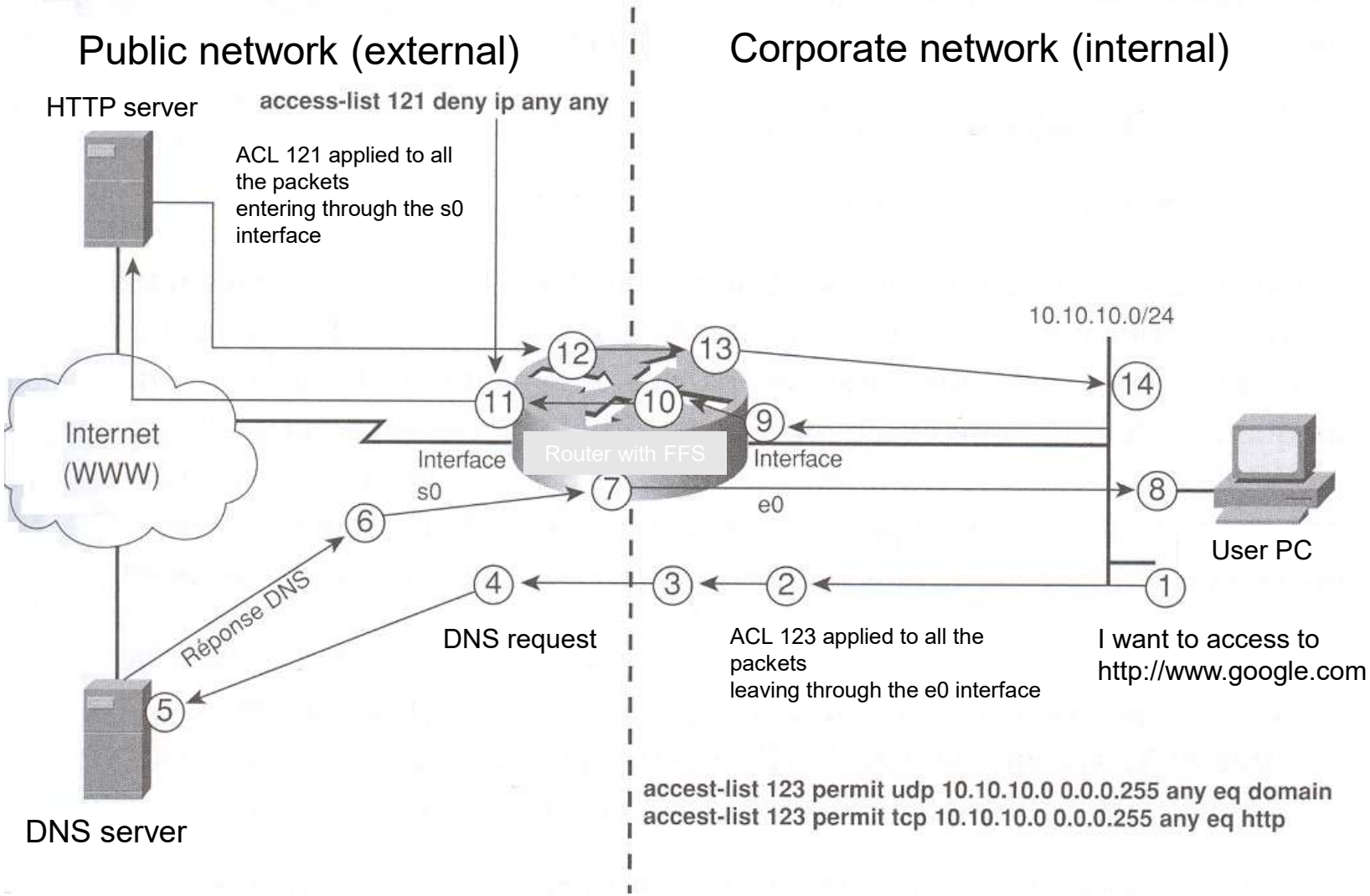
Ex: 121 ACL applied to router input, from Internet to LAN

Action Prot Adr. S. Adr. D. Serv./Port

```
ip address 192.168.254.1/30
ip address group 121 in
access-list 121 permit tcp any any eq 22
access-list 121 permit udp any any gt 1023
access-list 121 permit icmp any any gt 1023
access-list 121 permit icmp any any echo-reply
access-list 121 permit icmp any any unreachable
access-list 121 permit icmp any any administratively-
prohibited
access-list 121 permit icmp any any time-exceeded
access-list 121 permit icmp any any packet-too-big
access-list 121 permit tcp any 64.24.14.60 eq ftp
access-list 121 permit tcp any 64.24.14.61 eq smtp
access-list 121 permit tcp any 64.24.14.61 eq domain
access-list 121 permit udp 64.24.14.61 eq domain
```

1 action: permit/deny
4 parameters

Example


Public network (external)
Corporate network (internal)
HTTP server
access-list 121 deny ip any any
ACL 121 applied to all the packets entering through the s0 interface
10.10.10.0/24
Internet (WWW)
Interface s0
Router with FFS
Interface e0
User PC
Réponse DNS
DNS request
ACL 123 applied to all the packets leaving through the e0 interface
I want to access to http://www.google.com
DNS server
accest-list 123 permit udp 10.10.10.0 0.0.0.255 any eq domain
accest-list 123 permit tcp 10.10.10.0 0.0.0.255 any eq http

Some considerations on security for CPS

Everything which is not explicitely authorized is forbidden by default

In depth-security

- Global vision of the security strategy and implementation (not a juxtaposition of security mechanisms…)
- Security everywhere (internal, external)
- Application-oriented firewall

Some issues of security

- Organisational approach (security policy, human aspects, saving policy, management of users)
- Methodological approach (firewall configuration, attacks strategies and defense…)
- Technological approach (network, topology, servers, hardware and software firewalls, security protocols)
- Theoretic approach (cryptology, virology)
- Testing (quality) approach (checking, testing, audit…)

Question of implementation on low-resource embedded systems

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Some issues of cryptography

To guarantee as well as possible

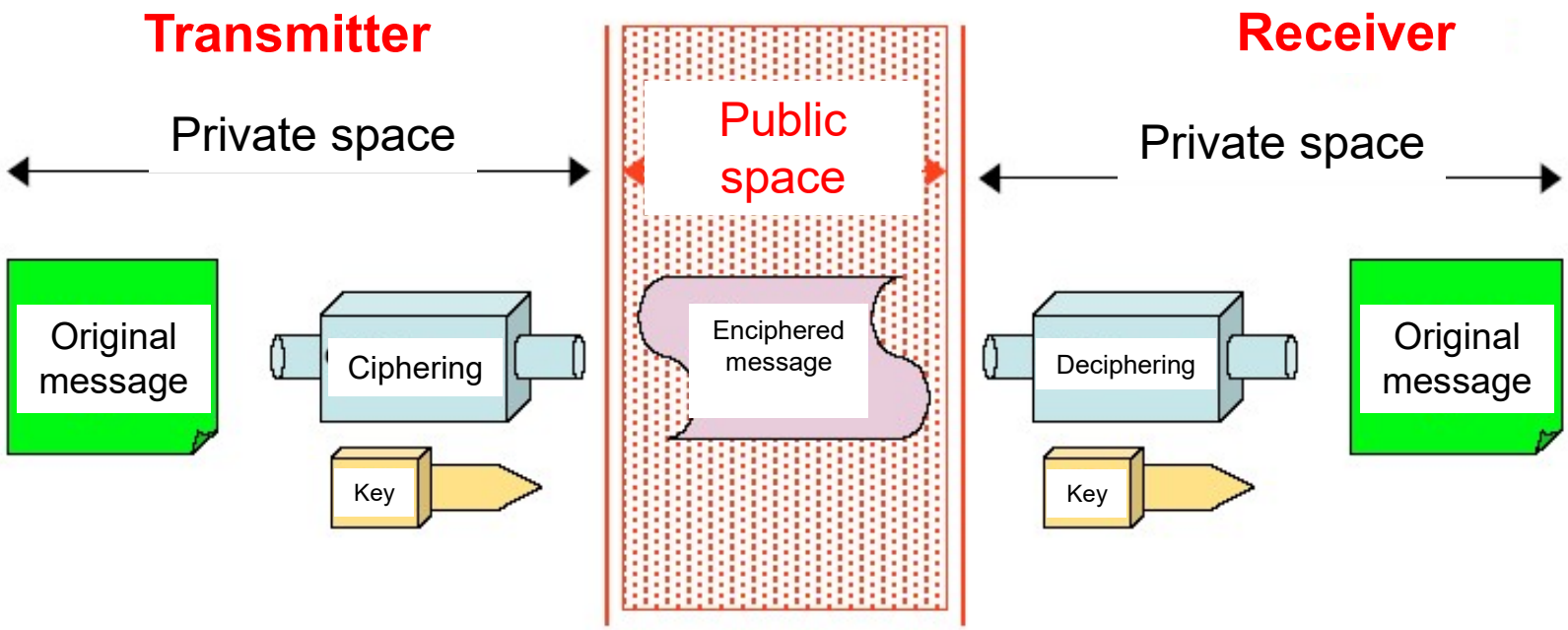
- Confidentiality
- Authenticity
- Integrity

of data (or information) exchanged

Two strategies

- Symetric cryptography
- Assymetric cryptography
- Hybrid cryptography

Symetric Cryptography (*common, shared* secret key)



- ✓ The same key is used for enciphering and deciphering
- ✓ Problem: how to transfer the key

Symetric cryptography: Caesar ciphering

Replacement of a letter by another

Robustness?

- Identical frequency contents
- Can be easily “broken” easily starting from a message of 28 letters…

Example: shift of two letters towards the line

- *Bonjour* => Dqplqwt

Another example: shift of a letter towards the left

- IBM => HAL (“2001: A Space Odyssey”)

Symetric cryptography: poly-alphabetical codes

- Let's consider an alphabet {A, B, C, D}

text t / key k	A B C D
A	C D B A
B	D C A B
C	C A B D
D	B D A C

plaintext: ABCB ACCB AACB B

Key: DBBC BAAC DDBB C

Encrypted text: BCAA DBBA BBAC A

- Require very large size keys not to be very vulnerable …

Symetric cryptography: Operations at the bit level
Distance permutations

- d1=1, d2 = 01, d3 = 001, d4= 0001…
- Distance permutation (di, dj)
- Example: TS
- Form substitution
- Example (d1, d2, d3, d4) substituted by (d2d3, d3d1, d1d4, d1d3)
=> increases the size of the data

TS

54 53

0101 0100, 0101 0011

d2 d2 d2 d4 d2 d3 d1

d3d1 d3d1 d3d1 d1d3 d3d1 d1d4 d2d3

0011 0011 0011 1001 0011 10001 01001

- Then to decipher…

Symetric cryptography: Operations at the bit level
Distance permutations: exercise

- Encipher *BON* by substituting (d1, d2, d3, d4, d5, d6) by (d2d3, d3d1, d1d4, d1d3, d2d4, d5d6) with d1=1, d2 = 01, d3 = 001, d4= 0001…

BON

42, 4F, 4E

Symetric cryptography: Inversion of bits according to a random suite

$(a_n) = (2, 14, 7, 11, 74, 25, 32, 37, 152, 99, 7)$

$\Rightarrow (b_n) = (2, 6, 7, 3, 2, 1, 0, 5, 0, 3, 7)$

F= 01001010 10010101 00101001 00010100 11010110 11110001

And

F'= 01**1**0100**01** 100**0**0101 00**0**01001 0**1**010100 **0**1010**0**10 **0**11**0**000**0**

Bit 2 Bit 6 Bit 3 Bit 2…

Symetric cryptography: Inversion of bits according to a random suite: exercise

BON with the random suite

$(a_n) = (3, 4, 11, 27, 32, 25, 12, 153, 77, 7)$

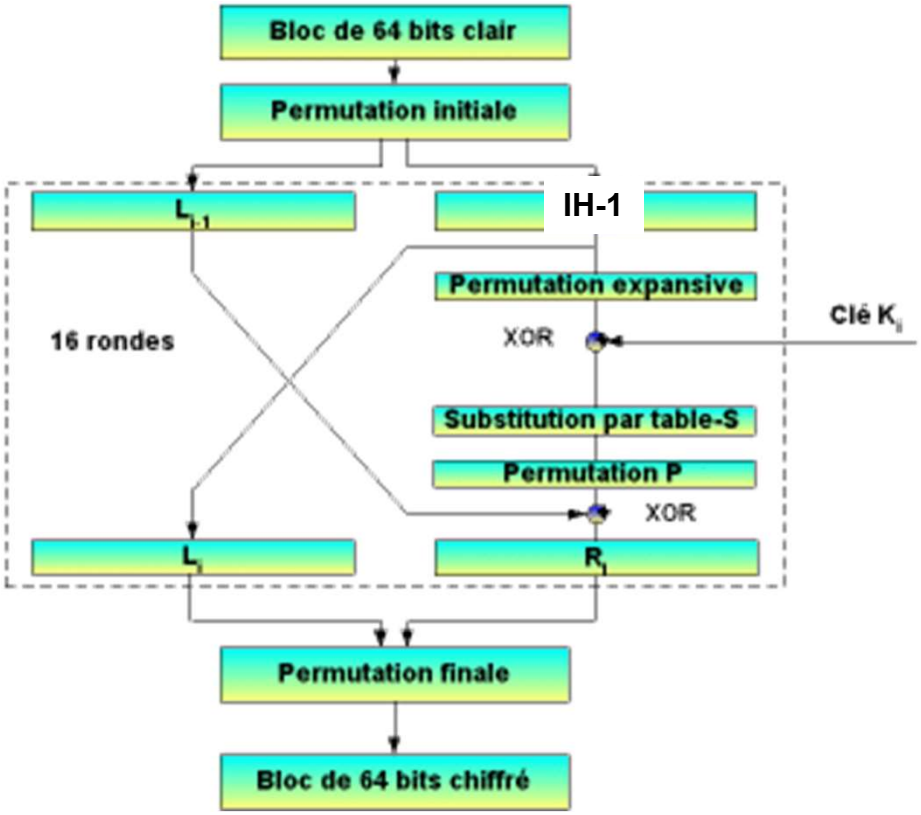
We work on 9-bit packets

42, 4F, 4E

Symetric cryptography: The standard algorithm for enciphering: IBM DES (Data Encryption Standard)

- Created 1977
- At first for classified or secret documents
- Today software and smart cards industry
- Enciphering and deciphering speed (rapidity)
  - Can be developed in less than 200 lines
  - Very fast on dedicated electronic charts
    - Smart cards
    - Electronic systems of telecommunications
- Implementation on Unix, Windows and MacOs available on Internet (chalmers.se/pub for example)

Symetric cryptography: The standard algorithm for enciphering: IBM DES (Data Encryption Standard)



- Based on XOR functions
- Sequential logics
- Sure
- Rapid
- Easy to implement

but

- Need to exchange the key
  - Problem of security during the transmission of the key

Symetric cryptography: Flow encryption vs. Block encryption *(chiffrement par flot, par bloc)*

- DES and classical symetric algorithms are based on block encryption, which means that the message/file to encrypt is divided into blocks
- For some applications, it is interesting to encrypt the message/file at once. Encryption may be achieved without waiting for other data.
- This technics is used for devices with electric consumption constraints (ex: smart phones)
- Based on linear feedback shift register (registre à décalage à rétroaction linéaire)

Symetric cryptography: Symetric algorithms

3DES (triple DES)

- It consists in using three times the DES algorithm with three keys k_1, k_2 et k_3 : m'=$DES_{k1}(DES_{k2}(DES_{k3}(m)))$
- Alternative with 2 keys and by using twice the algo of encrypting and once the algo of decoding: m'=$DES_{k1}(DES^{-1}_{k2}(DES_{k1}(m)))$, this alternative is considered more secure
- Another alternative: program TRAN (ripem.msu.edu/pub/crypt/other/tran.shar)
- DESX (DES XORed), GDES (Generalized DES), RDES (Randomized DES)

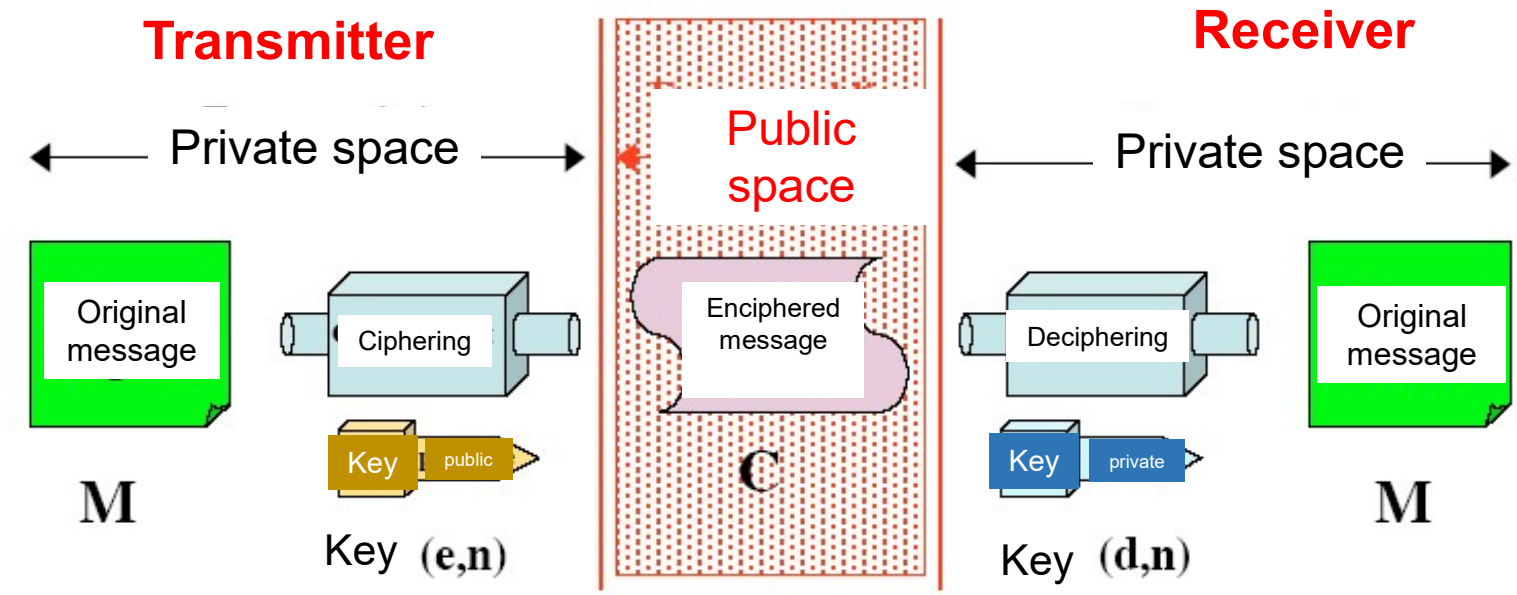
AES (Advanced Encryption Standard)

- Developed to replace DES and offer a better security
- N.B. At the end of 2003, the American department of defense approved its authorization
- Used in IPSec (secured IP) and IKE (Internet Key Exchange)

http://www.cisco.com/en/US/products/sw/iosswrel/ps1839/products_feature_guide09186a0080110bb6.html

Assymetric Cryptography (couples of private and public key)

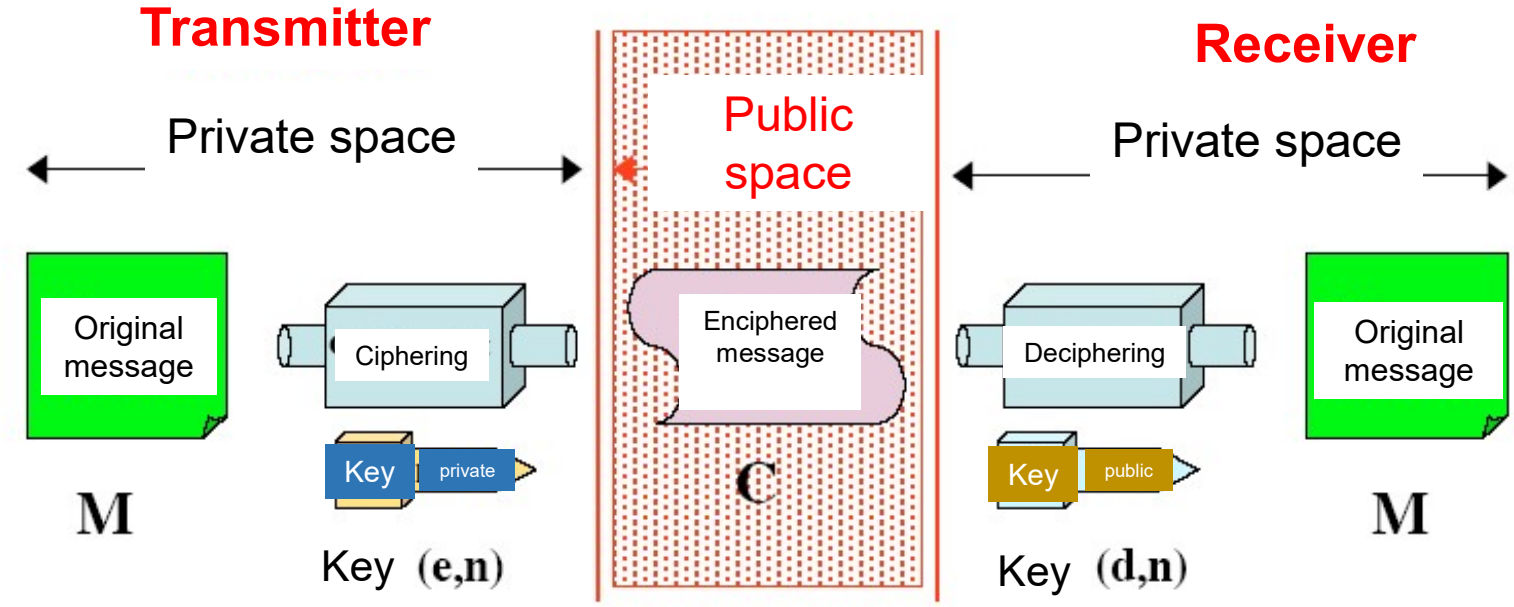
Protection of **confidentiality** = private key on the **receiver** side)



- ✓ Encryption is achieved thanks to the **public** key
- ✓ Warrant that the owner of the private key ONLY can **decrypt** the message

Assymetric Cryptography (couples of private and public key)

Protection of **authentication (signature)** = private key on the **transmitter** side)



- ✓ Encryption is achieved thanks to the **private** key
- ✓ Warrant that the owner of the private key ONLY can **sign** the message

Assymetric Cryptography: RSA ciphering Protocol

Proposed in 1977 by the cryptologists Rivest, Shamir and Adleman

Based on the modular exponentiation (trap function)

Main applications

- Sending of confidential messages to a person
- Authentication by any person of the message sent by an individual
- Authentication by password (smart cards, bank cards)

Security based on the impossibility of carrying out the factorization of a large number of a few hundreds of digits in a reasonable time

- The user selects two large prime numbers p and q, then multiplies them to obtain n=p.q (integer modulating the RSA protocol)

Assymetric Cryptography: RSA

The algorithm is remarkable by its simplicity. It is based on the prime numbers.

To encipher a message:

c = m^e mod n

To decipher: **m = c^d mod n**

m = clear message
c = encrypted message
(e, n) constitutes the public key
(d, n) constitutes the private key
n is the result of the multiplication of 2 prime numbers
^ is the power function (a^b: a power b)
mod is the operation of modulo (remainder of the *integer division*)

Assymetric Cryptography: RSA

Creation of a pair of keys

It is simple, but the **e**, **d** and **n** should be chosen with care! And the calculation of these three numbers is delicate.

Methodology:

- The user selects two large prime numbers p and q, and multiplies them to obtain n=p.q (integer modulating the RSA protocol), We should choose p and q with equivalent sizes.

  It is advised that n is higher or equal to 512 bits

- Take a number **e** which does not have any factor in common with

  (p-1) (q-1).

- Calculate **d** such as **ed mod (p-1)(q-1) = 1**

The couple **(e, n)** constitutes the public key.

(d, n) is the private key.

Various other rules are to be respected for the use of these prime numbers so that the algorithm cannot be “broken”

Prime numbers

Largest Known Prime Number:

$2^{77\,232\,917}-1$

Found in December 2017, composed of 23 249 425 digits

2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37, 41, 43, 47, 53, 59, 61, 67, 71, 73, 79, 83, 89, 97, 101, 103, 107, 109, 113, 127, 131, 137, 139, 149, 151, 157, 163, 167, 173, 179, 181, 191, 193, 197, 199, 211, 223…

Assymetric Cryptography: RSA

https://www.cs.drexel.edu/~jpopyack/IntroCS/HW/RSAWorksheet.html

Let's encipher the message "**HELLO**". Let's take first the ASCII code (into decimal) of each character and one puts them end to end:

m = 72-69-76-76-79

Then, it is necessary to cut out the message in blocks which is composed of less digits than **n**. **n** is composed of 4 digits, one thus will cut out our message in blocks of 3 digits:

726 976 767 900
(let's complete with zeros)

Then one encrypt each one of these blocks:

726^13 mod **21209** = 11600
976^13 mod **21209** = 5705
767^13 mod **21209** = 16590
900^13 mod **21209** = 3565

The encrypted message is **11600.5705.16590.3565**. One can decipher it with d:

11600^1609 mod **21209** = 726
5705^1609 mod **21209** = 976
16590^1609 mod **21209** = 767
3565^1609 mod **21209** = 900

I.e. the digit suite: **726976767900**.
We find the clear message: **72 69 76 76 79**: "**HELLO**".

Symetric vs. Assymetric Cryptography

1. Symetric
    1. Very simple operations (logical functions)
    2. Easy to implement (limited resources)
    3. How to exchange the key between the sender and the receiver and to be sure there are to “man-in-the-middle”
2. Asymetric
    1. “Complex” operations (exponential modulo),
    2. Needs calculation resources
    3. Private keys kept unique and secure, exchange of public keys only
3. Combine the advantages of both

    => Hybrid cryptography

Hybrid cryptography: generation of a sharing key

Two users will design a common key which will be useful for them only

ASSYMETRIC ASPECT

They choose n the multiple of 2 prime numbers p and q and an integer a (a and n can be known (not confidential))

Then each one chooses an integer X belonging to [1, n-1] and calculates the integer $Y=a^X \bmod n$

We obtain two couples (X_1,Y_1) and (X_2, Y_2) where the values Y_1 and Y_2 will be published

HYBRID ASPECT

Each one of them can then calculate the key $c=a^{X1X2} \bmod n$ because $c=(Y1^{X2} \bmod n)=(Y2^{X1} \bmod n)$

R: Each one knows its own X only

Security comes from the fact that it is impossible in a reasonable time to obtain the key C by the calculation of a discrete logarithm (unfeasible in a reasonable time taking into account the size of p and q)

SYMETRIC ASPECT

Users can now exchange encrypted data using a Symetric system with the common key c

Hybrid cryptography: generation of a sharing key: exercise

Generate a shared key with your neighbor

(ex:

a=3 et n=14 (public values (known)) n=2*7

X_1 = 4 (secret value known only by the participant on the left)

X_2 = 3 (secret value known only by the participant on the right)

Cryptography: Some considerations on breaking a 768-bit RSA key

- From an Inria document, 2010.

- Key used for bank cards

- To break the key, find the prime numbers which compose the key: it is a number composed of 232 figures (2^{768})…

- Need efficient algorithm

- Need large calculation capacities: use of Grid'5000 => 1544 computers with more than 5000 cores.

- Collaboration with CH, JP, NL, DE : on average 1700 cores used during one year of calculation…

- One week by using the supercomputer *Jaguar* (from *Oak Ridge National Laboratory*) if available (not such computers in Europe…)

- The purpose was to show if it is possible to break using grid of « classical » computers

- Next step: to break a 1024 bit-key => it should be possible around 2020

- Advise from ANSSI (2010):

  Use at least 1536 bit-keys for applications until 2010

  Use at least 2048 bit-keys for application beyond 2010

Conclusions on cryptography

- Hybrid cryptography
- Difficult implementation of assymetric cryptography
- Integrated in the certificates
- Integrated in security protocols (IPSec, SSL/TLS)
- Integration of cryptography and more generally of security mechanisms in industrial applications

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Intrusion detection and response

- Purpose: to detect and respond to network attacks and malicious code (anti-virus)

- Malicious code

  Intended to harm, disrupt, or circumvent computer and network functions (viruses, trojan horses, worms…)

- Network attacks

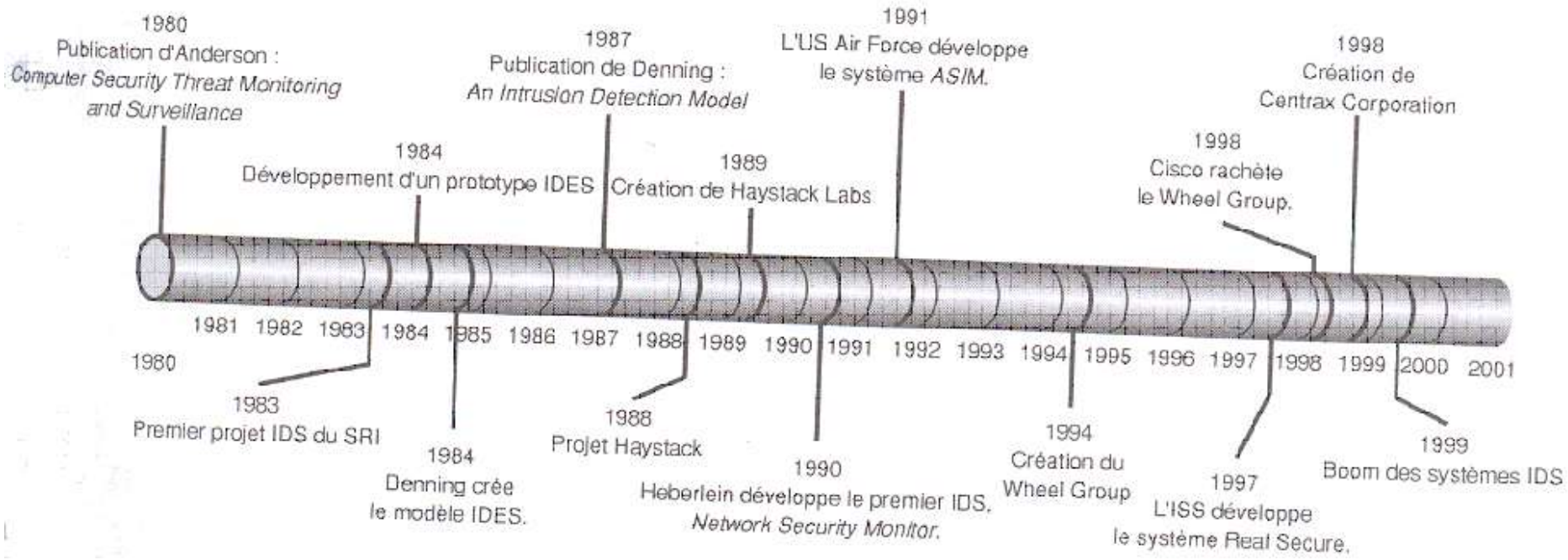
  Modification attacks: unauthorized alteration of information

  Repudiation attack: denial that an event or transaction ever occurred

  Denial-of-service attack: actions resulting in the unavailability of network resources and services, when required

  Access attacks: unauthorized access to network resources and information

History of the development of IDS (for IT)



Today, the products implement concepts dating from the years 1980

Signature-based IDSs

Signature-based IDSs: signature or attributes that characterizes an attack are stored for reference (if there is a match, a response is initiated)

Advantages

- Low false alarm rates
- Standardized (generally)
- Understandable by security personnel

Disadvantages

- Failure to characterize slow attacks that extend over a long period of time
- Only attack signatures that are stored in the database are detected
- Knowledge database needs to be maintained and updated regularly
- Because knowledge about attacks is very focused (dependent on the operating system, version, platform, and application), new, unique, or original attacks often go unnoticed

Statistical anomaly-based IDSs

Statistical anomaly-based or behavior-based IDSs: dynamically detects deviations from the learned patterns of « normal » user behaviour and trigger an alarm when an intrusive activity occurs

Needs to learn the « normal » usage profile (which is difficult to determine)

Advantages

- Can dynamically adapt to new, unique, or original vulnerabilities
- Not as dependent upon specific operating systems as a knowledge-based IDS

Disadvantages

- Does not detect an attack that does not significantly change the system-operating characteristics
- High false alarm rates. High positive are the most common failure of behavior-based ID systems
- The network may experienced an attack at the same time the intrusion detection system is learning the behaviour

Functionalities of IDS: Responses to the detected intrusions

Active answers

- -To undertake an aggressive action against the intruder
  - (! Attention with legality!)
- -To restructure the network architecture
  - To isolate the attacked system
  - To modify the environment parameters which made the intrusion possible
- -To supervise the attacked system
  - To collect information in order to understand the intrusion
  - To identify the author of the intrusion and his approach
  - To identify security failures

Passive answers

- -Generation of an alarm
- -Emission of a SMS message towards the administrator

Some tools (for IT)

- -Snort, Suricata, Bro, Cisco secure IDS, Billy Goat, Enterasys

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   - 7.2 Intrusion detection on GOOSE messages for smart grids
   - 7.3 Processus-oriented detection attacks
   - 7.4 Risk analysis of a drone
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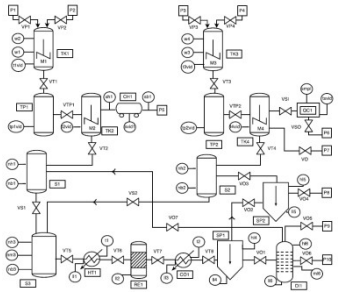
Industrial control Systems [Stouffer 2011]

Generic term regrouping

SCADA (Supervisory Control And Data Acquisition)

- Distributed on several geographical areas



DCS (Distributed Control Systems)

- Just in a local zone

other configurations based on **PLC** (Process Logic Controller)

Evolution of ICS systems

- Previously isolated and using proprietary protocols
- Security not taken into account (security by obscurity)
- Now more and more connected for economic reasons
- Use of classical IT solutions (architecture, OS, network protocols)
- More vulnerable to attacks

Comparison between ICS and classical IT systems

Category	IT systems	ICS systems
Performances	Delays and jigs acceptable	Real time, critical time Strict time constraints
Availability	Some tolerance on degradations, depending on situations	High availability Inacceptable loss of connection (depends) Advance planning
Resource constraints	Available resources	Design for industrial processes Limited processing and memory resources
Targeted properties	Confidentiality Integrity Availability	Timeliness Availability Integrity Confidentiality

ICS Specificities

	Information Technology	*Operation Technology*
Cyber security culture	Awareness of risks Methods and tools	Recent
Life duration	3-5 years	> 20 years
Performance	Throughput	Latency Real-time constraints
Resources	Abundant	Limited
Networks Protocols topologies	Numerous connection points Dynamic topologies	Fixed topologies "Simple" protocols Defined communication strategy, scheduling
Security Attributes	Cyber sécurity: Confidentiality Integrity Availability	Dependability: Availability Reliability Safety

Some other considerations on ICS

- Define the model of trust
- Define the model of threats
- Vulnerabilities linked to security procedures and policy
- Vulnerabilities linked to the architecture
- Vulnerabilities linked to networks

- Control systems
  - Communication: protocole, flow
  - Tasks: state, scheduling
  - Resources: memory, cpu, traffic
  - Data and control flows: timestamp, values intervalles

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   - 7.4 Risk analysis of a drone
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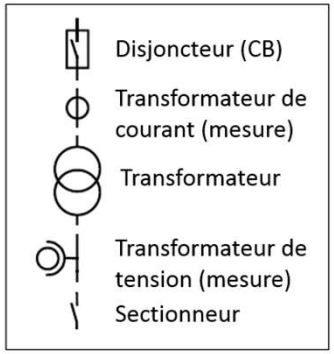
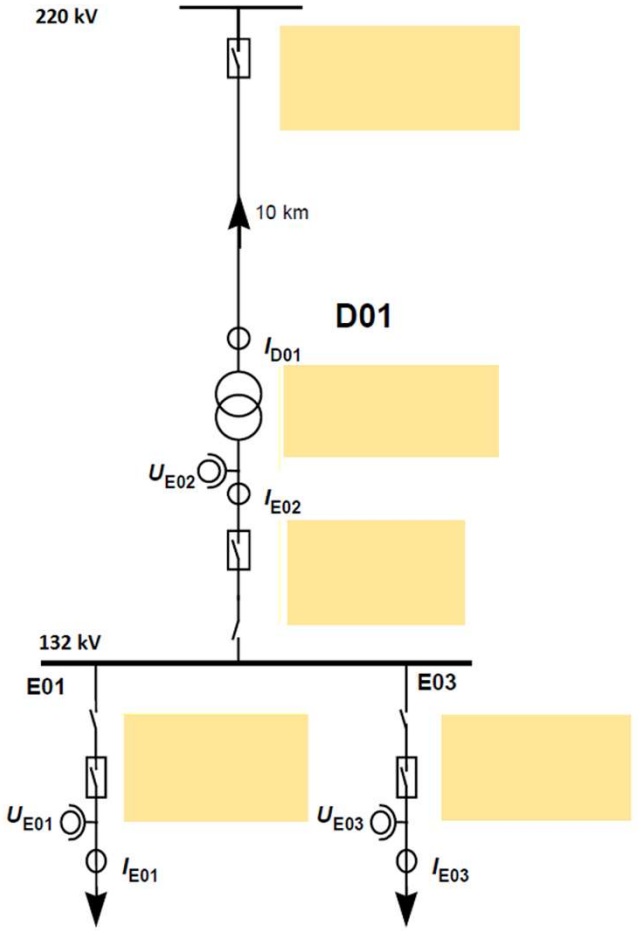
Analyse des risques cyber sécurité d'un poste IEC 61850 typique 1/3

- Objectifs
  - Comprendre le risque de cyber attaque sur le transfert de données IEC 61850
  - Comprendre l'impact sur le fonctionnement optimal et sûr du poste
- Attributs de sécurité
  - Disponibilité
  - Fiabilité
  - Sûreté
- Méthodologie
  - Simple
  - Description fonctionnelle du système (VS. une implémentation particulière)

Analyse des risques cyber sécurité d'un poste IEC 61850 typique 2/3

- Système
- **Primaire** (réseau électrique) → transport et distribution électrique
- **Secondaire** (système d'automatisation du poste - SAS) → contrôle, supervision, protection et monitoring



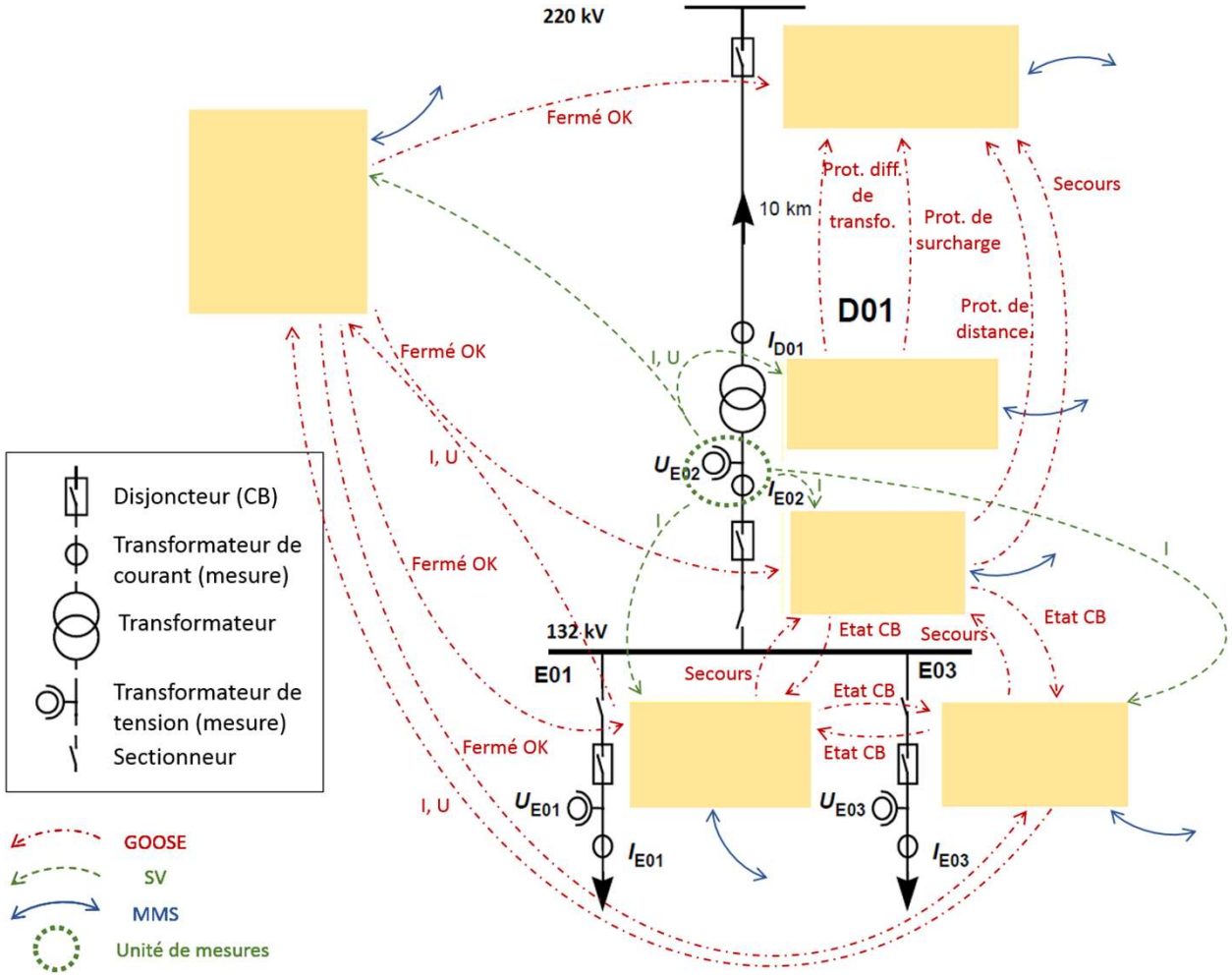


Exemple d'un poste de transport de petite taille

Analyse des risques cyber sécurité d'un poste IEC 61850 typique 2/3

- Système
- **Primaire** (réseau électrique) → transport et distribution électrique
- **Secondaire** (système d'automatisation du poste - SAS) → contrôle, supervision, protection et monitoring

- Fonctions distribuées basées sur la communication



Exemple d'un poste de transport de petite taille

Analyse des risques cyber sécurité d'un poste IEC 61850 typique 2/3

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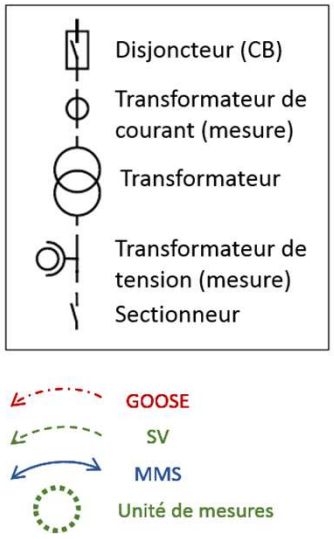
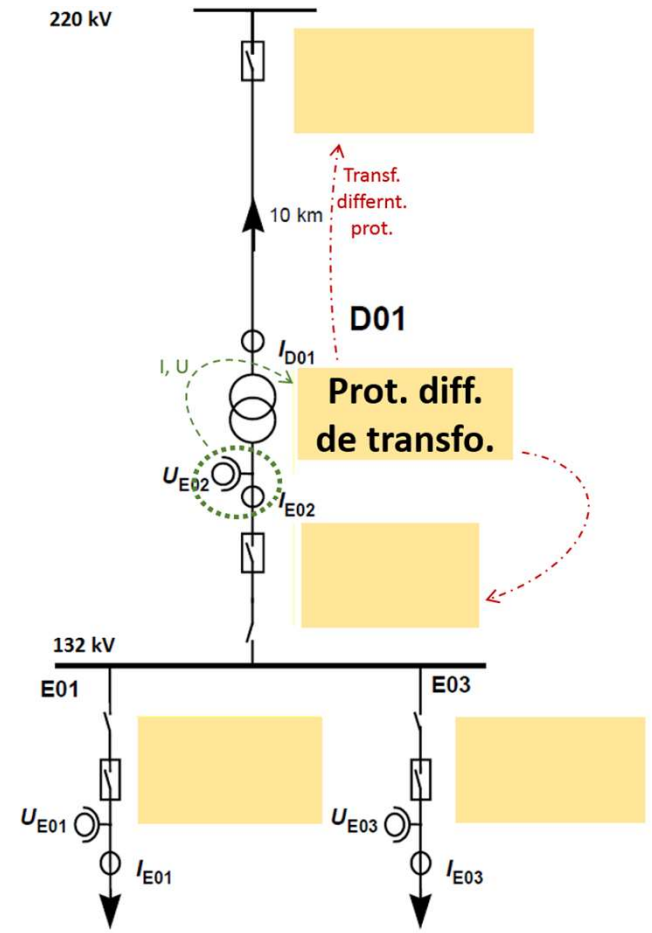
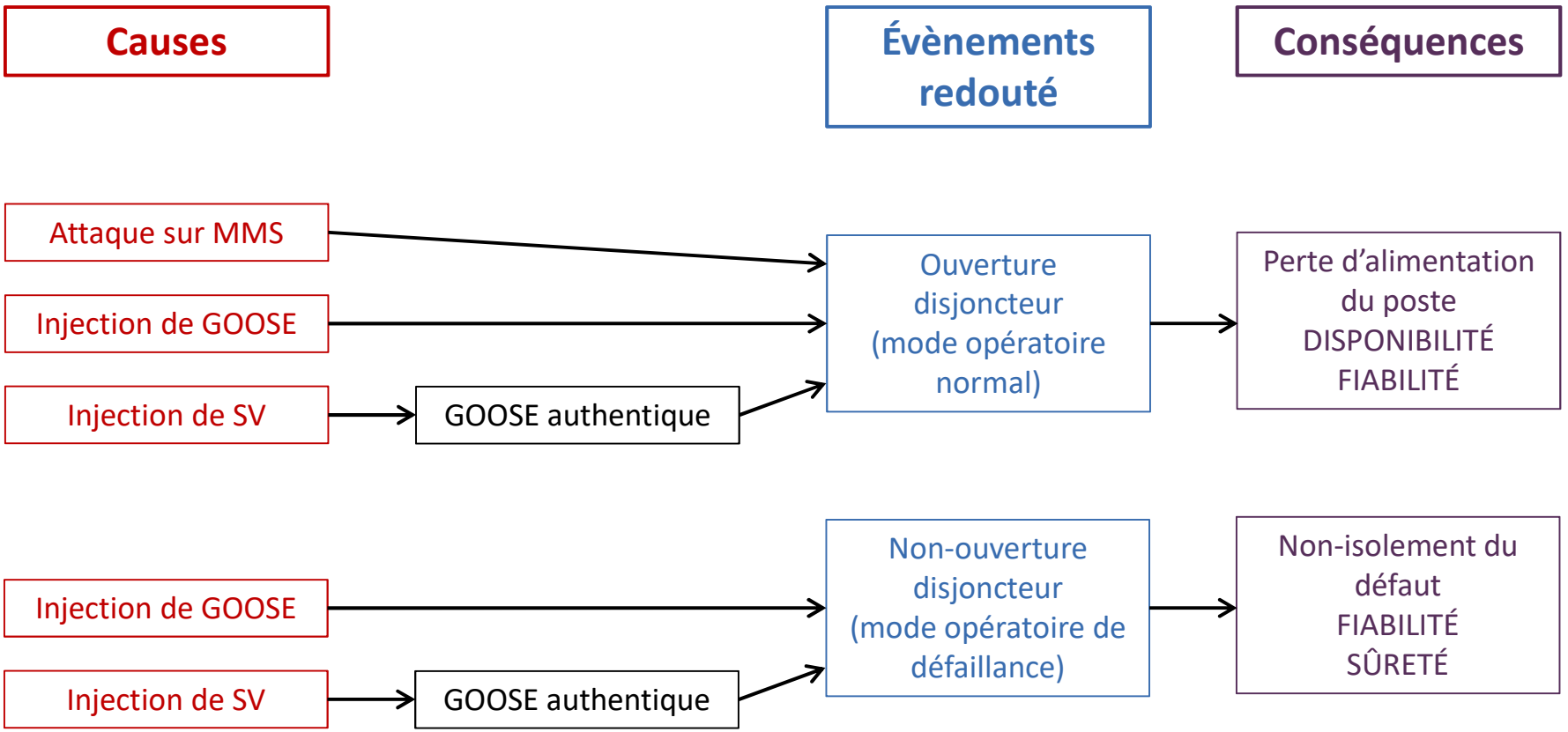




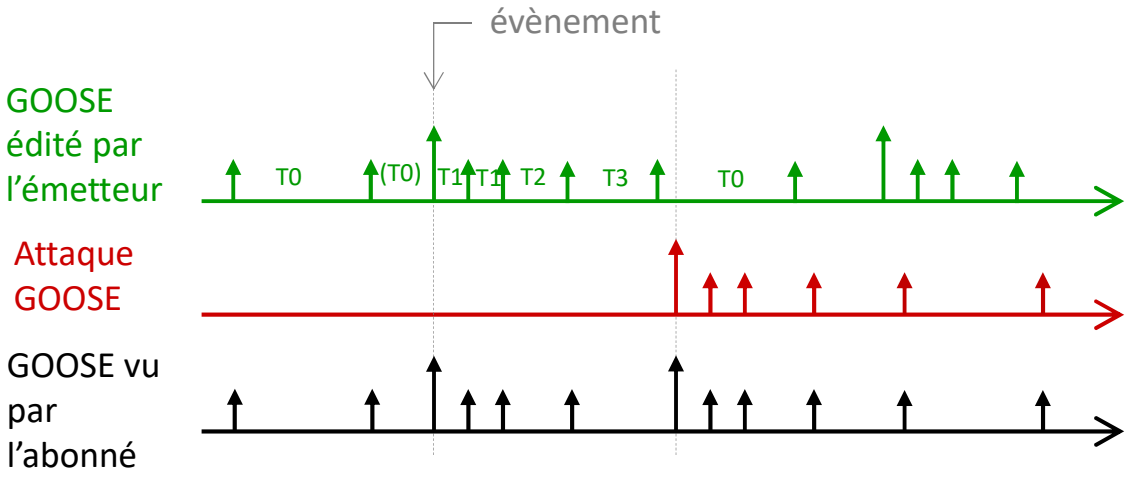
Exemple d'un poste de transport de petite taille

Analyse des risques cyber sécurité d'un poste IEC 61850 typique 3/3



Fiabilité et injection de faux messages GOOSE

- Mécanisme de transfert de données GOOSE
  - Editeur / abonné
  - Broadcast
  - Compteurs : Numéro d'état (*State number - StNum*) et numéro de séquence (*Sequence Number - SqNum*)



Mécanisme de transfert du protocole GOOSE … et exploit

T0	Retransmission en conditions stables
(T0)	Cycle de retransmission en conditions stables peut être interrompu par un évènement
T1	Délai de retransmission le plus court, après un évènement
T2, T3	Le délai de retransmission double jusqu'à T0

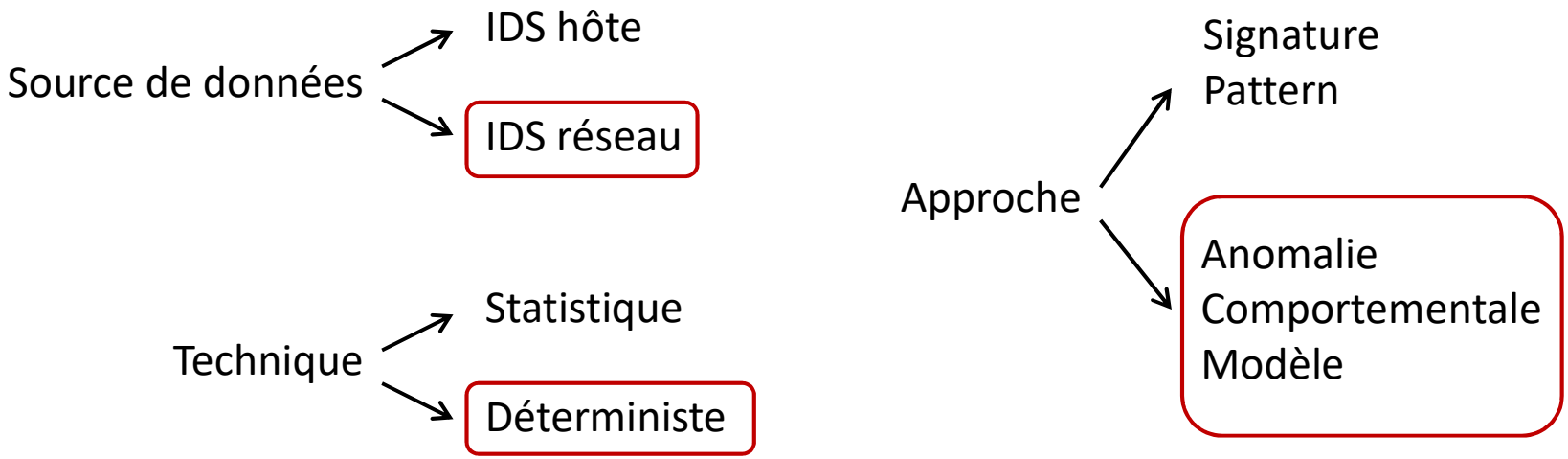
Approche de détection d'intrusion

- La détection d'intrusion est une mesure clé pour une sécurité "end-to-end"

(IEC 62351 "Gestion des systèmes de puissance et échange d'informations associé - Sécurité des communications de données")

- Détection d'Intrusion : "service de sécurité qui monitore et analyse les événements système dans le but de détecter, et avertir en temps-réel ou presque temps-réel, toute tentative d'accès aux ressources du système de façon non autorisée"

(IEC 62443 "Sécurité des automatismes industriels et des systèmes de commande")



Système de détection d'intrusion réseau pour la communication GOOSE, approche déterministe et basée anomalies 1/3

Ethernet				Ethernet	
@ destination	@ source	Ethertype 0x88b8	APDU	Pad	CRC

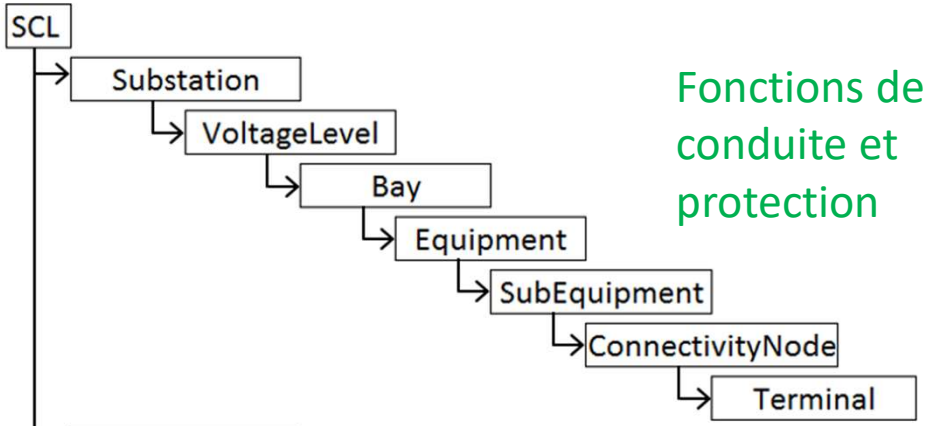
Structure simplifiée d'une trame GOOSE

- Vérification d'une trame unique
  - Définition du protocole (ex. : valeur d'un champ)
  - Origine/destination (ex. : couple @ source / @ destination)
  - Configuration du système de communication (ex. : paramétrage du mécanisme de transfert GOOSE)
  - Configuration de l'application GOOSE
- Vérification multi-trames :
  - Profil de temps
  - Séquence de messages

Système de détection d'intrusion réseau pour la communication GOOSE, approche déterministe et basée anomalies 2/3

- Information sur le vocabulaire et la grammaire du protocole ainsi que la structure de la communication
  - Norme
  - Fichiers de configuration SCL

- *"Substation Configuration Language"*
  - Fichier "*Substation Configuration Description*"



Fonctions de conduite et protection

Structure d'un fichier SCL

Système de détection d'intrusion réseau pour la communication GOOSE, approche déterministe et basée anomalies 3/3

- Extraction d'informations d'identification et de paramétrage pour le PDU
- Directement ou indirectement

- Anomalies ≠> vulnérabilités
  - Adresse de destination MAC
  - APPID (*Application Identifier*)
- Anomalies ? vulnérabilités
  - Adresse source MAC
- Anomalies => vulnérabilités
  - Horodatage T (IEC 62351)

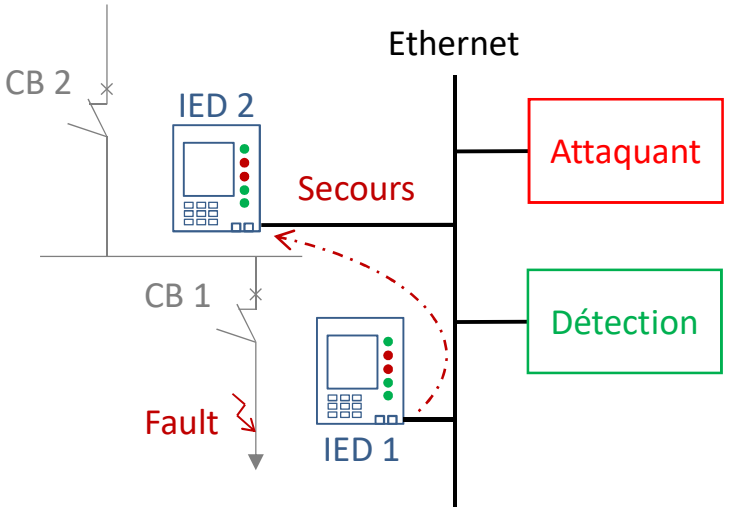
GoCBRef	*GOOSE Control Block Reference*
TimeAllowedToLive	
DatSet	*Data Set*
GoID	*GOOSE Identifier*
T	*Time*
StNum	*State Number*
SqNum	*Sequence Number*
Test	
ConfRev	*Configuration Revision*
NdsCom	*Needs Commissioning*
NumDatSetEntries	*Number of Data Set Entries*
AllData	
Security	

Structure du PDU GOOSE

Implémentation

- Validation de l'approche en C avec les sources de Tcpdump
  - Vérification de l'ensemble des propriétés intra et inter trames GOOSE
- Dissémination avec Bro
  - Intégration d'un analyseur syntaxique de GOOSE
  - Script de vérification du mécanisme de transfert GOOSE
  - Temps d'analyse d'une trame (161 octets) = ~ 2.3ms

  VS. 0.3ms, 32 règles couvrant MMS, SV et GOOSE [YAN2017]



Architecture de test

https://github.com/bro/bro/pull/76

[YAN2017] Yang et al., Multidimensional Intrusion Detection System for IEC 61850 based SCADA Networks, 2017

Contributions

- Etudes des vulnérabilités de la communication IEC 61850
  - Analyse de risques cyber sécurité IEC 61850
  - Test d'injection de fautes sur le protocole GOOSE
  - Preuve de faisabilité d'injection de fausses données GOOSE
- Modélisation IDS pour l'IEC 61850
  - Extension au modèle d'information IEC 61850 dédiées à la détection d'intrusion
- Développement et implémentation de notre approche de détection comportementale déterministe
  - IDS réseau, basé anomalies, déterministe pour GOOSE
  - Spécification de règles à partir des fichiers de configuration
  - Deux implémentations (Tcpdump, Bro)
- Proposition d'architecture du système de contrôle résiliente aux attaques GOOSE

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Détection d'intrusions dans les systèmes de contrôle industriels

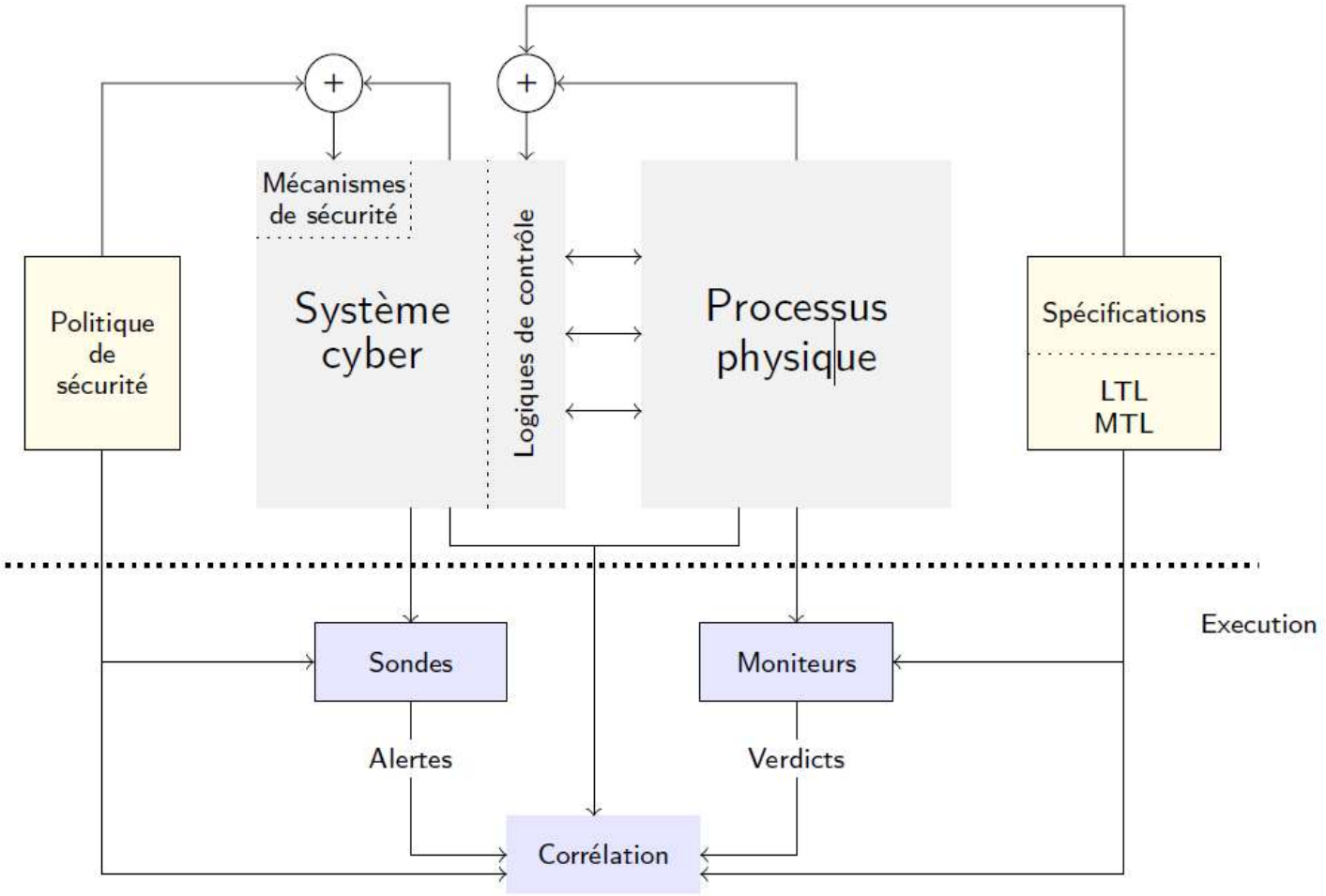
Motivation

- Les systèmes industriels sont de plus en plus connectés aux systèmes d'information traditionnels
- Utilisation de solutions IT classiques (architecture, OS, protocoles réseaux)
- Surface d'attaque accrue

Détection d'intrusions

- Nécessité de tenir compte des spécificité des systèmes industriels : présence d'un processus physique
- Mieux comprendre les faux positifs

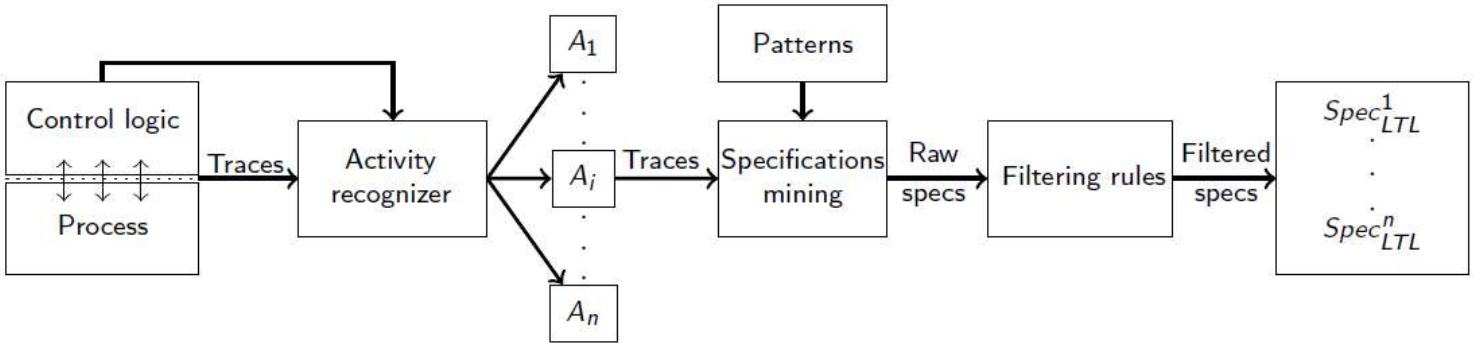
Global approach: correlations between IDS probes (Cyber system) and safety monitors (Physical process)



Détection d'attaques orientée processus : Inférences de spécification

Motifs de spécifications

- L'écriture manuelle de spécifications est fastidieuse
  - → Inférer les spécifications à partir de traces d'exécutions
  - → Se baser sur des **motifs de spécifications**
- Les motifs de spécifications représentent des propriétés souvent utilisées pour la vérification formelle [Dwyer, 1999] :
  - **Nature :** absence, universalité, ordre
  - **Portées :** avant, après, ou entre des états/événements



Inférence de spécifications : fouille par portées

- **Observation :** les traces d'exécution générées par les logiques de contrôle sont hautement structurées
- **Idée :** diviser l'espace des propriétés instanciables selon les portées afin d'éviter la vérification de propriétés inutiles
- Une propriété inutile est une propriété qui n'est pas **falsifiable**

Exemple

- Pour la trace : $\{vp1,m1\},\{p1,m1\},\{vp2,p1\},\{p1,p2\},\{end\},\{end\}\ldots$
- Une propriété instanciée possible est : $absence\_after(vp1^{\uparrow}, m1^{\uparrow})$
- Cette propriété n'est pas falsifiable car $vp1^{\uparrow}$ n'est jamais vraie sur la trace.
- Toutes les propriétés ayant pour portée $vp1^{\uparrow}$ ne sont pas falsifiables et peuvent être ignorées.

Inférence de spécifications : fouille par portées

Vérification de la falsifiabilité

- La falsifiabilité est déterminée à l'aide de ***moniteurs auxiliaires*** tournant en parallèle avec les moniteurs associés à la vérification d'une instance
- Si, pour une trace donnée, une propriété n'est jamais violée mais que le moniteur auxiliaire associé indique la non falsifiabilité de la propriété, celle-ci est ignorée et la portée associée est mise en liste noire
- Différentes politiques possibles sur plusieurs traces

Filtrage de spécifications

Règles de filtrage

- Introduction de règles de filtrage afin de réduire le nombre important de spécifications inférées
- Règles de la forme :

$$\frac{\psi_1, \quad \psi_2, \quad \forall \sigma \in \Sigma^\omega, \sigma \models \psi_2 \Rightarrow \psi_1}{\mathit{filter}(\psi_2)}$$

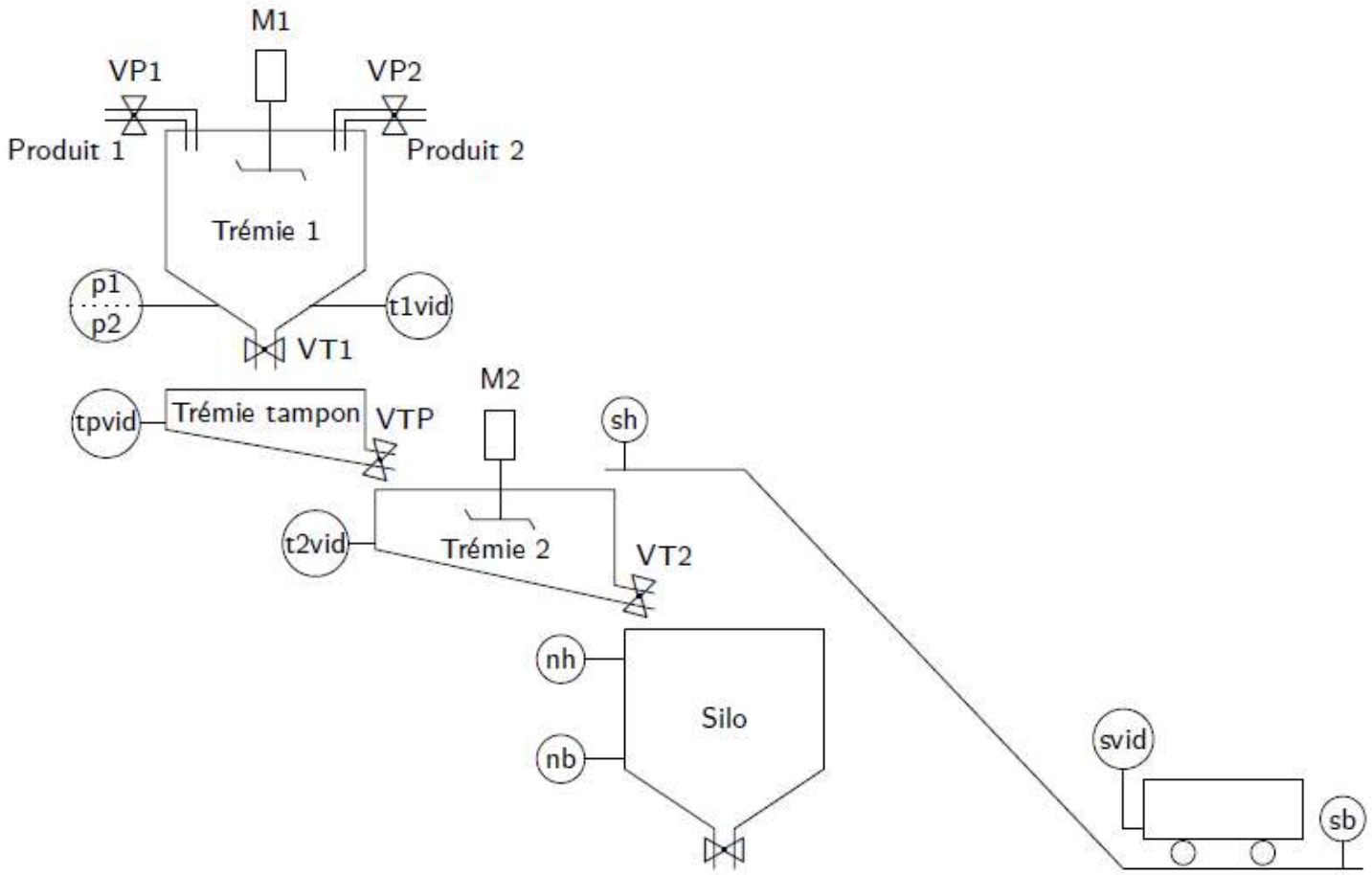
- Exemple :

$$\frac{\mathit{universality\_after}(X, Y), \quad \mathit{absence\_after}(X, Y^{\uparrow})}{\mathit{filter}(\mathit{universality\_after}(X, Y))}$$

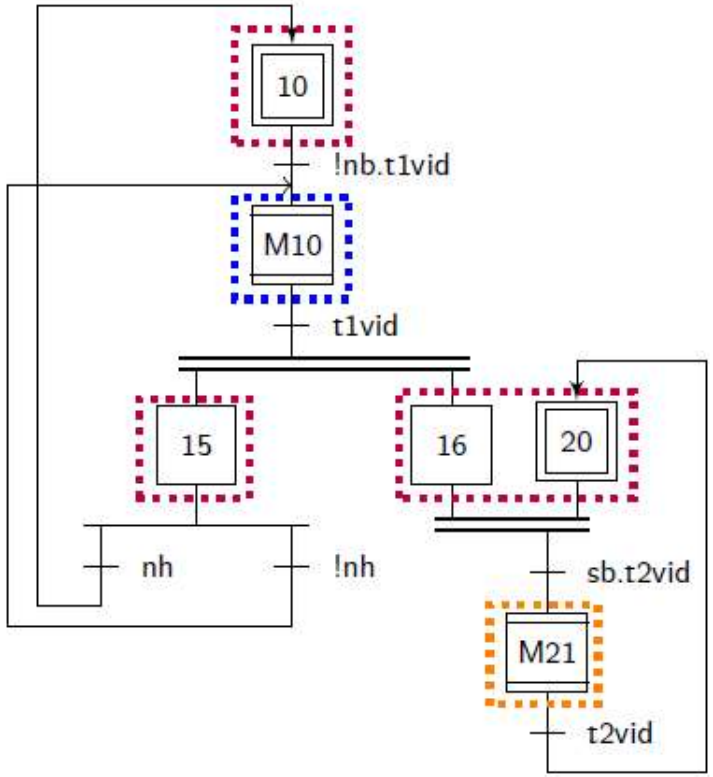
- Ces règles représentent des relations logiques entre les spécifications inférées

Evaluation

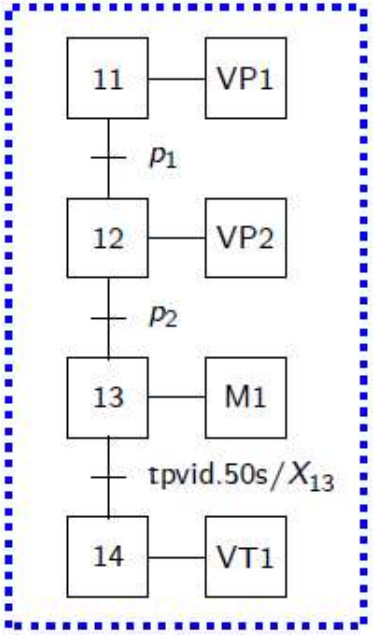
[Foulard, 1997]



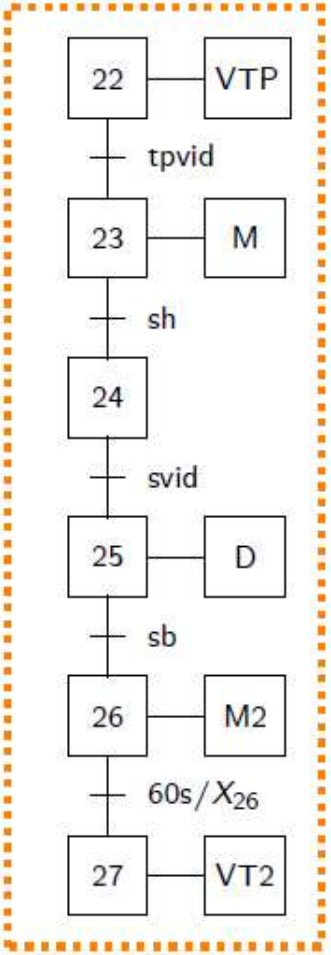
Evaluation



Macro étape M10



Macro étape M21



Evaluation

Comportement permis

- **Activité 1**
  - Ouvrir/fermer la vanne V1 tant que le poids P1 n'est pas atteint. Aucune manipulation permise après.
  - Ouvrir/fermer la vanne VT1 après l'arrêt du moteur M1. Aucune manipulation permise avant.
- **Activité 2**
  - Ouvrir/fermer la vanne VT2 après l'arrêt du moteur M2. Aucune manipulation permise avant.

Quelques attaques effectuées

- Ouverture de VP2 après le démarrage de M1
- Ouverture de VT1 avant l'arrêt de M1
- Enclenchement de M1 avant P2
- Ouverture de VT2 avant l'arrêt de M2

Evaluation

Inférence de spécifications

Activité	Texada 1	Texada 2	Fouille par portées
Activité 1 (242 entrées sur 11 exécutions)	11m15	1m38	45s
Activité 2 (215 entrées sur 8 exécutions)	10m6	1m14	55s

Plateforme : Intel Dual Core i5 2.4 GHz , 4Go de RAM
Texada : [Lemieux, 2015]

Détection d'attaques

Alert	Type	Properties violated	Interpretation
Alert 1 (act. 1)	TP	$absence\_between(m1^{\uparrow}, p1^{\downarrow}, vp2^{\uparrow})$ $absence\_between(m1^{\uparrow}, p2^{\downarrow}, vp2^{\uparrow})$	*vp2* opened after starting *m1* (attack)
Alert 3 (act. 1)	FP	$absence\_global(vt1^{\downarrow})$ $absence\_after\_until(m1^{\downarrow}, p1^{\downarrow}, vt1^{\downarrow})$	*vt1* closed after *m1* is stopped (legitimate action)
Alert 5 (act. 2)	TP	$absence\_before(m2^{\downarrow}, vt2^{\uparrow})$	*vt2* opened before the end of the mixing task (attack)

* TP : True Positive, FP : False Positive

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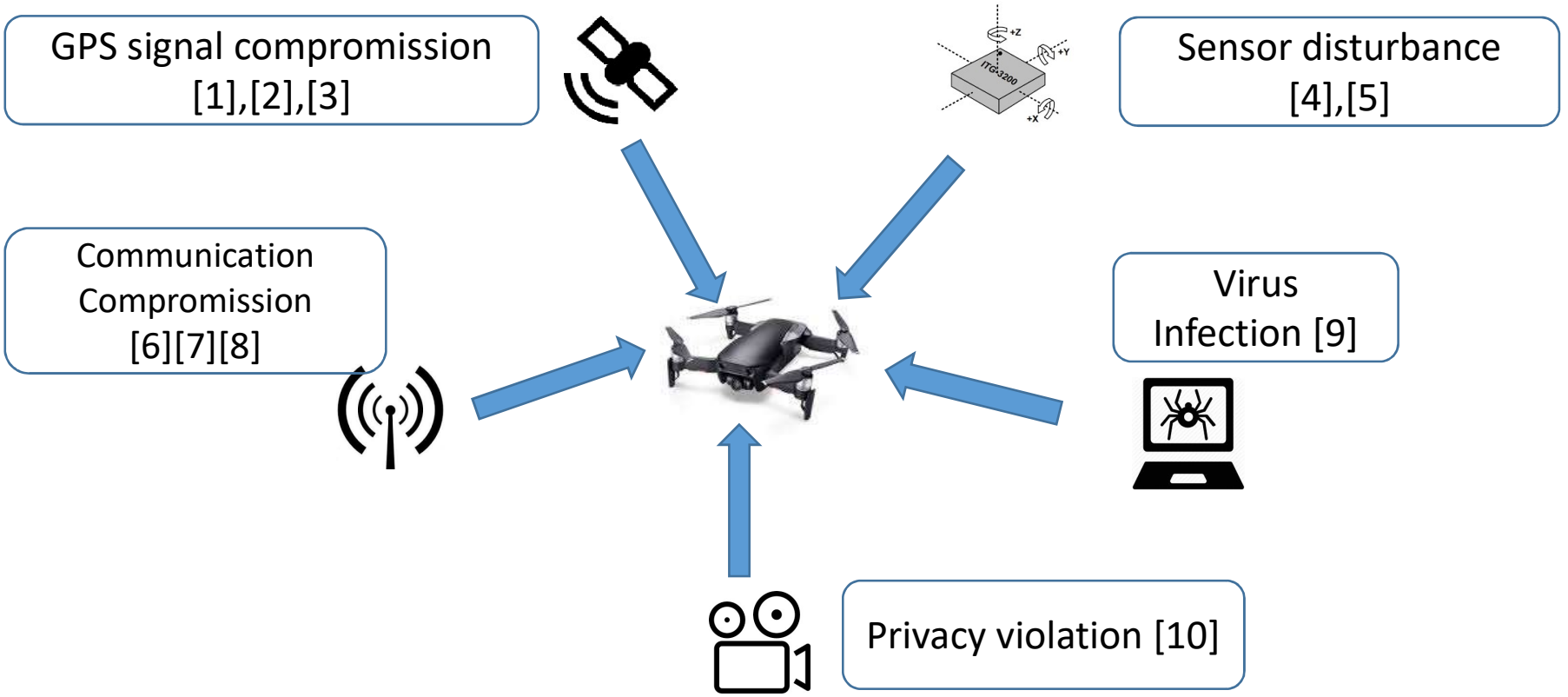
Cyber-security of flying drones

Vulnerability of the drone:



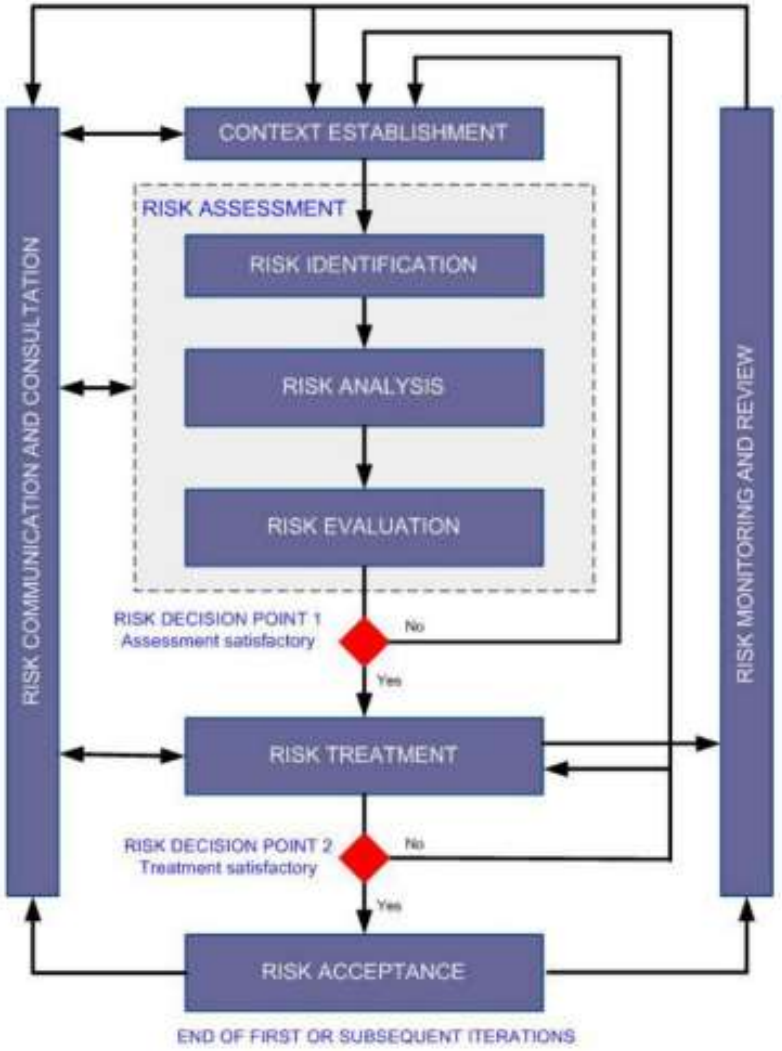
Need of a methodology to get a cartography of the drone security in a systematic way and to ensure completude

Methodologies in the industrial domain

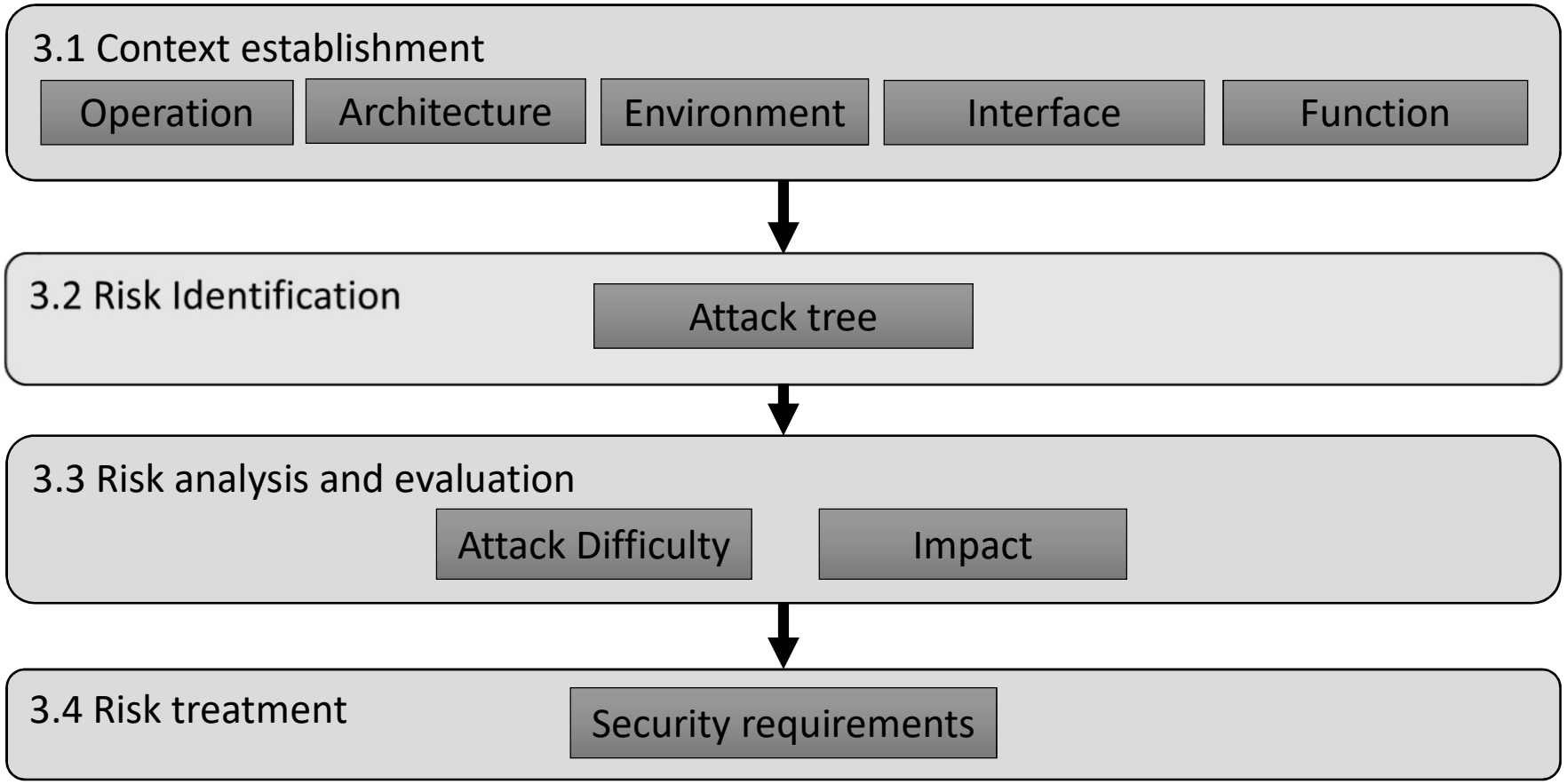
- **ISO27005 Standard**: Information security risk management [11].
  Propose a work-flow[12]

- **MEHARI[12]:**
  - IT Security in companies
  - Databases
  - Security Evaluation Tools

- **ED202A/DO326A Standard:**
  - Avionics security
  - During the processus of aircraft development



Proposed methodology



Example of Steps of the methodology

Operation Description – based on SORA, Risk Assessment for unmanned airborne Mobility **[15]**

- How, when, where and under which constraints the system runs
- Automation level of the system and operators involvement
- Procedure for operation, maintenance
- Procedure for safety

Steps of the methodology

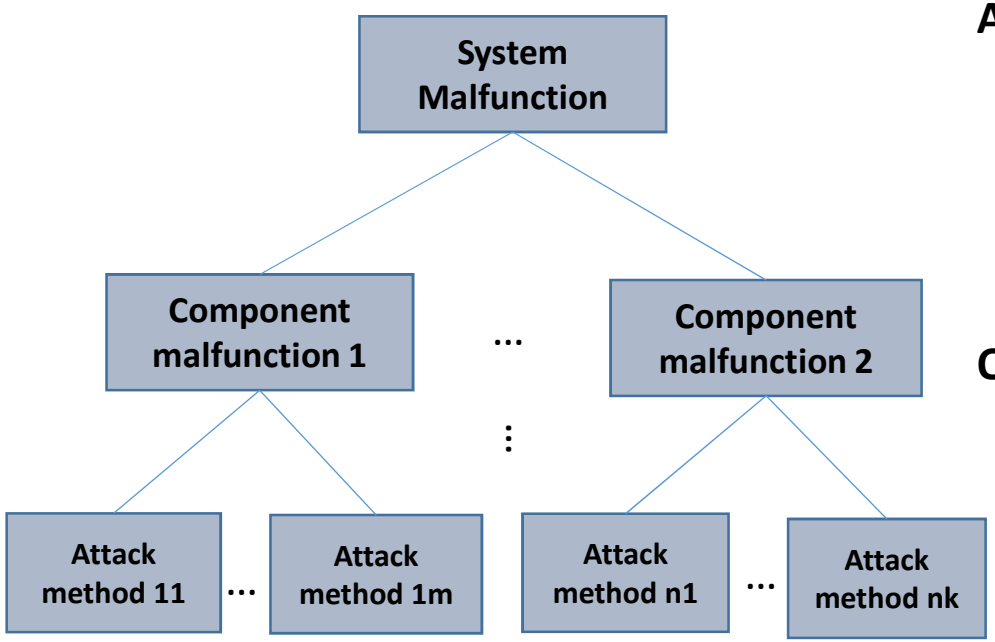
Interface [based on DO 202 standard]

- List of *entry points (inputs)* of environment elements interacting with the system
- Details of data flows crossing each interface
- Details the elements of the security environment for each interface

Steps of the methodology

3.2 Risk Identification

Attack tree



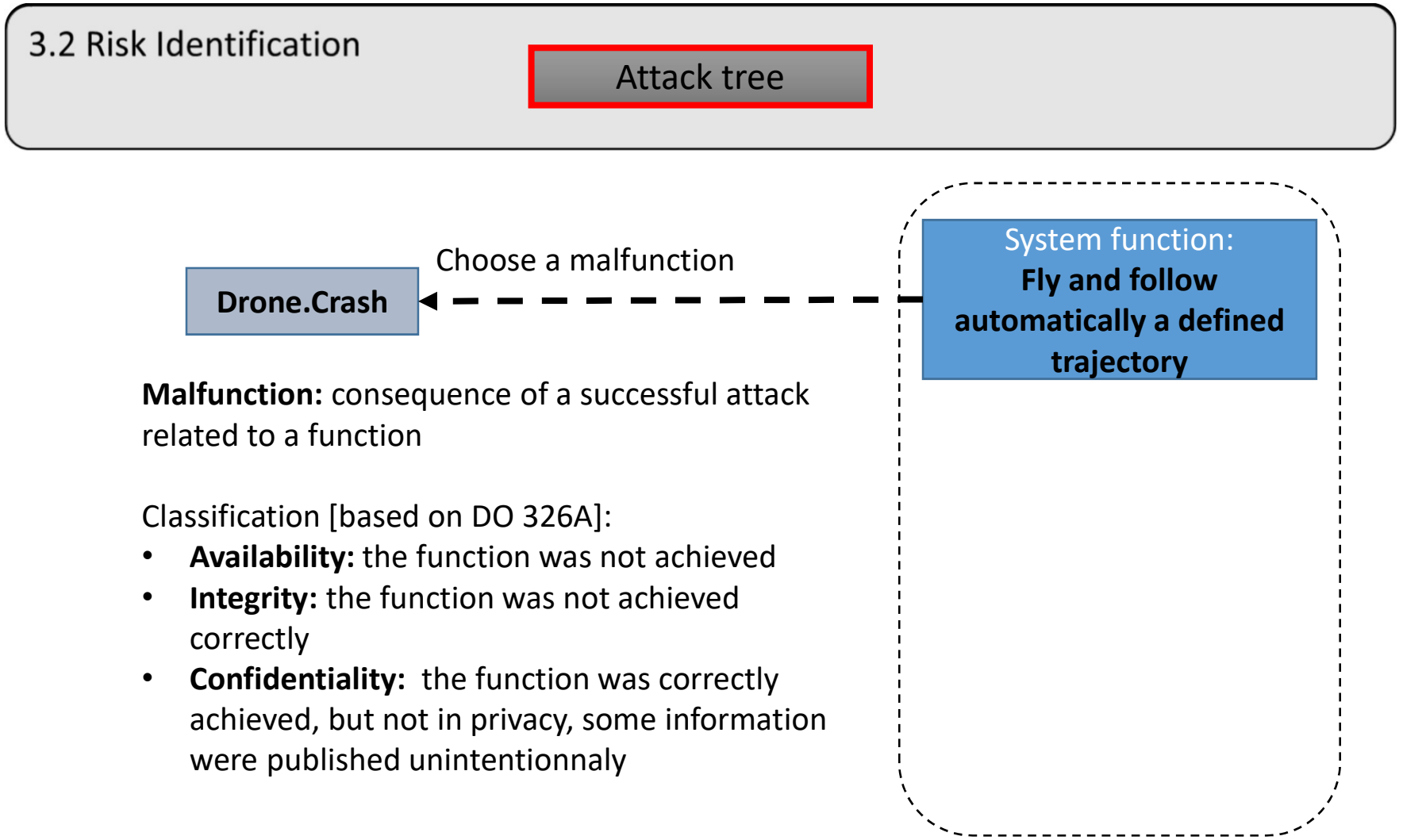
Attack tree:

- Presented by B. Schneier (1999)[17]
- Deductuve reasoning
- Used in various applications : cars [14], aeronautics [19], Smartgrids [18], Drones [20]

Objectives

- List of the risks
- Understand the risks
- Facilitation of the steps of definition of security exigences

Steps of the methodology

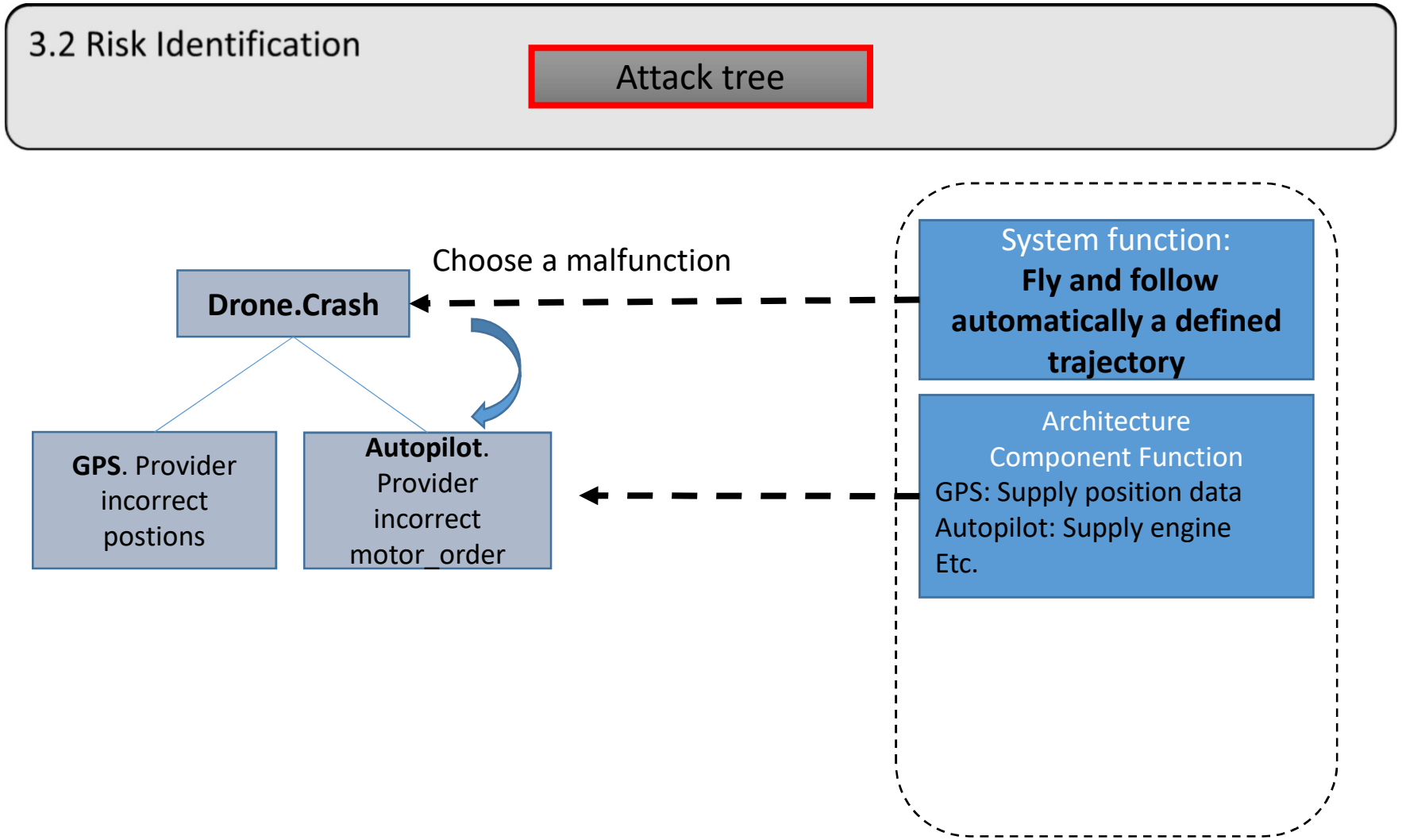


Malfunction: consequence of a successful attack related to a function

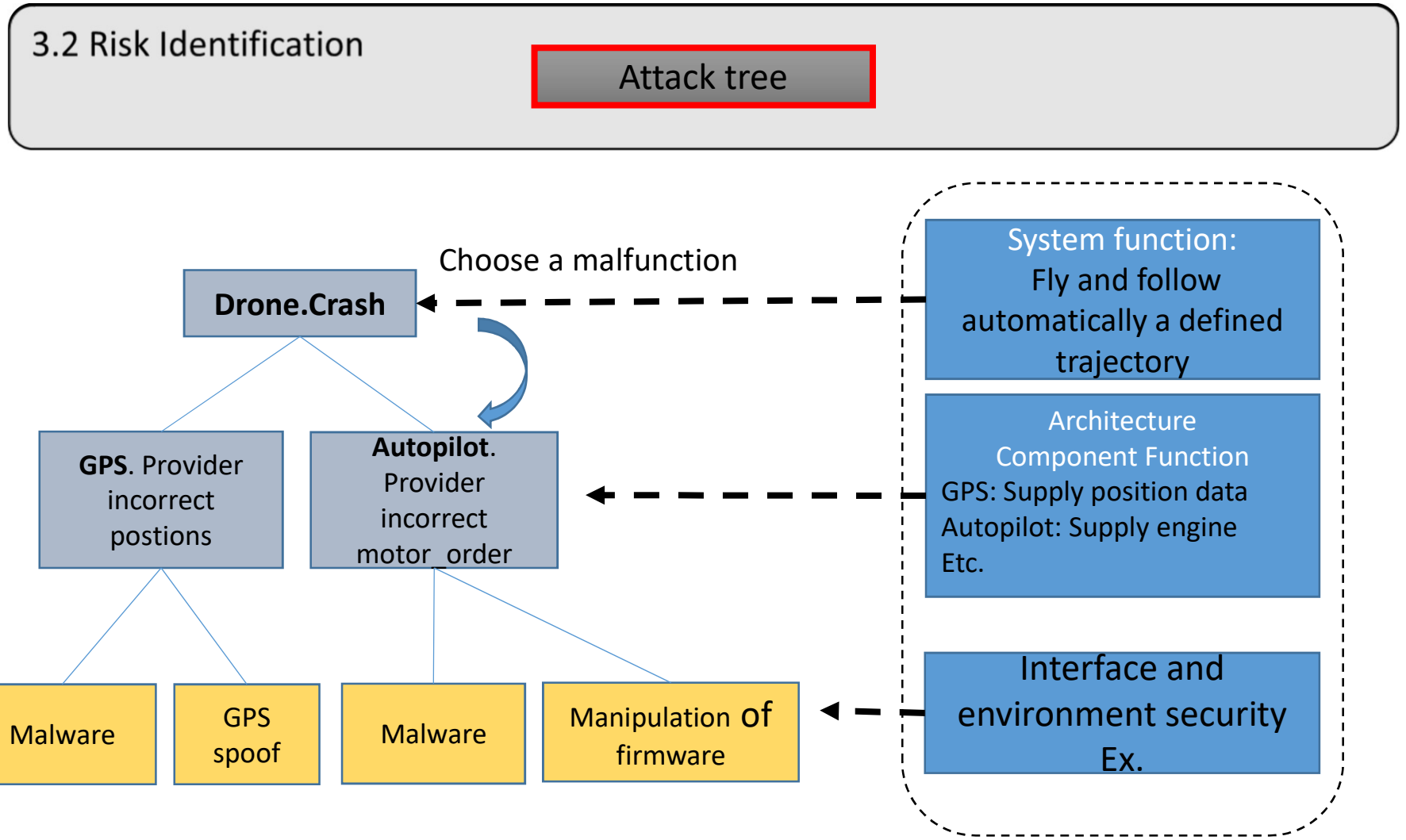
Classification [based on DO 326A]:

- **Availability:** the function was not achieved
- **Integrity:** the function was not achieved correctly
- **Confidentiality:** the function was correctly achieved, but not in privacy, some information were published unintentionnaly

Steps of the methodology



Steps of the methodology



Steps of the methodogy

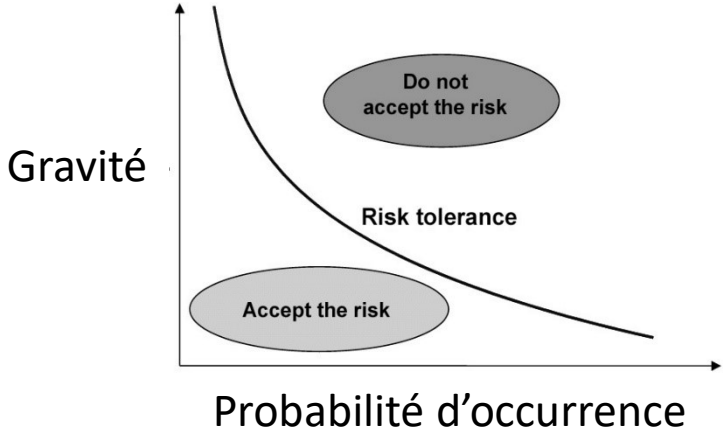
3.3 Risk analysis and evaluation

Attack Difficulty | Impact

Analyse et évaluation

- Décider quels risques doivent être traités avec quelles propriétés
- Analogie avec la sûreté de fonctionnement
- Donner la décision basée sur deux éléments: probabilité de risque et gravité de l'impact
- Gravité de l'impact : retour d'expérience

→Problème : pas de retour expérience pour l'analyse probabiliste



La question n'est pas seulement la probabilité d'être victime d'une attaque.
La question est que l'on veut se protéger d'une attaque considérée comme suffisamment probable, pour laquelle nous nous intéresserons à la difficulté d'attaque

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Approaches: Modelling and Evaluation

- Complexity
- Methods and tools, graph-type
  * Automata
  * Queues
  * Petri Nets (MocaRP, DesignCPN,…) and extensions (colored, stochastic, timed, aging tokens…)
    Study of marking or occurrence graphs
    Detection of catastrophic states
    Study of scenarios leading to these states
  * Stochastic Activity Networks (Möbius)
  * Network simulators (OpNet, Network Simulator NS3)
- Probabilist approaches
  * Markov Chains, graphs
  * Distributed Dynamic Bayesian Networks

Approaches: Modelling and Evaluation

True-Time

- Co-design approaches
- Hybrid systems simulation (soft co-simulation)
- BUT, Simplified model of the network

Monte-Carlo Simulation

Co-simulation

- Soft co-simulation, SITL (Software in the Loop)
  (interaction between software, ex: OpNet & Matlab)
- Hard co-simulation, HITL (Hardware in the Loop)
  (interaction with hardware devices)

Conclusion

- Dependability and safety (SIL level)
- Dependability of dynamic systems
- Components (hardware and software)
- Network
  - Independent communication links
  - Actual network
- Physical Architecture (topology)
- Functional architecture (Common Cause Failures)
- Intelligent-based architecture
  - Complexity
  - Integration of diagnosis and/or security devices
- Cyber-security issues for critical applications

Conclusion

Evaluation of the dependability of a networked control system
- Multi time-scale and hybrid
- Transient « failures »

State of the system, dynamic aspects

Critical information

Integration of approaches
- SITL
- HITL

No magic formula

Give priority to formal approaches, whenever possible

Still some scientific deadlocks with societal implications…

ANSSI

Conclusions on Cyber-security of CPS

- New issues
- Integration of the IT and ICS worlds (convergence)
- Double culture (computer science/engineering and automation)
- Behaviour of the system
- Security of the Communication/Information system => Safety of the networked control system
- Implementation of cryptography
- In-depth security

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Merci pour votre attention

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