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UGA Université Grenoble Alpes

Concept of Industry 4.0: PLC network extensions and Real Time Networks

Asean-Factori 4.0 project

Grenoble-Valence , May 12.05.2022

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Condensed CV

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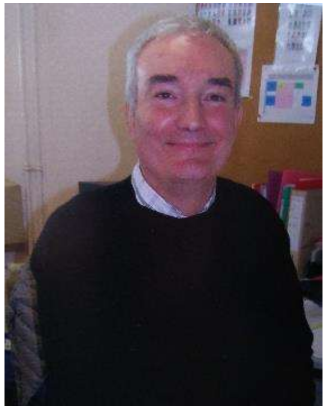

-1993- Docteur (Ph.D.) Applied Physics from Joseph Fourier University
former name of Grenoble University Alpes
-1995 Teams for ESISAR engineer school foundation in Valence - Grenoble INP.
Head of the Electronics Department new curricula include 6 month Industrial project
-1998 New challenge Telecoms chair for the creation of the Telecoms and Networks Dpt.
IUT – Valence : Technological Institute in the University Grenoble Alpes.
- 2002- Founder and Head of the Administration and Security Networks Bachelor.
- 2010 to 2013 President of all French Networking and Telecommunication Departments
Design the new curricula for 29 Departments (still applied in 2021).

Research
-1996, one of three founders of the LCIS Laboratory first research labs in Valence.
ID: EA 3747 Research laboratory with 30 permanents researchers (ERC , MIT-35 Etienne Perret)
and up to 40 PhD Post Doctorate, internships students,..
Contributions research : Embedded systems and designing new architecture and protocols for some patents
(Fieldbus, low power RF and PLC communication system).

- IEEE, SPIE, ..member and since 2006 EAEEIE European association treasurer
- LCIS leader for several European projects : ITEA2-Osami, Artemis-Arrowhead,
  and Frenchs industrials partnerships : ANR-POUCET, ANR-C3µ, BGLE- ADN4SE,..
  Supervising many industrials PhD : Critical Fieldbus Networks, Smart Buildings, DC autonomous Buildings,..

Contact : Denis.genon-catalot@univ-grenoble-alpes.fr

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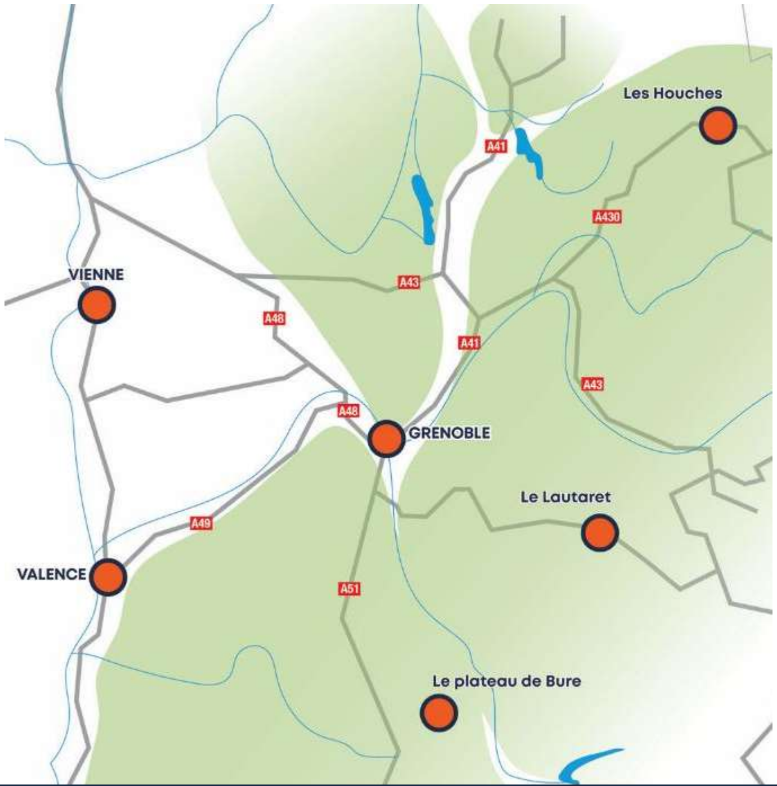
University Grenoble Alpes location and International position

- **56,000** students
- **3,400** PhD students (45% international)
- **7,500** employees, of which
  - **5,500** academic
  - **2,000** staff



Ranking 2020 : 99^{e} position over 1000 Universities

ACADEMIC RANKING OF WORLD UNIVERSITIES SINCE 2003

http://www.shanghairanking.com/Shanghairanking-Subject-Rankings/index.html

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Summary :

UGA-1 From Sensors to PLC :
Requirements for automation architecture

UGA-2. Field bus network
RS232c / RS-485/ Modbus RTU/ Profibus…

UGA-3. Ethernet network
Modbus TCP/ Profibus IP/…

UGA-4. Real time Ethernet
Ethercat/Powerlink/ …

UGA-5. Wireless sensors/actuators
Mbus/LoRa

UGA-6. Unified communications
Informations over the cloud

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2. Automation architecture

Industrial communications will be the common thread of our PLC presentation

Communications : CIM pyramid

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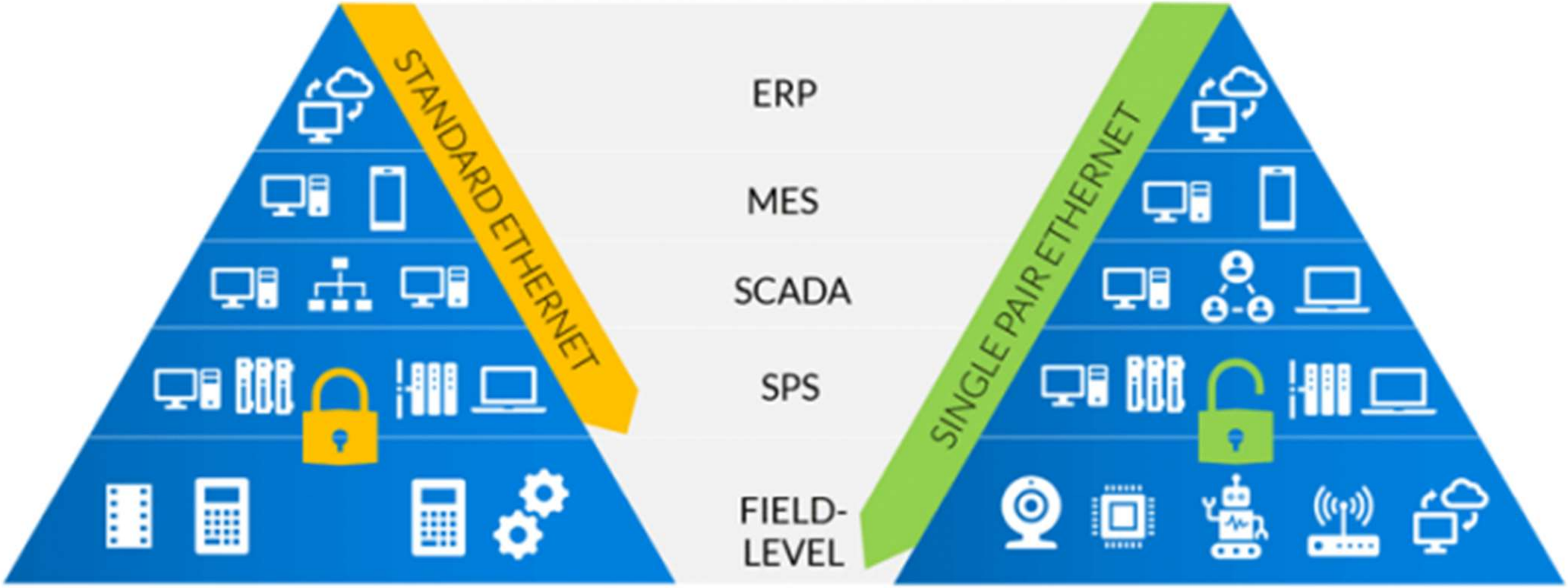

Computer Integrated manufacturing (**CIM**) : Describe integration layers

Example with the actual Ethernet standard (4 twisted pairs)
versus the new Single Pair Ethernet (1 twisted pair)

Small Hydro Power Plant : Automation Architecture

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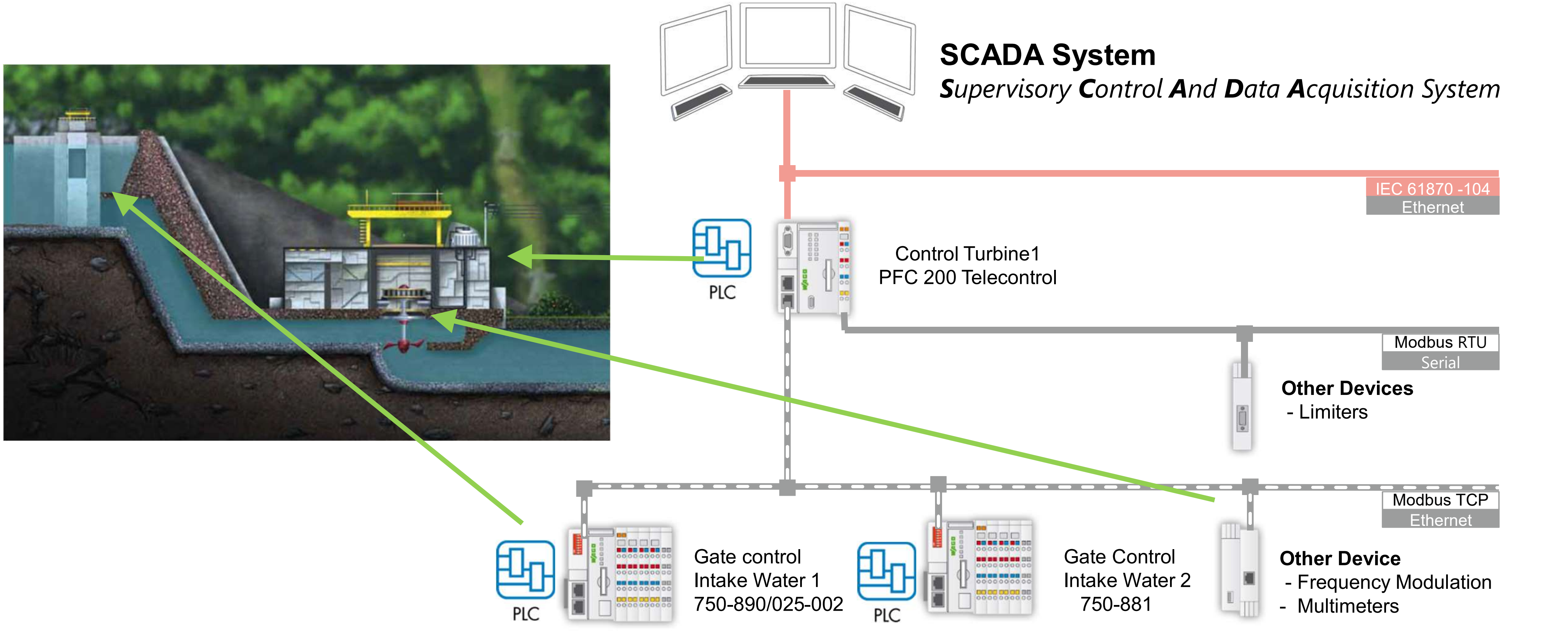

courtesy WAGO

PLC languages: IEC 61131

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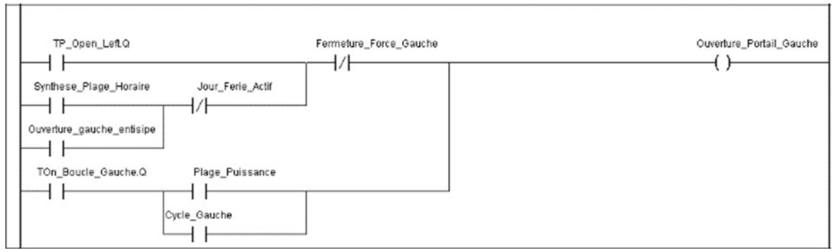

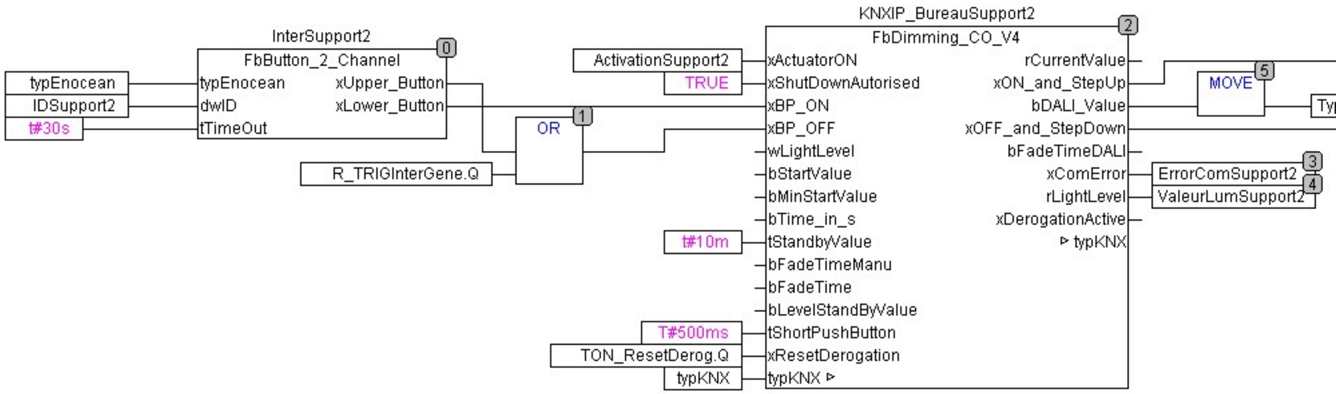

<u>PLC languages according IEC 61131:</u>

- **IL** (*Instruction List*)
- **LD** (*Ladder*, Schematic relais)
- **FBD** (*Function Bloc Diagramm*)
- **SFC** (*Sequence Flow Chart*, GRAFCET)
- **ST** (*Structured Text*)
- **CFC** (*Continuous Function Chart*)

```
(*********Gestion du bit de vie (Requête 6)*********)
TON_Vie(IN:=NOT TON_Vie.Q, PT:=T#5s);
IF TON_Vie.Q THEN
    IF Requete_To_Send=0 THEN
    Requete_To_Send:=1;
    END_IF
    z:=1;
    WHILE Z<Requete_To_Send AND Buffer_Request_To_Send[z]<>6 DO
    z:=z+1;
    END_WHILE
    IF Z=Requete_To_Send THEN
    Buffer_Request_To_Send[Requete_To_Send]:=6;
    Requete_To_Send:=Requete_To_Send+1;
    Start_Com:=TRUE;
    END_IF
END_IF
```

2.2 Intelligent centralized automation

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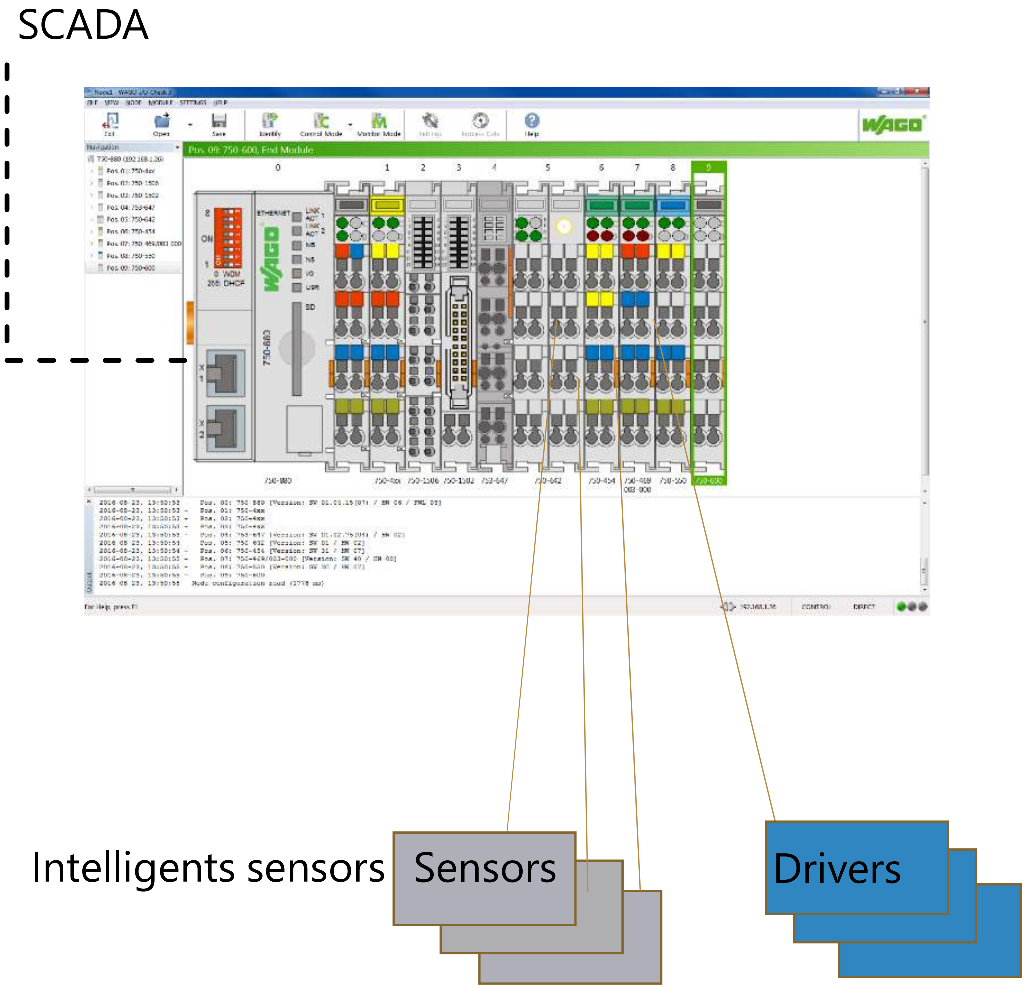

Analog sensors actuators information's become numerical information !

Connexions systems needs to understand each other
....must be more "smart"

Point to point communication protocol with "intelligent" sensors

Protocol specifications for energy metering : Modbus
Binary date exchange with differents ranges

2.3 Communication : physical layer

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TIA : Telecommunication Industry Association
previously
EIA : Electrical Industry Association

ITU-T : International Telecommunicaiton Union - Technical (normalization)
previously
CCITT : Consultative Comity International Telephony Telegraphique

TIA/ EIA ITU-T / CCITT	RS232C V24/V28	RS422 V11/X27	RS485 V11/X27	TTY
Interface	Bipolar	Differential	Differential	Current Loop
Signal level	± 25 V max	± 5 V	± 5 V	0-20 mA
Sensibility	± 3 V	± 0,2 V	± 0,2 V	± 0,4 mA
Distance	10 to 15 m	1200 m	1200 m	1 to 2 km
Maximum throughput	19200 bds	10 Mbds	10 Mbds	19200 bds
Multipoint	Point to point	Point to multipoint	Point to multipoint	Point to multipoint
Nb. Transmitter	1	1	32	
Nb. Receivers	1	10	32	




2.4 Point to point connexion

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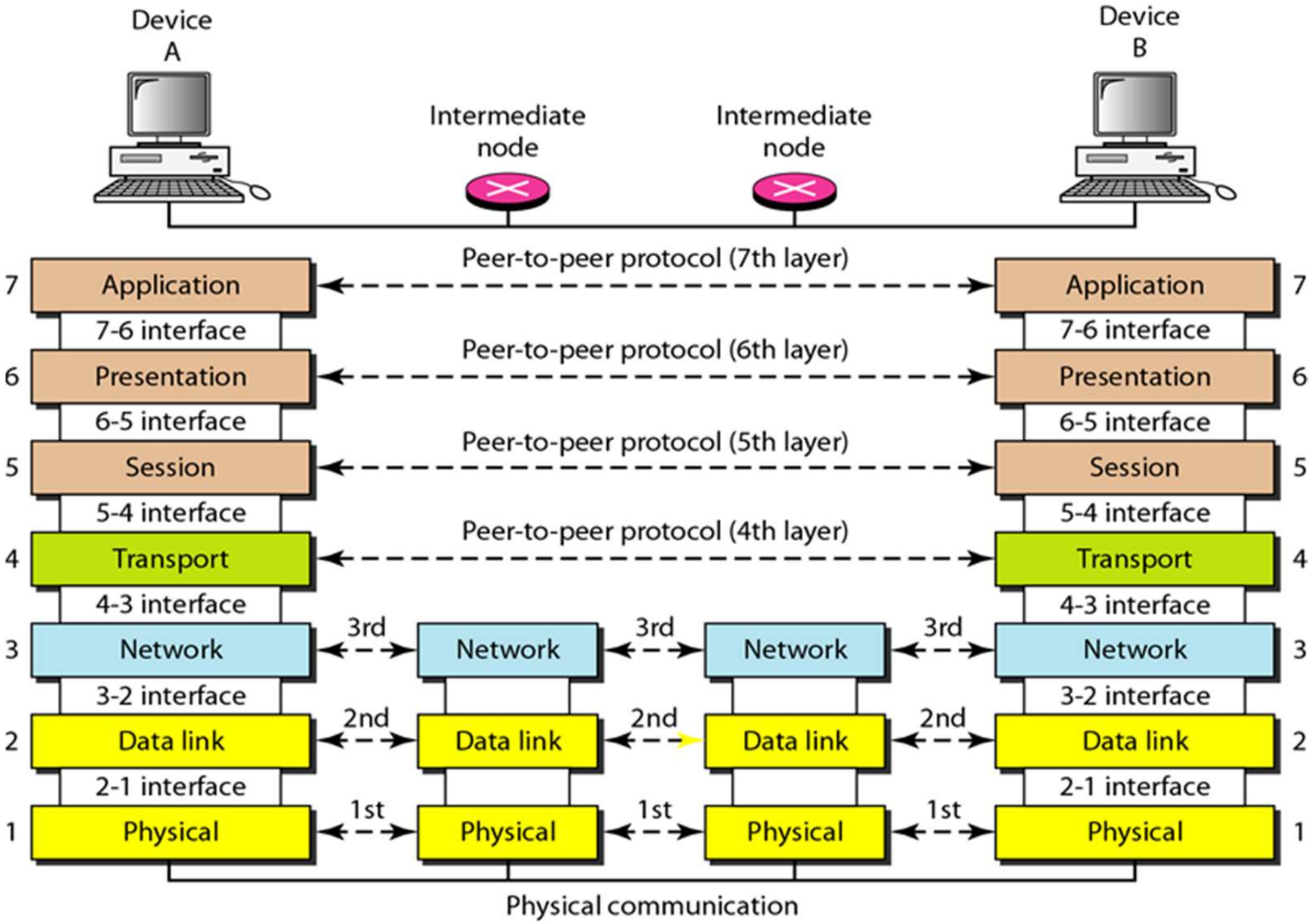

2.5- Network layers protocols map

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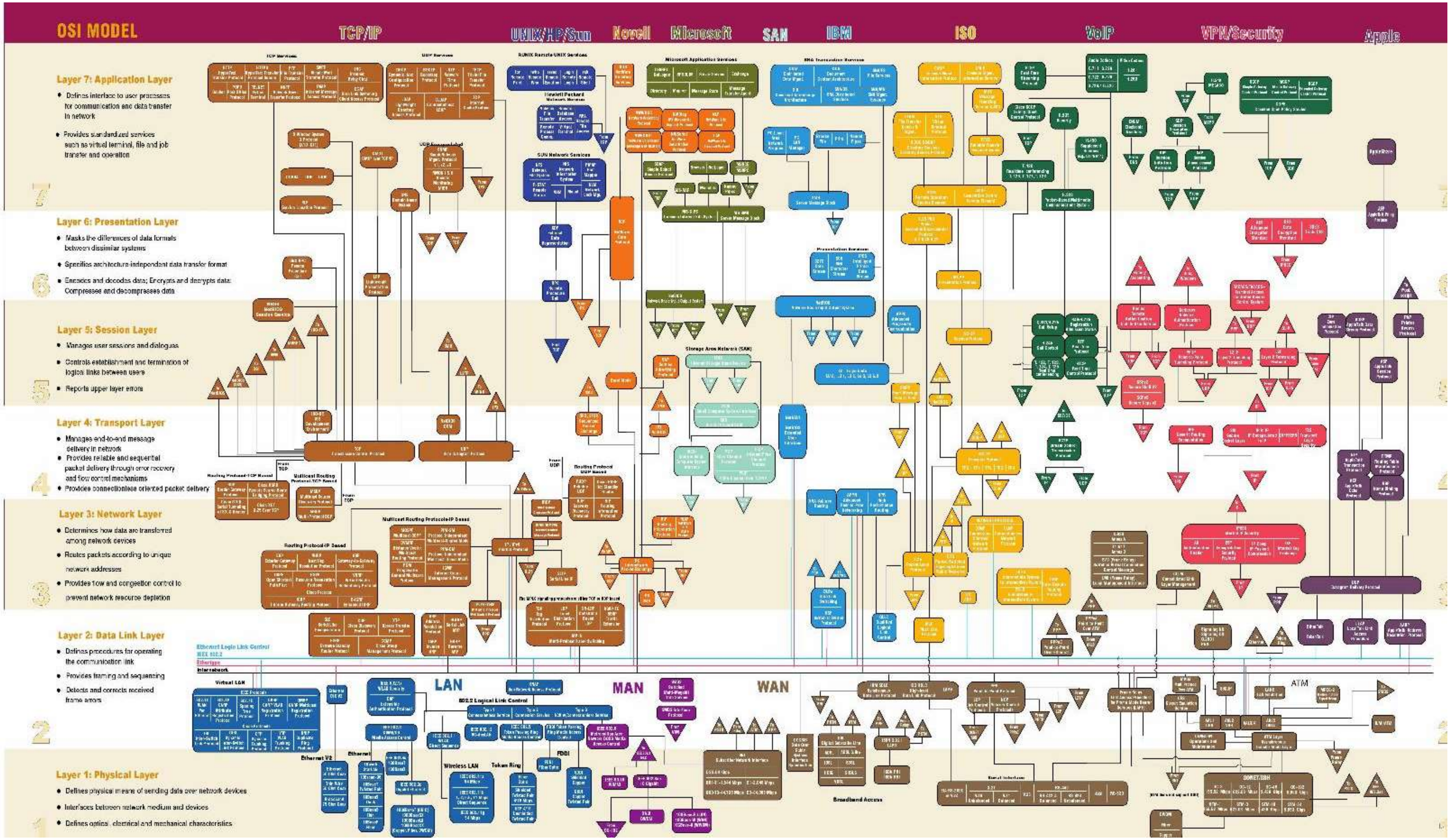

2.6 - Protocols for datas exchange

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STATE-OF-ART NETWORKING

Network Models

TCP/IP MODEL	OSI MODEL	PROTOCOLS
Application Layer	Application Layer	FTP,HTTP,Telnet
	Presentation Layer	JPEG,MPEG
	Session Layer	NFS,SQL,PAP
Transport Layer	Transport Layer	TCP,UDP
Network Layer	Network Layer	IPv4,IPv6
Network Access Layer	Data Link Layer	ARP,CDP,STP
	Physical Layer	Ethernet,Wi-Fi

IP adressing -V4

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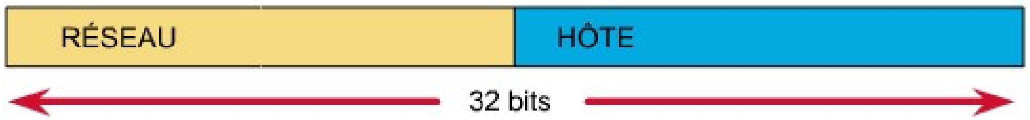
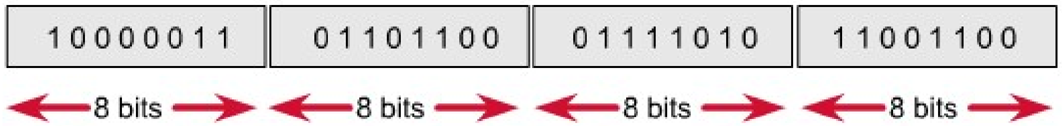
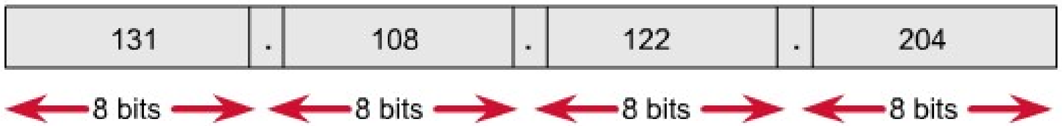
- Adresse Internet Protocole (Version 4 -) :
  - **32 bits address encoded (4 bytes)**
  - **Split in 2 complementary parts :**
  - Network reference number network()
  - Unit/machine host number (host)



  - **Division en groupe de 8 bits (1 octet) séparé par des points**

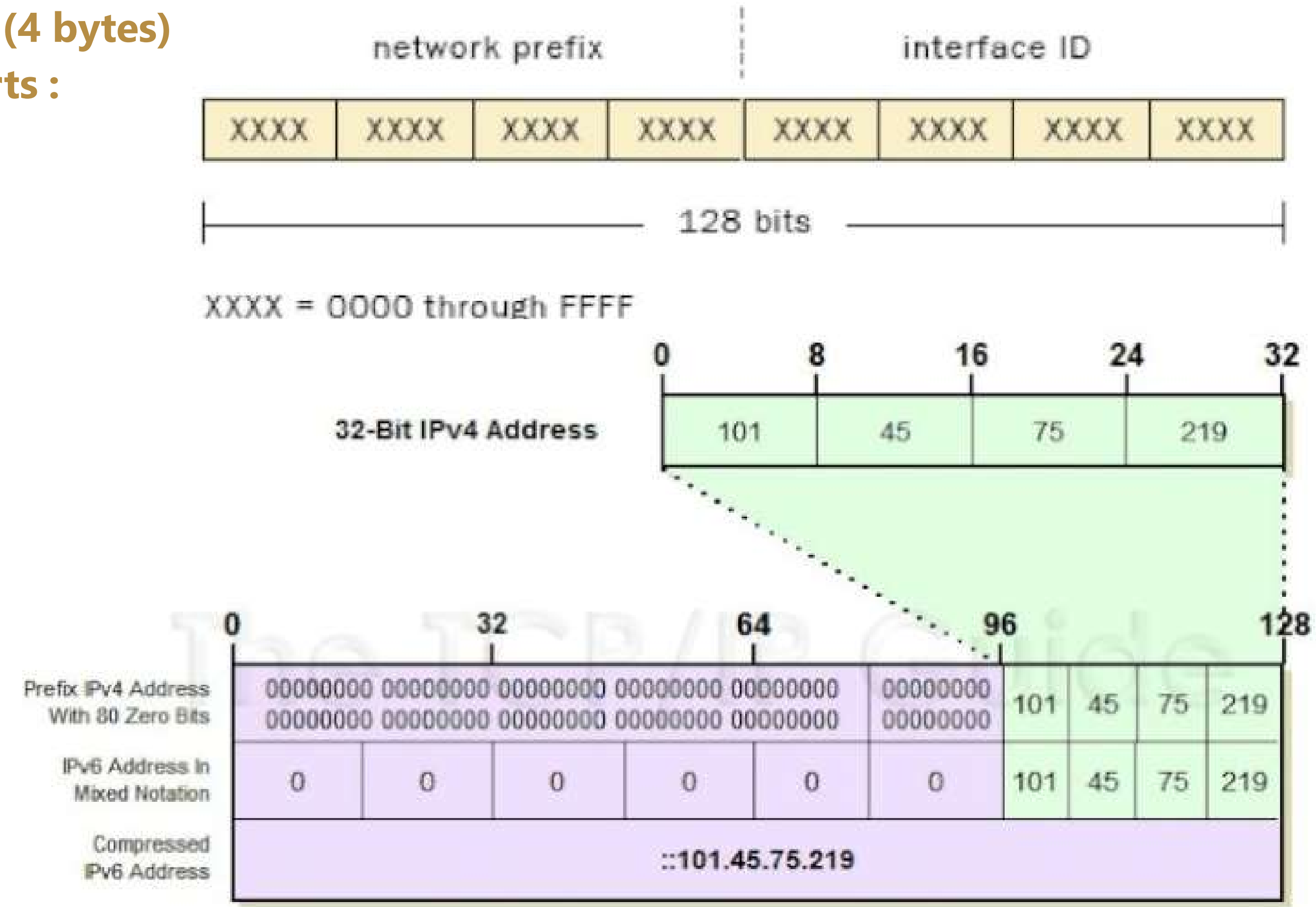


  - **Par souci de simplicité, représentation au format décimal**

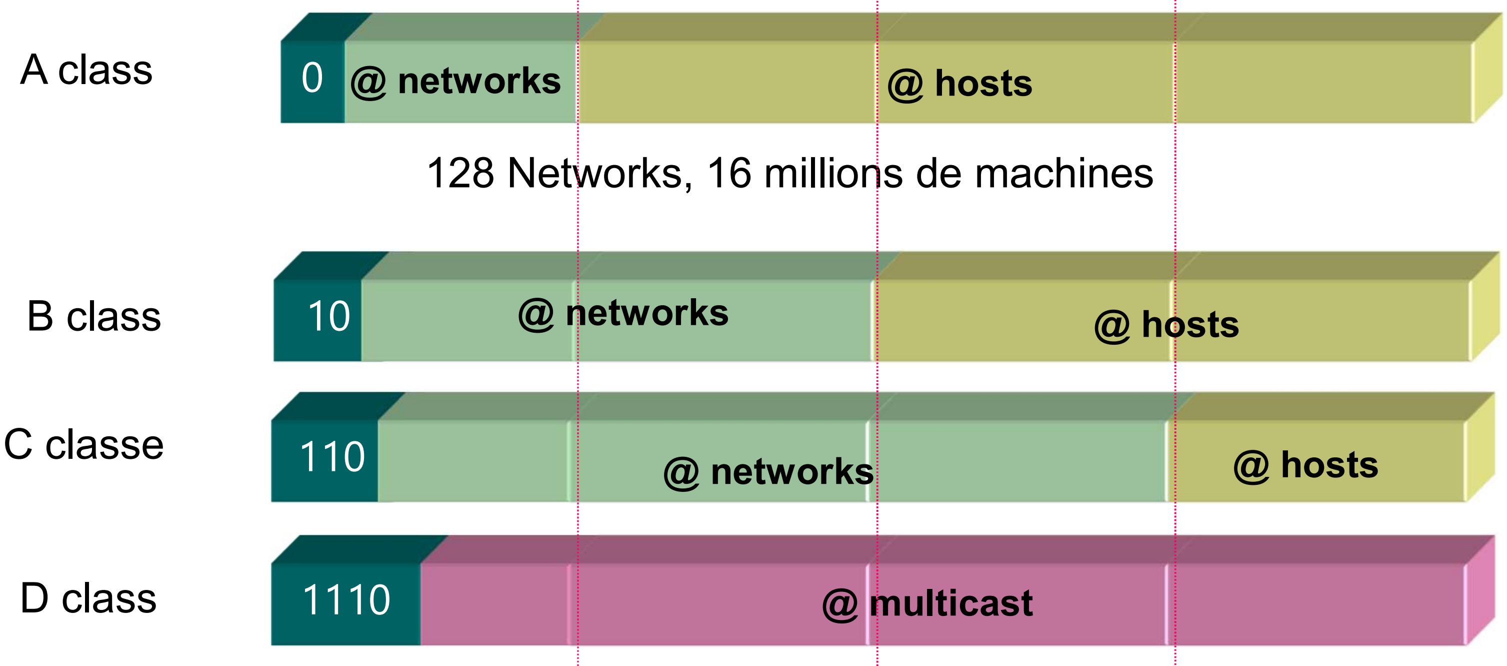


IP adressing –V6

- New Adressing Internet Protocole (Version 6) :
    - **128 bits addressing encoded (4 bytes)**
    - **Split in 2 complementary parts :**
    - Network prefix network()
    - Interface ID Host number (host)



Internet Protocol adresses classes



Dedicated adress: for example in classe A: 0.0.0.0
loopback adresse in class A: 127.0.0.0

Broadcast adress : class A: X.255.255.255

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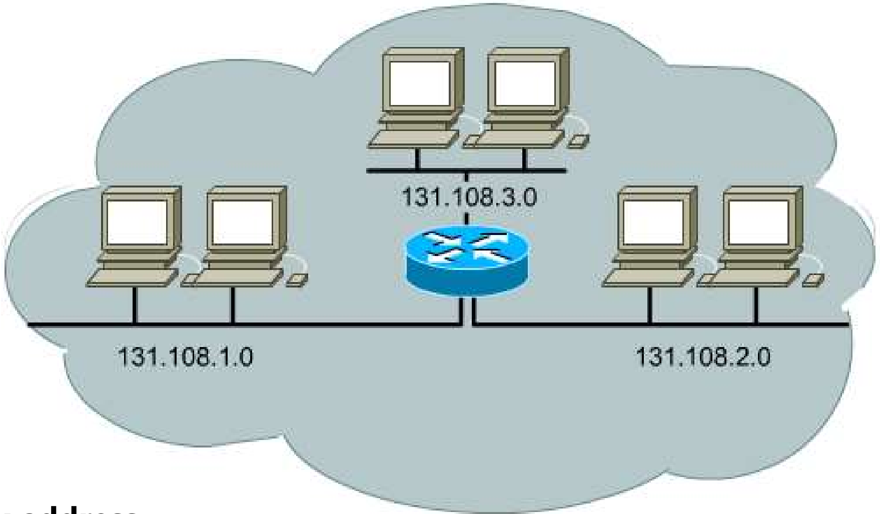
IP Subnets network exemple

- Exemple:
  - **B class** with IP address : **131.108.0.0**, (B class is also define /16)
  - We want to split or local area network (LAN) in **3 subnets class network with the address :**
    - 131.108.1.0 /16 subnet 1
    - 131.108.2.0 /16 subnet 2
    - 131.108.3.0 /16 subnet 3



131 108 03 00

1000.0011 . 0110.1100 . 0000.0011. 0000.0000

Mask / 16

1111.1111 . 1111.1111 . 0000.0000. 0000.0000

Address & Mask / 16

1000.0011 . 0110.1100 . 0000.0000. 0000.0000 Global network address

Hosts

1000.0011 . 0110.1100 . 0000.0000. 0000.0001 1st host (machine)
1000.0011 . 0110.1100 . 1111.1111. 1111.1110 Last host (machine)
1000.0011 . 0110.1100 . 1111.1111. 1111.1110 Broadcast address (for all the host in the network)

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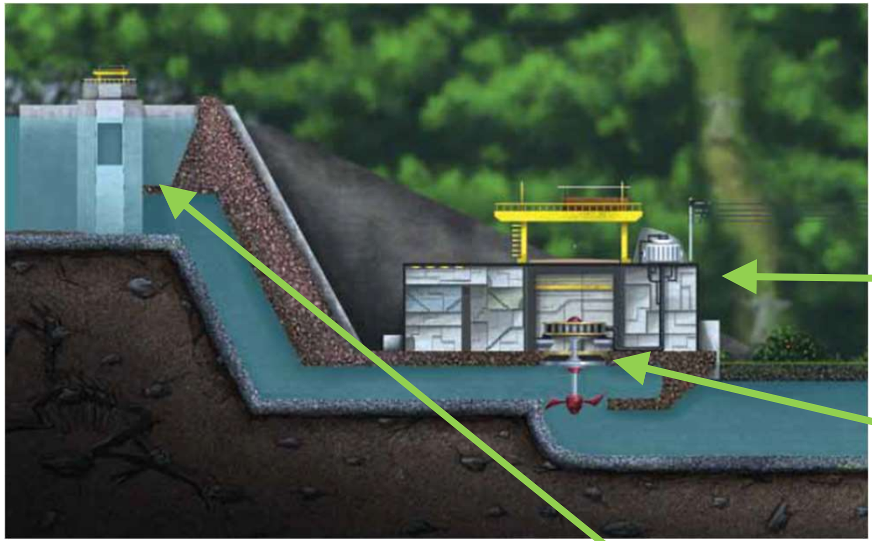
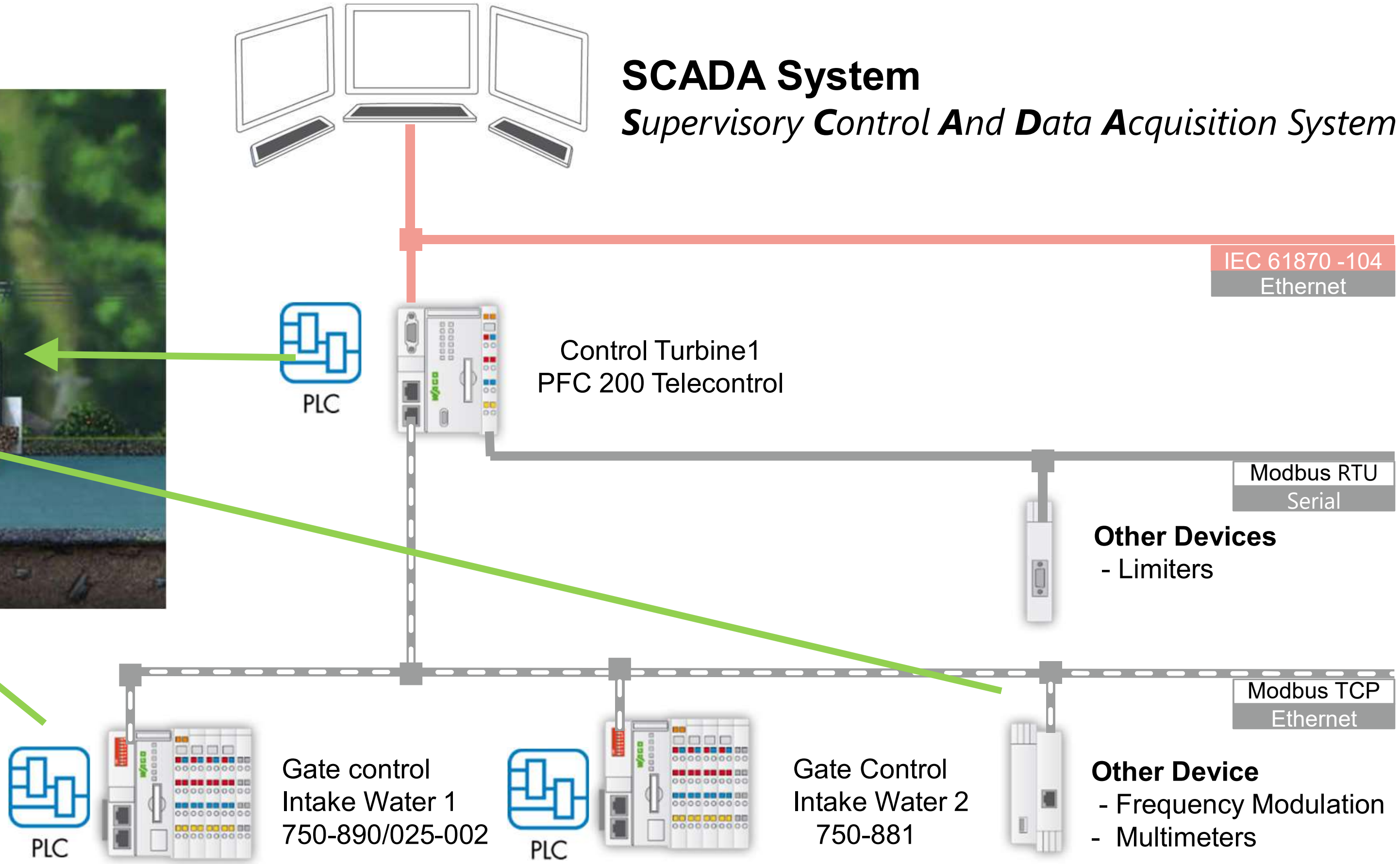
Small Hydro Power Plant : Automation Architecture





courtesy WAGO

2-7 ModBus Protocol

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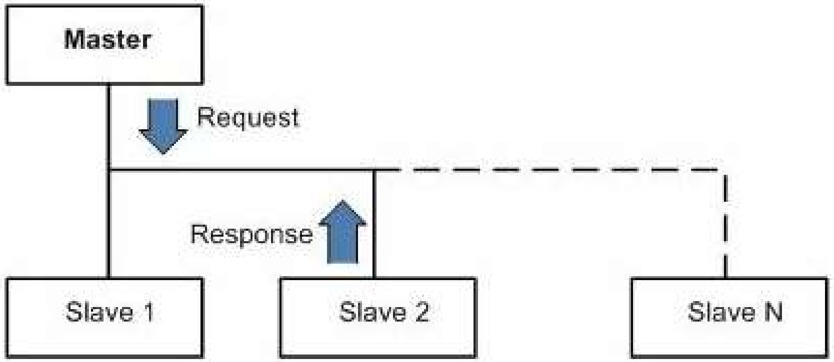
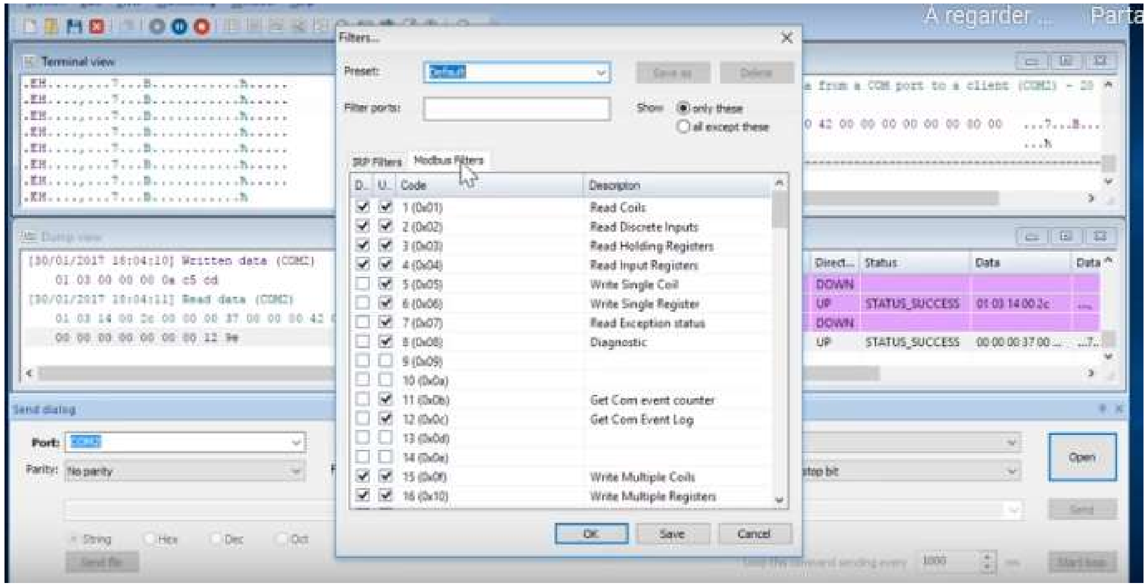
Serial protocol based on master (s) / slave (s) dialogue
Data exchange with “Request / Response”





Extension on Internet protocol
Internet Protocol based on Client / Server dialogue

Data exchange in the form “Request / Response”

Most PLC support both Client/Server modes

2-8 Modbus frames

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First and simple implementation

ASCII Mode

ASCII : American Standard Code for Information Interchange

Start sequence	Address	Function	Payload Data	LRC	End sequence
“:”	1 Byte	1 Byte	Nb Bytes	1 Byte	“CR + LF”

95% of deployed installations

RTU Mode

RTU : Remote Terminal Unit

Start sequence	Address	Function	Payload Data	CRC	End sequence
3.5 Ts	1 Byte	1 Byte	Nb Bytes	2 Bytes	4 Ts

2.10- Modbus frames

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Basic Frame layer Link layer independent

- PDU :

  (Protocol Data Unit)

Code Function	Data

- ADU : RTU

  (Application Data Unit)

Address	Modbus PDU	CRC

- ADU : TCP

Transaction	Protocol	Length	Unit ID	Modbus PDU

  (Transmission Control Protocol
  .....over Internet Protocol)

2-9 Modbus – Simple configuration link layer

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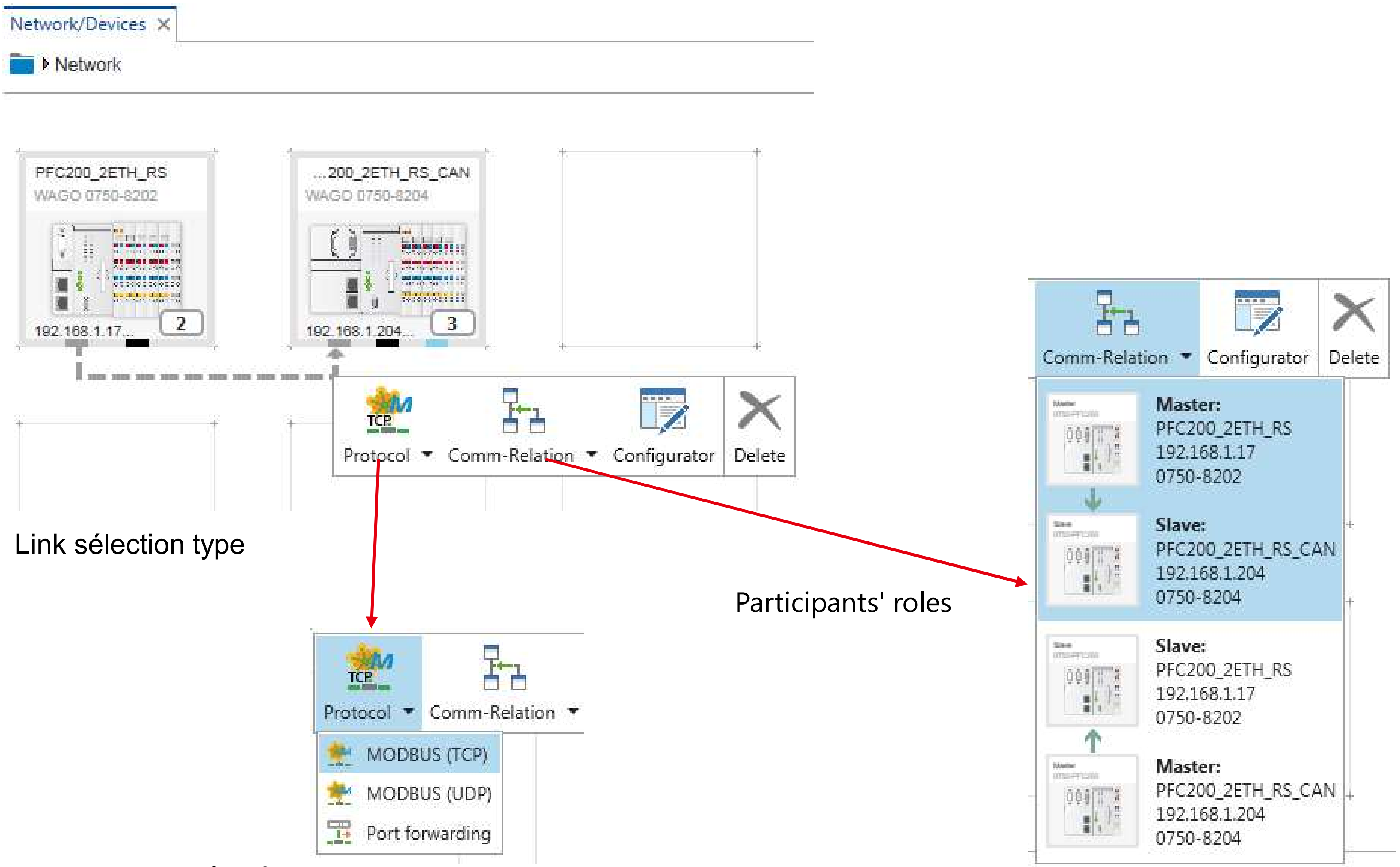

2.11- Modbus bridging

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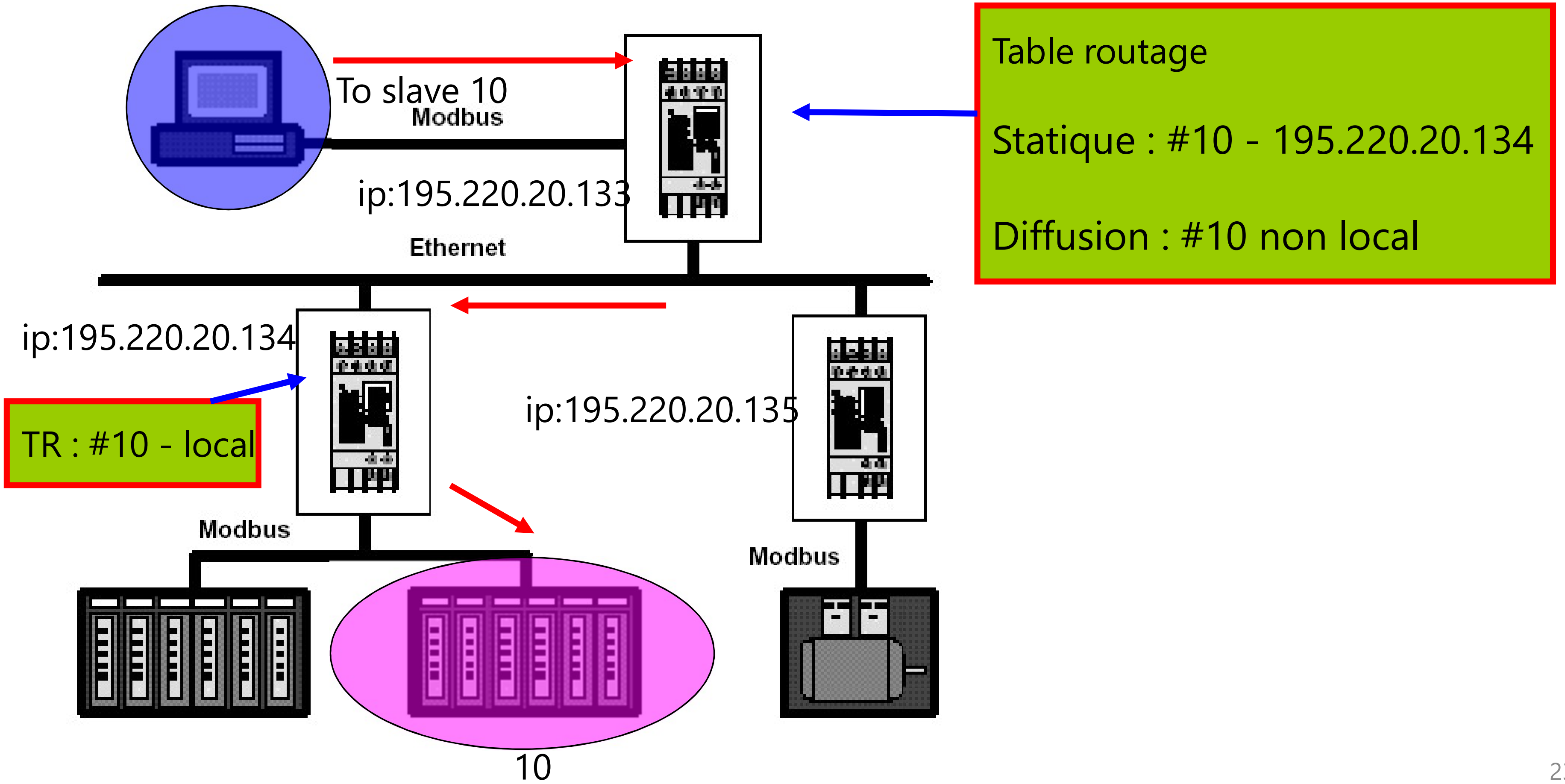

3-Fieldbus specifications : IEC 61158/ 61784 series Industrial communication networks

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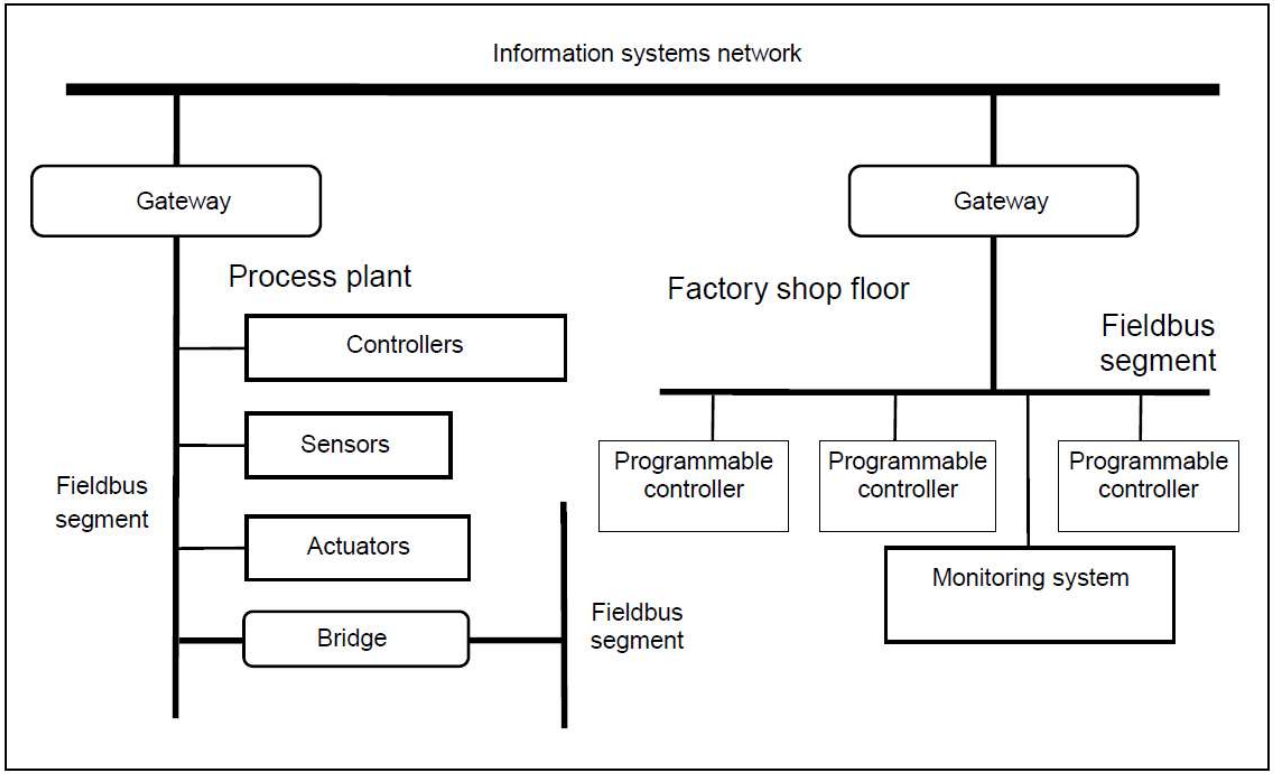
Industrial process measurement and control
Data communication networks
Multilayer applications



3.1 Protocols normalized by IEC 61138/ 61784

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	Name	Vendor
1.	Fieldbus Foundation,	EU
2.	ControlNet, EtherNet/IP, DeviceNet	ODVA
3.	PROFIBUS, PROFInet	Siemens
4.	P-Net,	Danmark
5.	WordFIP	Alstom, Cegelec
6.	INTERBUS	Phoenix Contact
7.	Swiftnet (retired)	Boeing
8.	CC-Link	Mitsubishi
9.	HART	Hart
10.	Vnet/IP	Yokogawa
11.	Tcnet	Japon
12.	EtherCAT	EtherCAT group
13.	ETHERNET Powerlink	Open source
14.	EPA	Chine
15.	MODBUS-RTPS	Schneider
16.	SERCOS	Sercos
17.	RAPIEnet	Korea
18.	SafetyNET p	Pilz Gmbh

All these protocols are incompatible each other
IP gateway is the solution to transfer data

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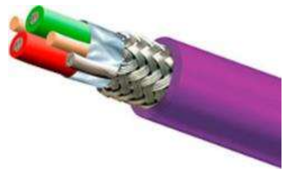
3.2 Profibus – Serial Bus

In 1987, in Germany, 21 companies (mainly Germans including Siemens)) and institutions joined forces to work on a project called "field bus". The goal was to develop a serial communication field bus.
These association members have agreed on a common technical concept for production and for automation.
First denomination : Profibus-PA (Process Automation)
For highly communicative tasks, the Profibus-FMS (Field bus Message Specification) protocol, which is particularly complex, was specified.

In 1993, the Profibus-DP (Decentralized Peripherals) protocol improved its predecessor in terms of simplicity and above all speed.

Profibus is part of the IEC 61158 recommendation.

Communication over twisted pair RS-485 type (characteristic impedance 150 ohms)
Data transmission support numerical base band in NRZ mode on physical medium.



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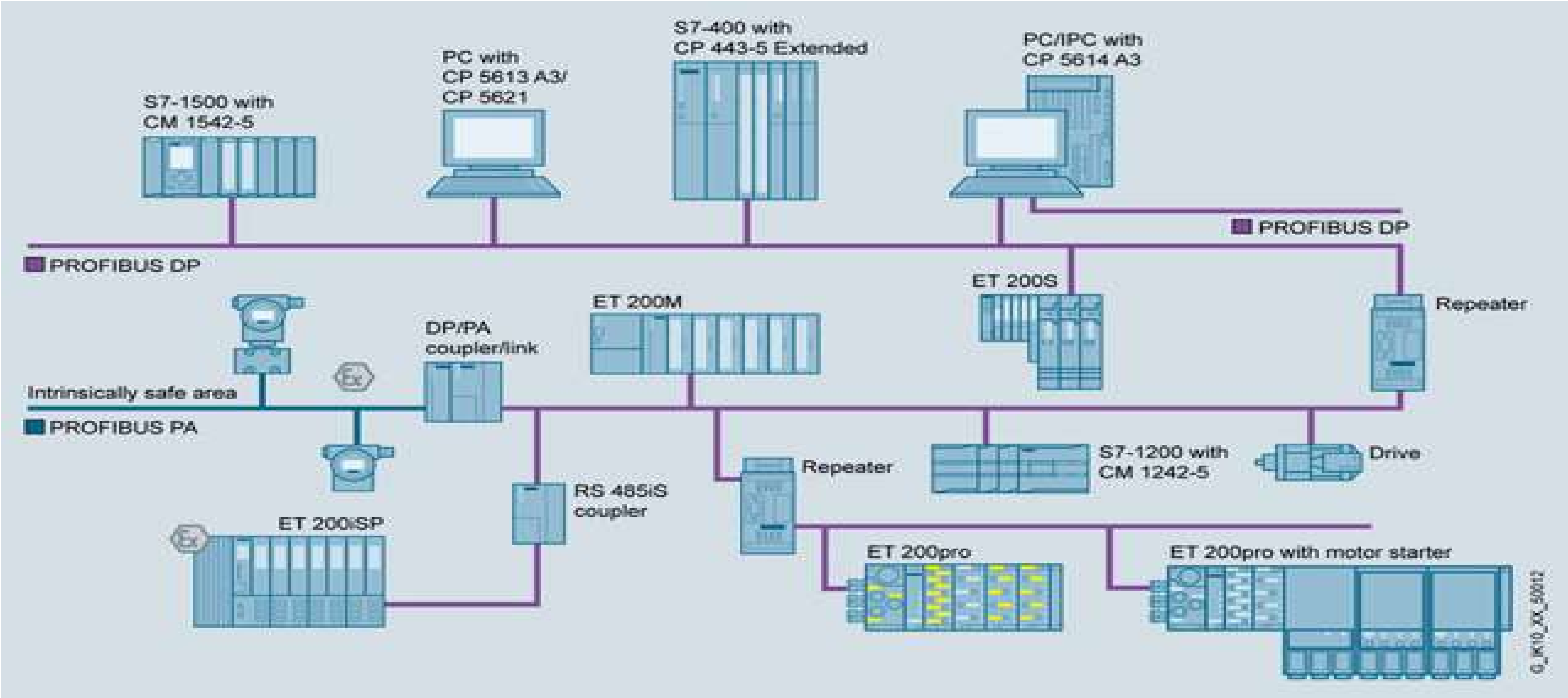
3.3 Profibus DP/ PA

Bus or tree topology with repeaters
RS– 485 transmission line



courtesy SIEMENS

3.4 Profibus DP : Ethernet version

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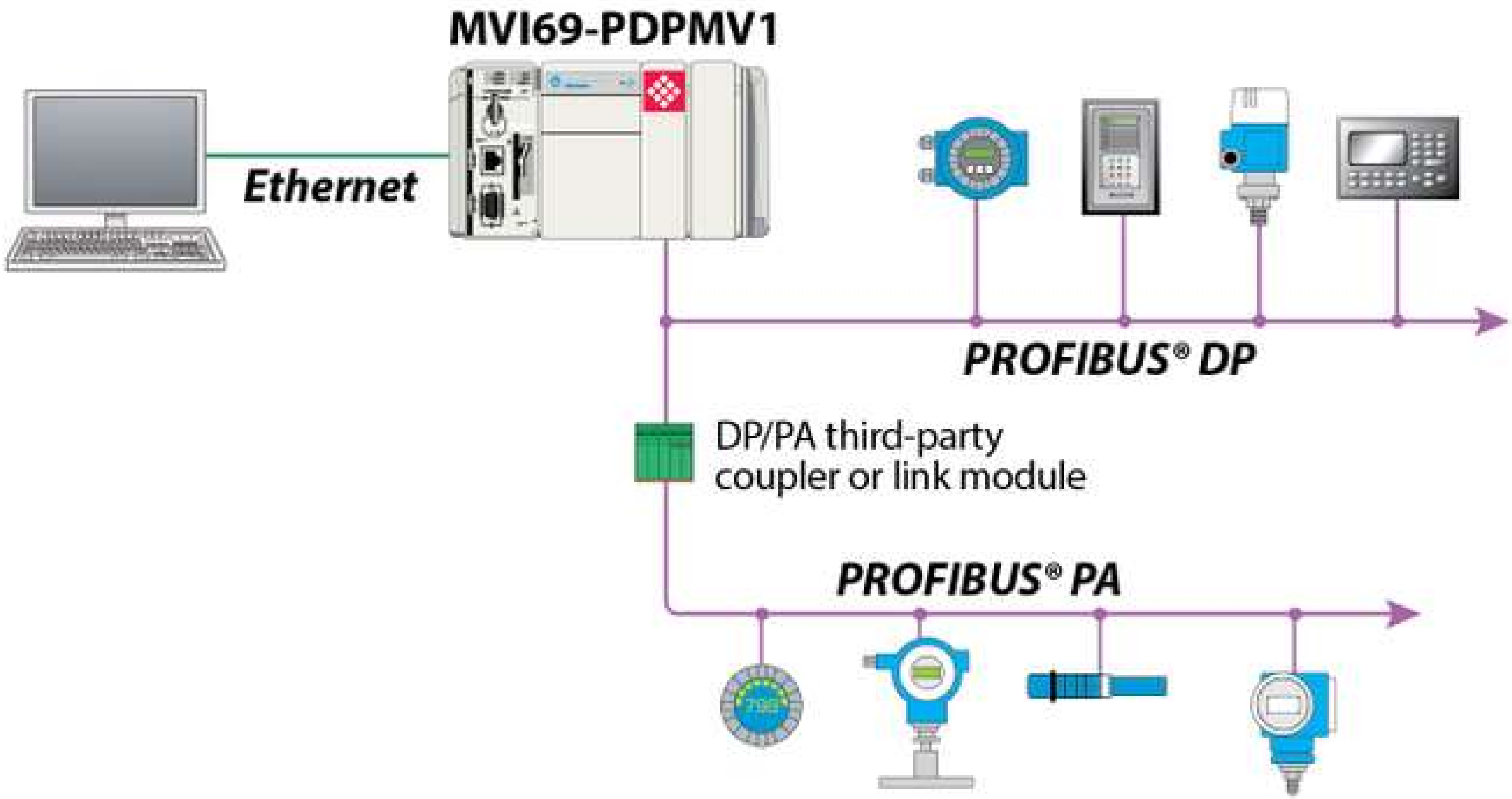
Profibus-DP for Decentralized Peripheral bus is used "real-time" deterministic control of sensors and actuators by performing automation and regulation functions on PLC.

Used for the connection of a "distributed intelligence",

Communication between several PLCs (with each other analog and digital input/output) supporting PROFIBUS-FMS.

Data rate reach up to 12 Mbits/s on
Twisted pair : STP, UTP, FTP or optical fiber.



4. Industrial Ethernet

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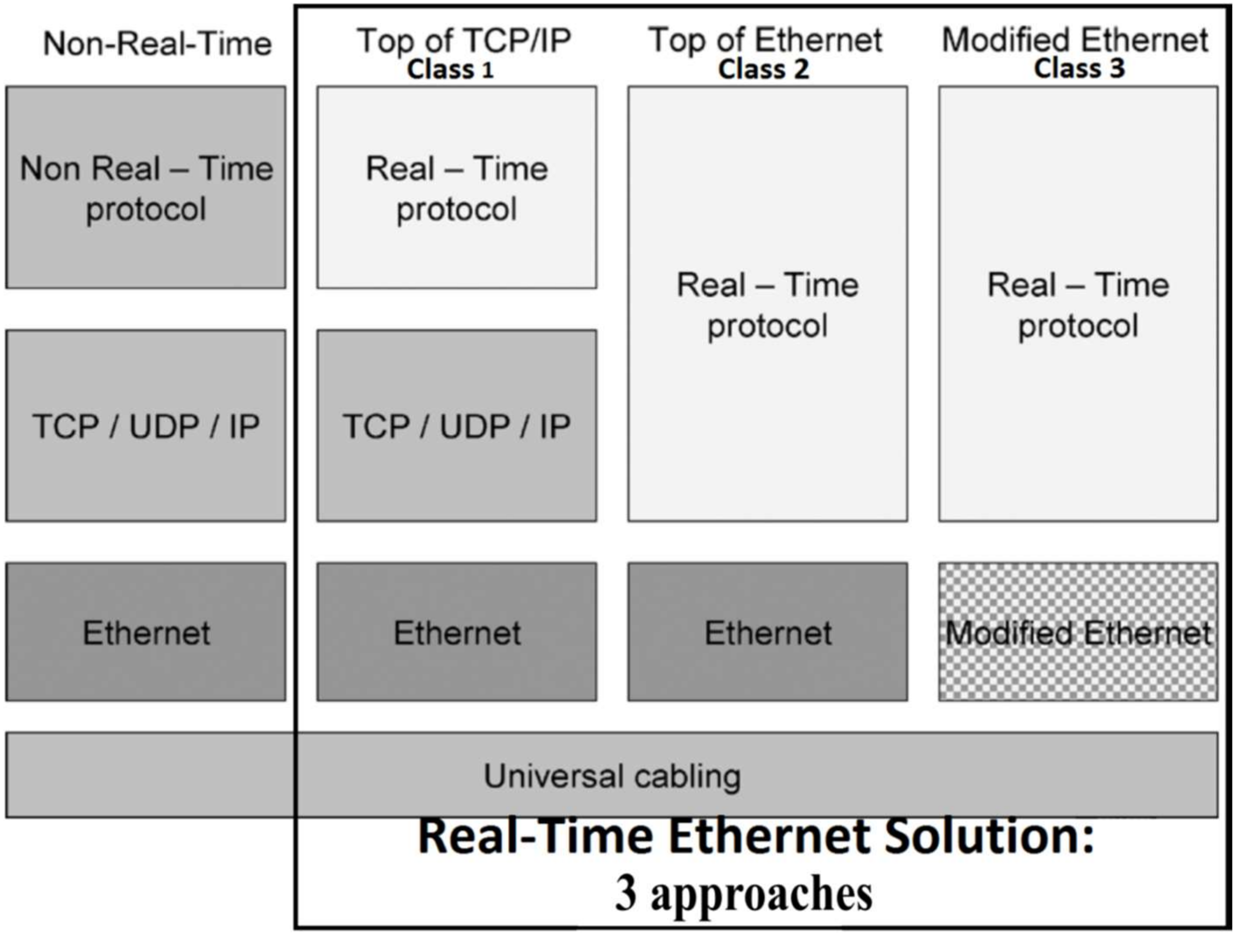

Ethernet protocol is not deterministic
best effort for frames distribution

Industrial reality required time constraints and need Ethernet evolution.

4. Industrial Ethernet : Powerlink

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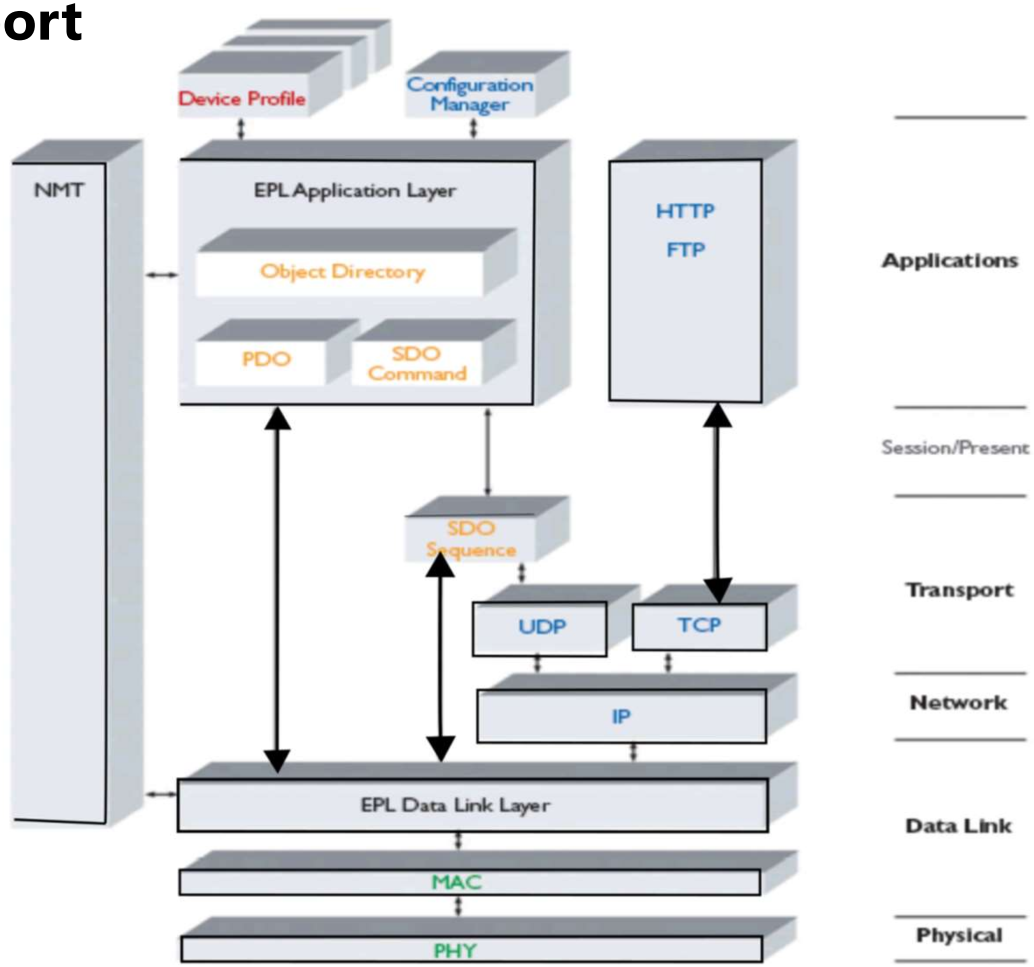
CAN protocol over Ethernet support



4. Switched Ethernet : IEC 61850

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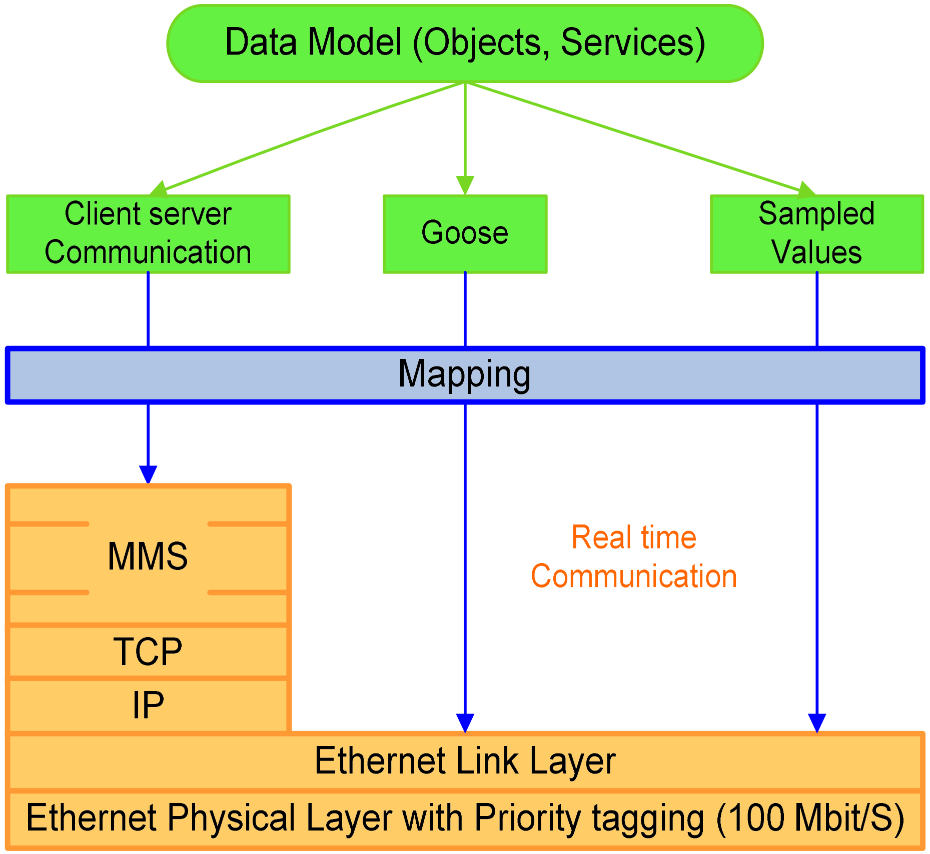

Network for Smart Grids

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

5. Wireless network

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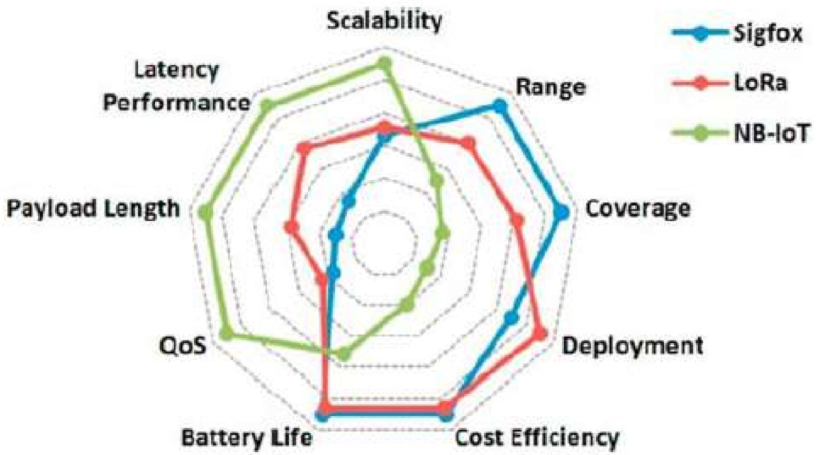
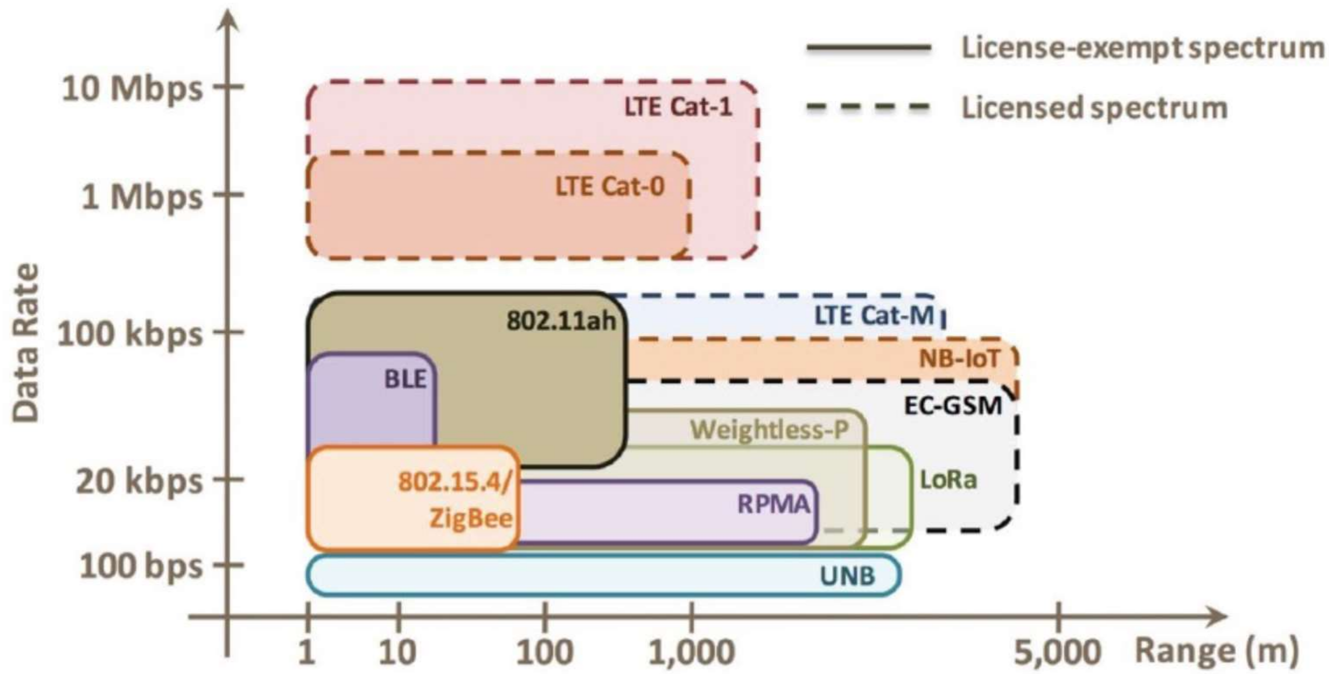
The main evaluation criteria for Low Power Wide Area Network - LWPAN:

- Range / Coverage
- Deployment / infrastructure cost
- Payload / Latency / Performance
- Consumption (battery life)
- Quality of service / Latency





Source https://iotfactory.eu/

5. Industriel scientifique et Médical Band

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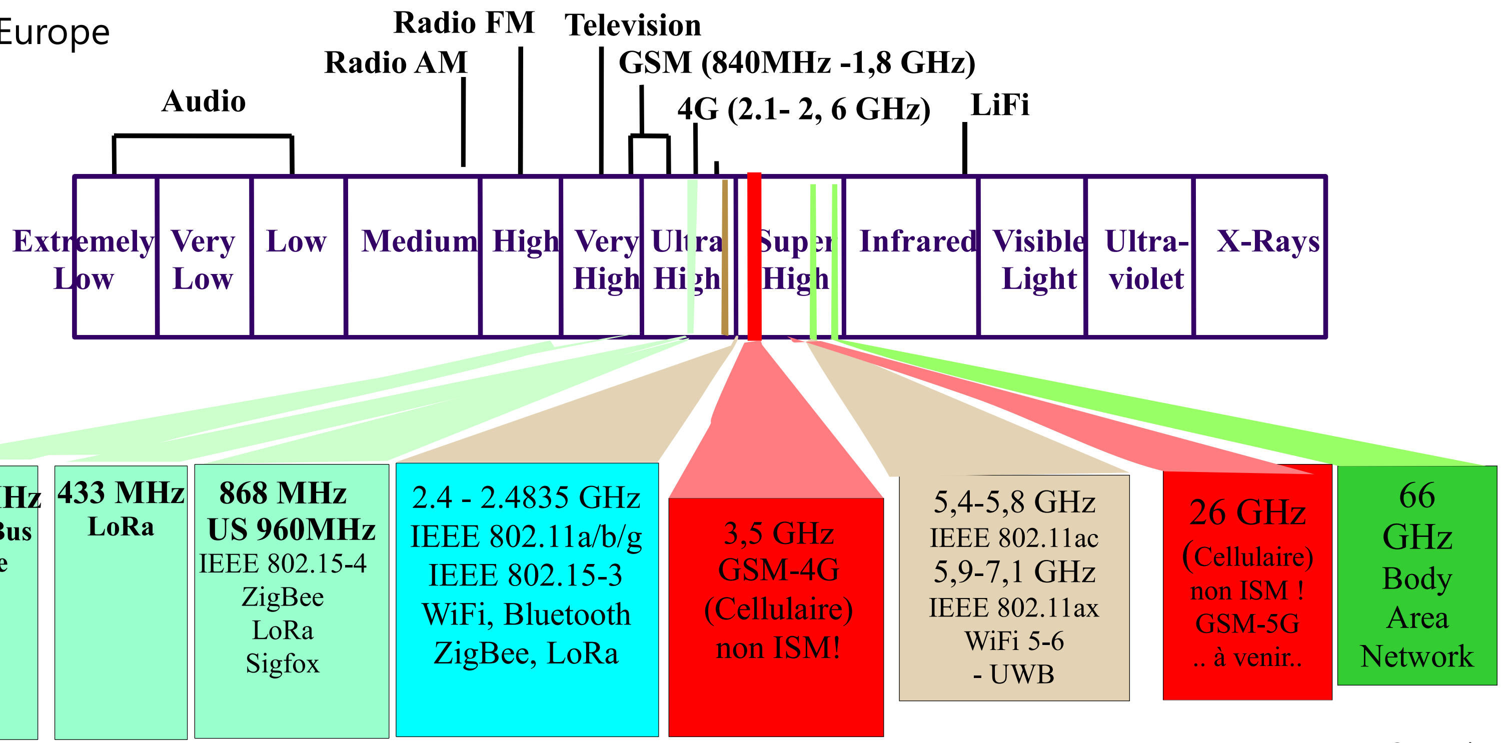
ISM Frequency Band ISM (Industrial, Scientific, and Medical)

Licence free – free for your transmissions, but with limited power transmission

As exemple in Europe



Source https://iotfactory.eu/

5. Industriel scientifique et Médical Band

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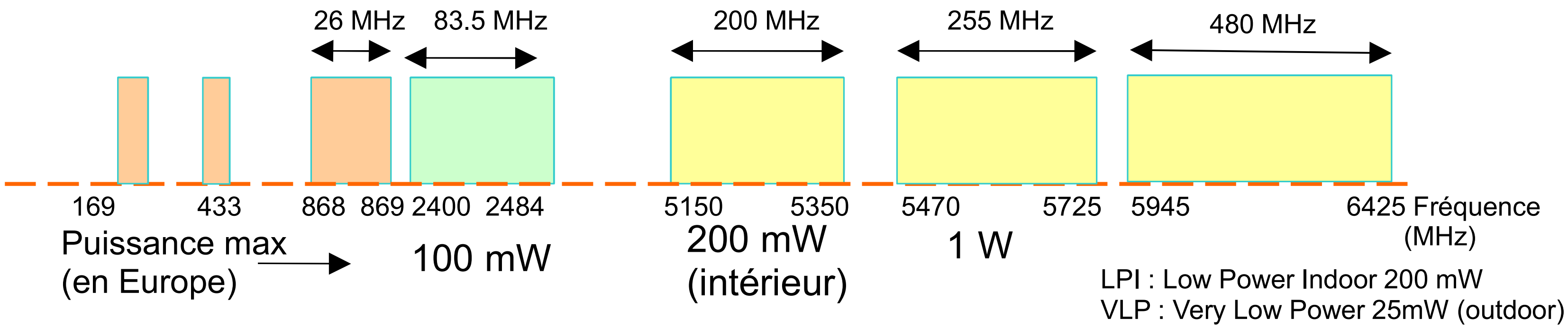
- Standards IEEE 802.11 et débits associés (* théorique maximun)
  - IEEE 802.11 (1997) 1 Mbps and 2 Mbps (bande 2.4 GHz) plus supporté
  - IEEE 802.11a (1999) **WiFi 1 :** 54 Mbps* (bande UNI -5 GHz)
  - IEEE 802.11b (1999) **WiFi 2 :** 11 Mbps* (bande 2.4 GHz)
  - IEEE 802.11g (2003) **WiFi 3** : 54 Mbps* (bande 5,4GHz)
  - IEEE 802.11n (2009) **WiFi 4** : 150 Mbps* (2.4 + 5,4GHz)
  - IEEE 802.11ac (2013) **WiFi 5** jusqu'à 910 Mbps* (bande UNI- I et II 5,4 GHz)
  - IEEE 802.11ax (2019) **WiFi 6** jusqu'à 10 Gb/s* (2.4 + 5,4 GHz)
  - IEEE 802.11ax (02/2021) **WiFi 6E** jusqu'à 11 Gb/s* t (2.4 + 5,4 + 6 GHz)
  - IEEE 802.11ay (03/2021) **.........**jusqu'à 176 Gb/s* (58,3 à 70,2 GHz uniquement US !)



5. Wireless network

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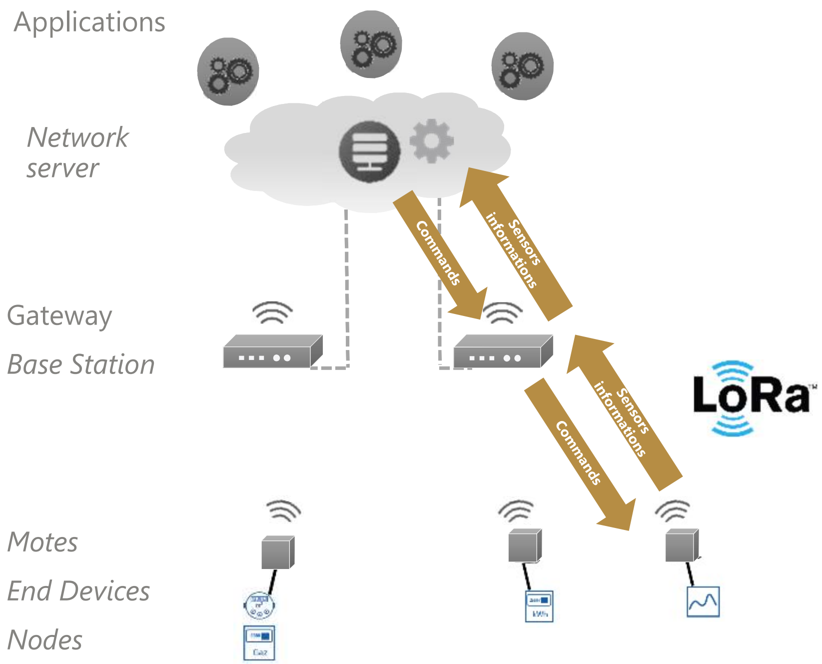
Low Power Wide Area Network LWPAN : LoRa Long Range Wireless Network



Nom	DevEUI	OTA_AppKey	OTA_AppEUI
Temp extérieure	70:B3:D5:E7:5E:00:2F:07	45B36F05429E6B3D74AAAA2A12740***	70B3D5E75F600000
Contact porte	70:B3:D5:E7:5E:00:35:72	49A5495E312BBBB614CD354140341***	70B3D5E75F600000
Compteur Gaz	70:B3:D5:E7:5E:00:36:C4	718E1F2F315B0D933DCCC1F725D53***	70B3D5E75F600000
Temp Humidité RDC	70:B3:D5:E7:5E:00:37:F4	7EE54A7745E82D5AAAAE5E3A25B839***	70B3D5E75F600000
Anémomètre	70:B3:D5:E7:5E:00:41:93	23411FF30200BBBB560A226527713***	70B3D5E75F600000
Temp Etage 1	70:B3:D5:E7:5E:00:41:B3	1ED153B417E60DF35233CC1C716D4***	70B3D5E75F600000
Centrale de mesure	70:B3:D5:E7:5E:00:44:75	74730B42770D752AAAAD1BEA47D53***	70B3D5E75F600000

Severals gateways listening frequencies Motes messages
Only the gateway with the best signal sends messages to the network server

Sensors Motes

Actuators Motes

5- Wireless Mbus or LoRa

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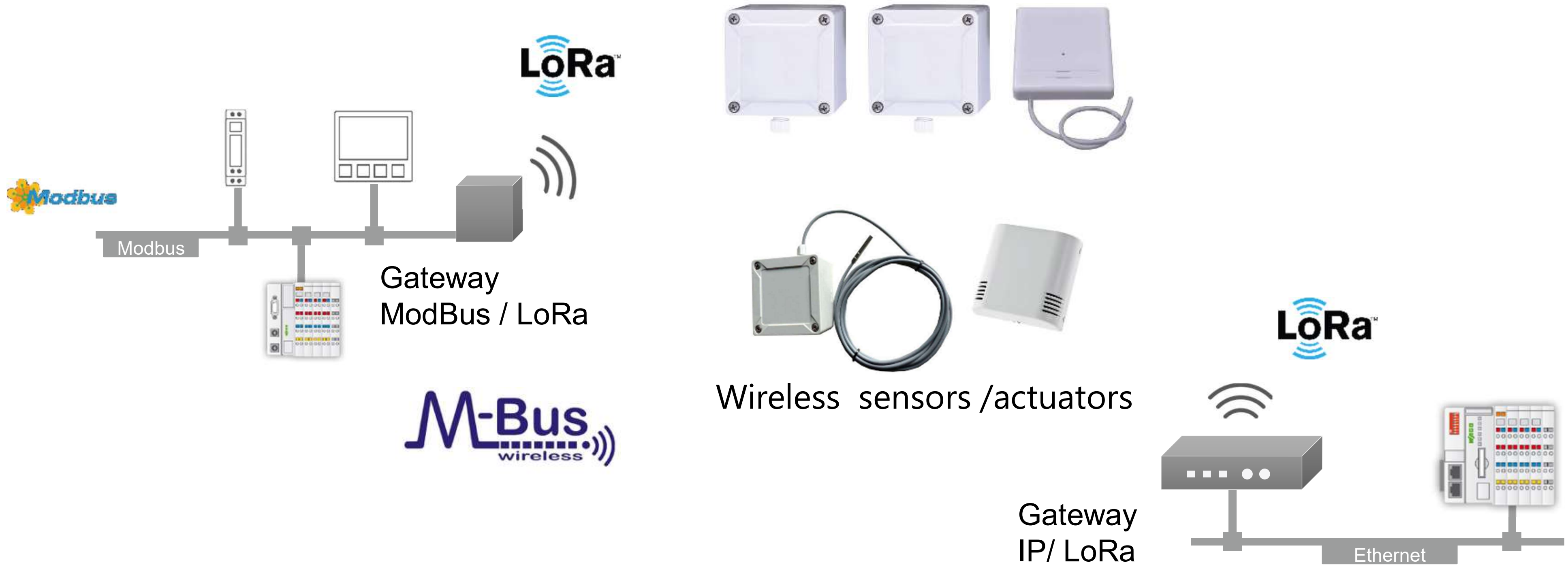
- Wireless Modbus versus Lora transmetteur



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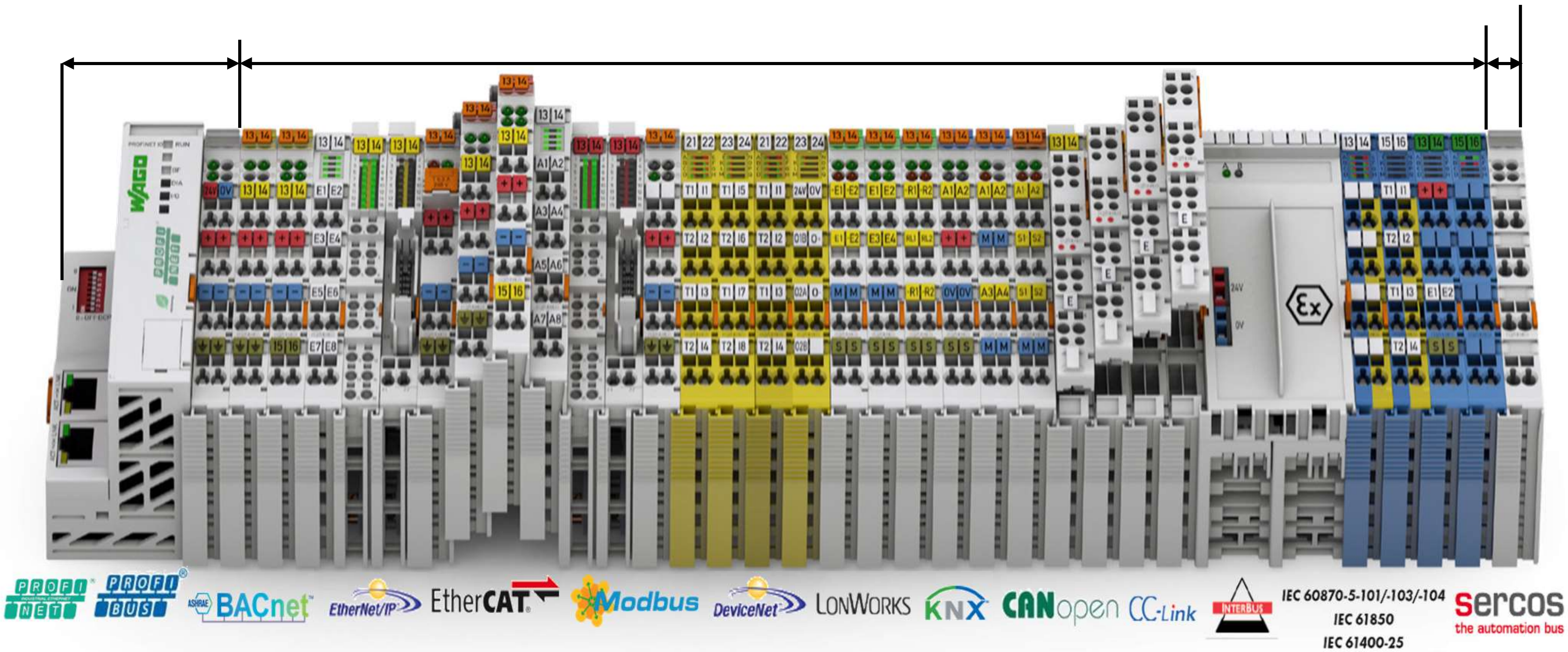
6- Convergent information through various fieldbus network and IT network

❶ PLC Ethernet controller ❷ I/O connexions ❸ Borderline



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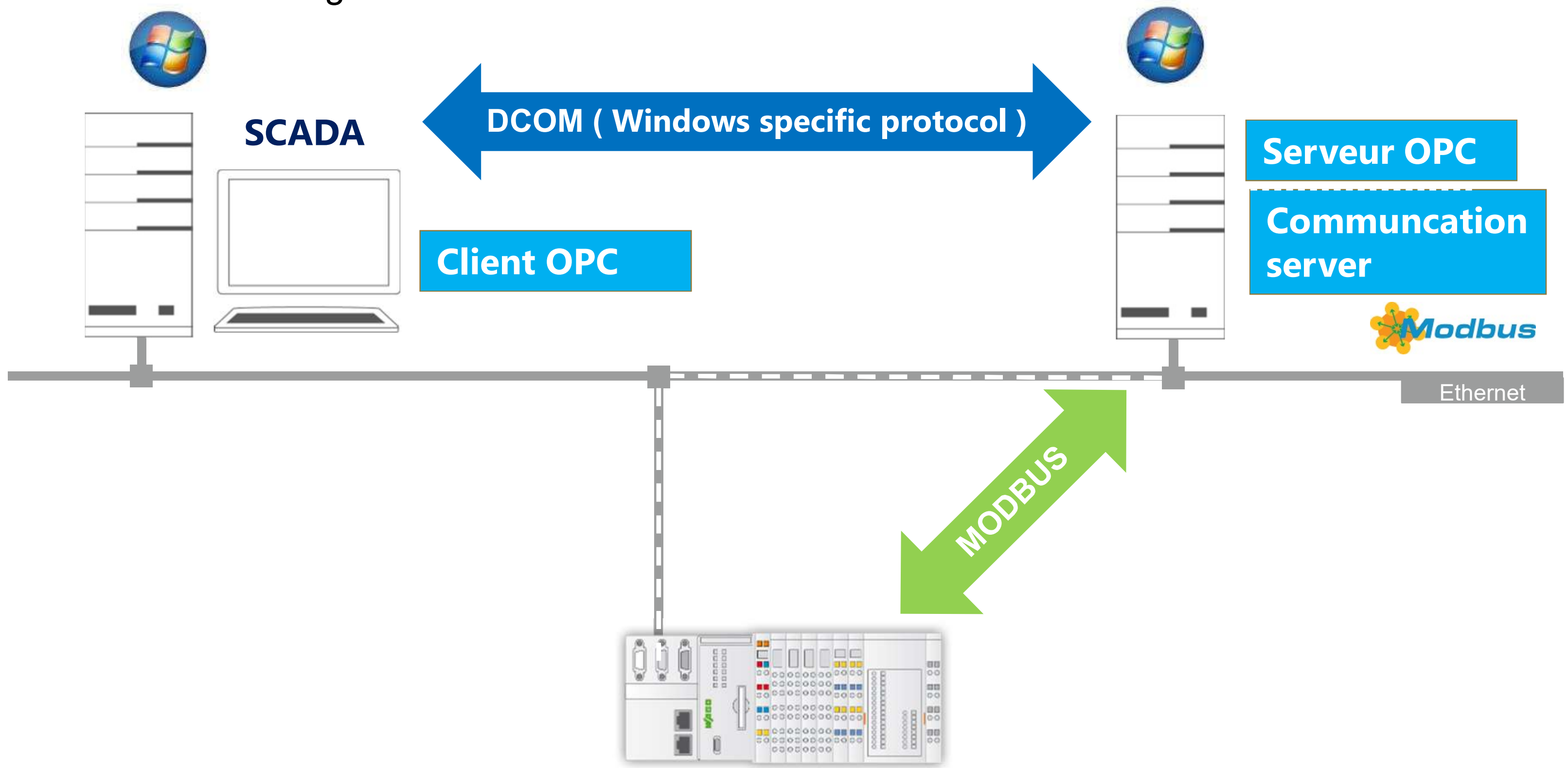
6-1 Open Platform Communications

- **First implementation with Microsoft system sharing informations over DCOM for SCADA**
- First reference OPC: O(bject Linking and Embedding) for Process Control
- Reference (2011) : Open Platform Communications

  OPC standard exchange based on Windows technologies



6.2 -OPC Unified Architecture

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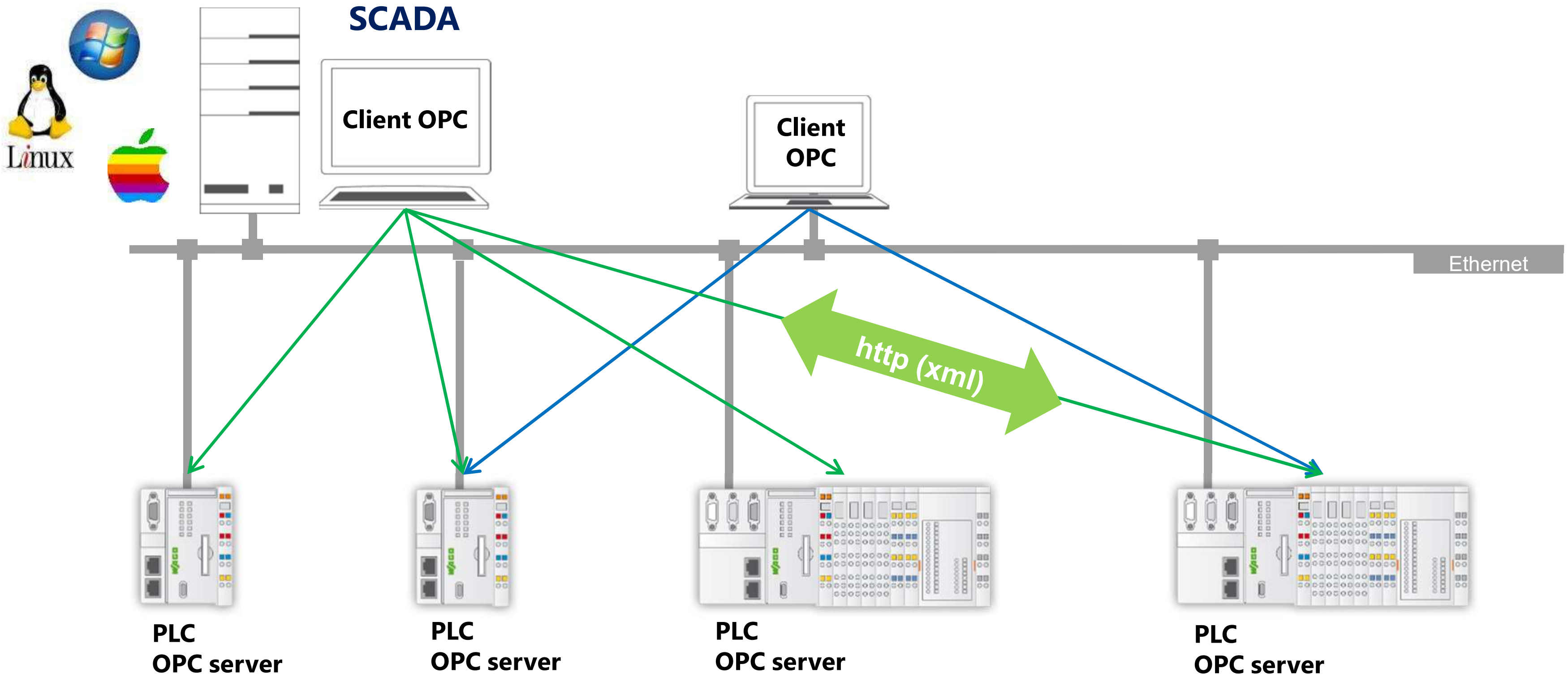
- **O**pen **P**latform **C**ommunications - **U**nified **A**rchitecture : **OPC-UA**

  Objectives :
  - Communication protocol abstraction
  - No more dependence on Microsoft Windows
  - OPC server directly implemented in the PLC equipment



6.3 -Message Queuing Telemetry Transport

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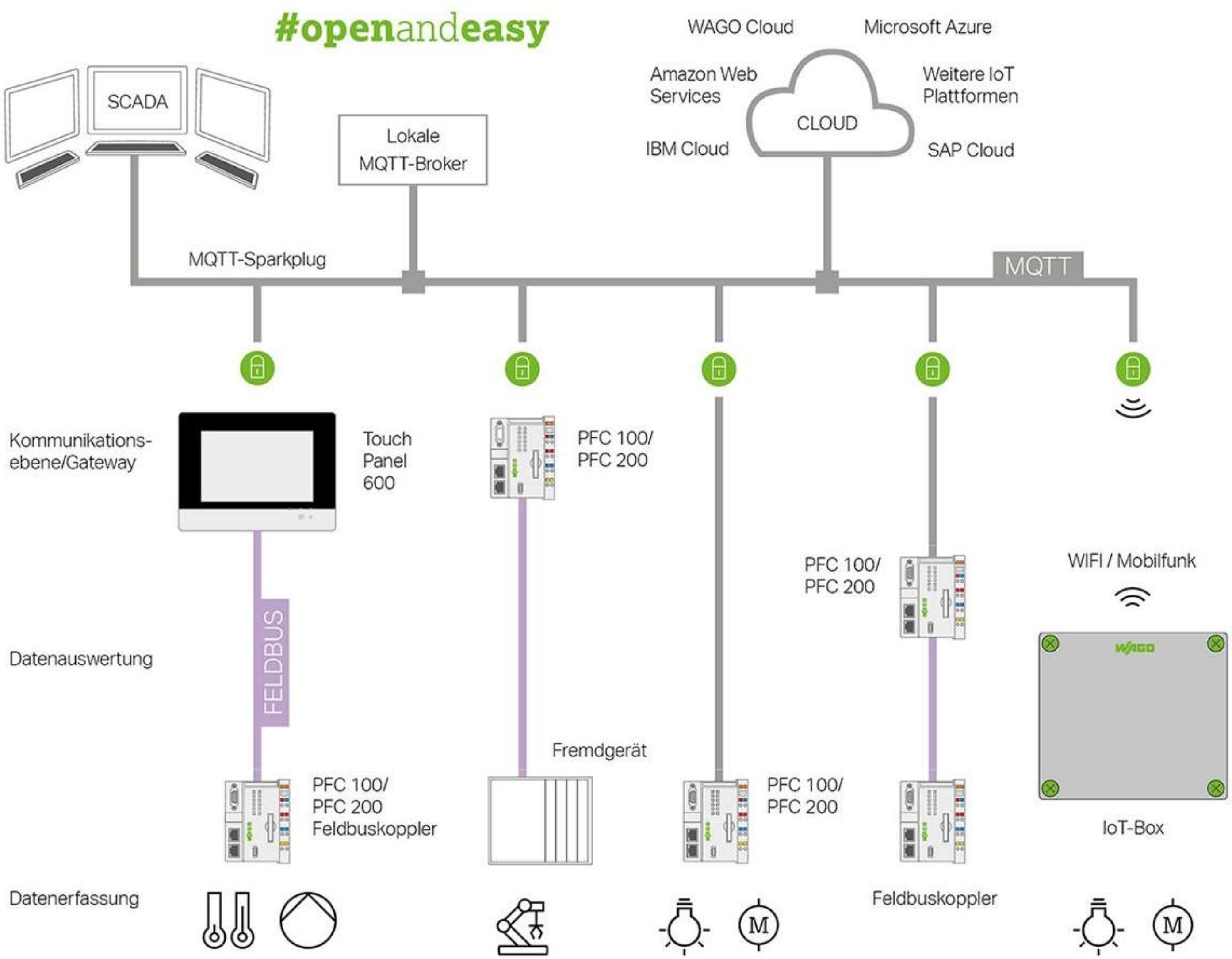
Version :
MQTT 1.0 (1999)
…
MQTT 3.1.1 (2019)

Publish-subscribe messaging protocol based on the TCP / IP protocol.

Data virtualization over networks and cloud

Proposed by
IBM
&
Eurotech



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Conclusion

- New opportunities for Industry 4.0
  - Process information's systems
    from the process information (sensors, actuators) « the field »
    to the higher levels of management (SCADA / IA) for optimization
  - Various functionalities: Production, but also Maintenance, Logistics, Transport

- Based on PLC, Programmable Logic Controller
  - Today dedicated modules ..soon versatile Industrial computer with programs and connectivity
  - Inputs/outputs to be connected to physical processes
  - Communication interface
    - Fieldbus networks, « Industrial networks »,
    - Ethernet networks for supervision
    - Gateways to Cloud devices (virtualization of the control)

- Integration IT (Information Technology) versus ICS (Industrial Control Systems)

- Next course : « Challenges in Dependability/Safety and « Cyber-Security »
  Pr Jean-Marc Thiriet

Future of industry 4.0

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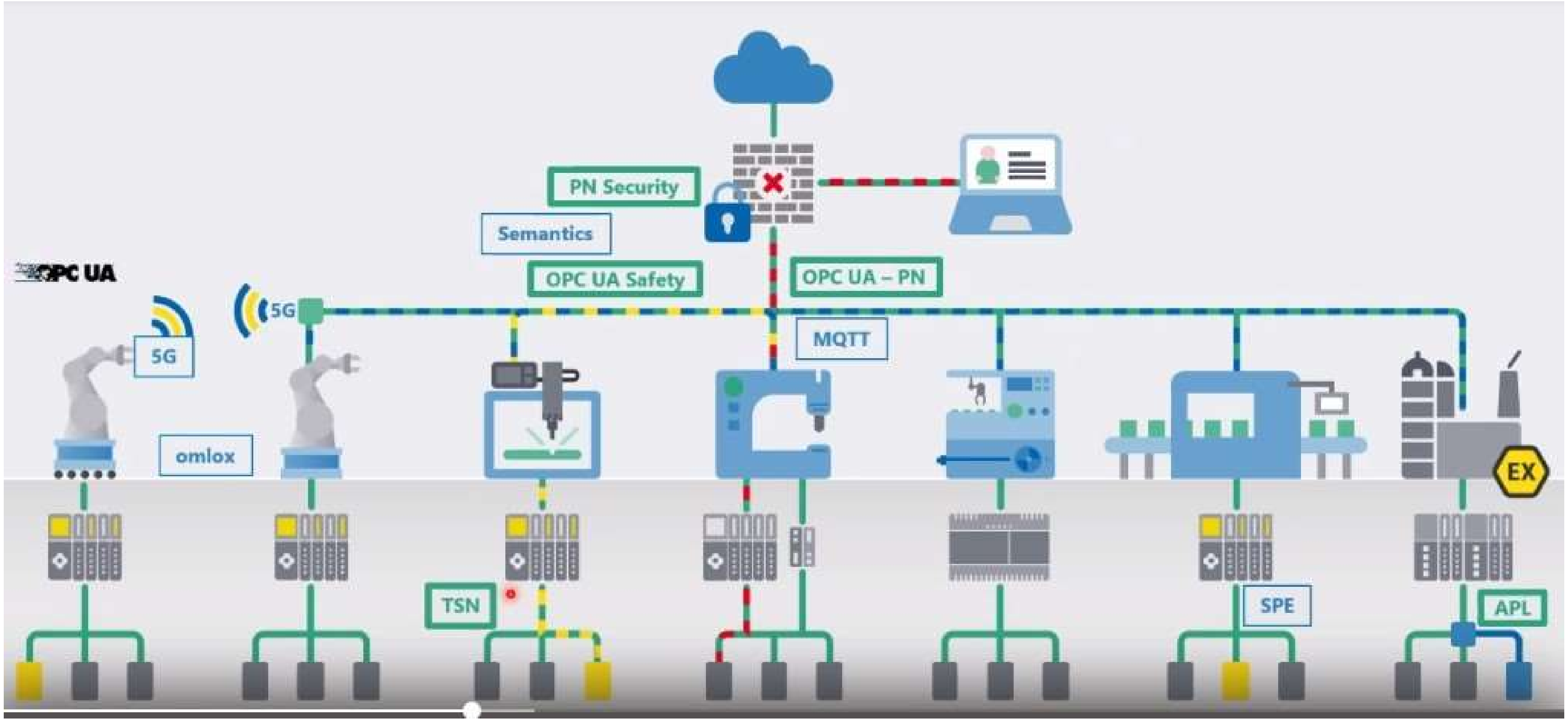

Next PLC architecture network generation will be IP (end to end)

Merci pour votre attention
Merci pour votre attention

Grignan castle

Université Grenoble Alpes

Thank you for your attention

Natural bridge over the river

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