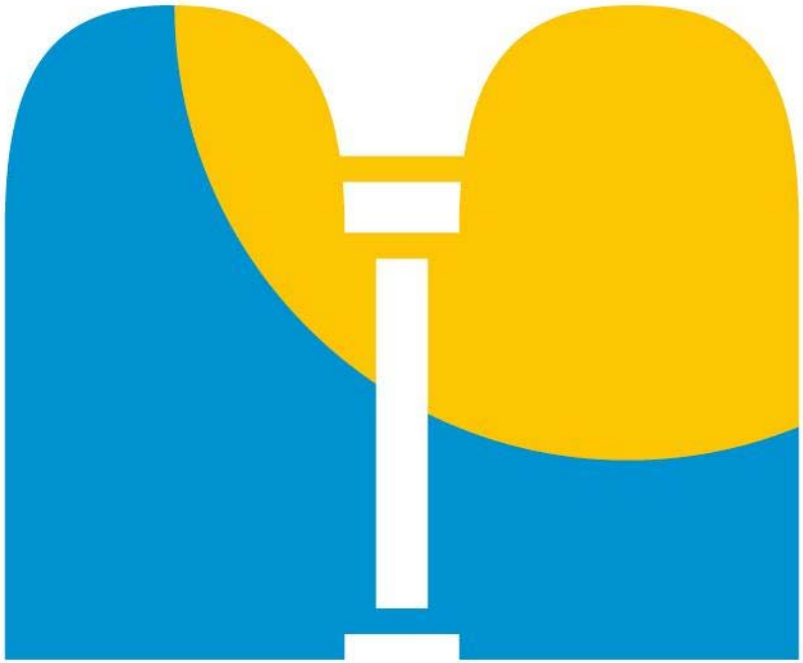

D8.9 Educational Material for University Studies

Monitoring and control: Technology and methodology approach

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Guiding principle

Presentation 1
Author: Giacomo Paci
Partner: Università degli Studi di Bologna, Dipartimento DEIS (UNIBO)
University course: TIS Innovation School
Date: 2012/07/23
Place: TIS, Bolzano
Title of the lesson: Monitoring and control: Technology and methodology approach
Description of the contents: The lesson regards the monitoring and control concept and in particularly the development of sensors, sensor interfacing, data acquisition and transmission.
Network infrastructure and protocol
Name of the file: WP8_D8.9_20131007_UNIBO-Presentation 1

Lesson content

- Technical overview
  - Monitoring and control concept
  - Sensors
  - Sensor interfacing and data acquisition
  - Data transmission
  - Network infrastructure and protocol
- Commercial systems
  - X10
  - LonWorks
  - KNX
- Monitoring and control system design
  - “Palazzina della Viola” example

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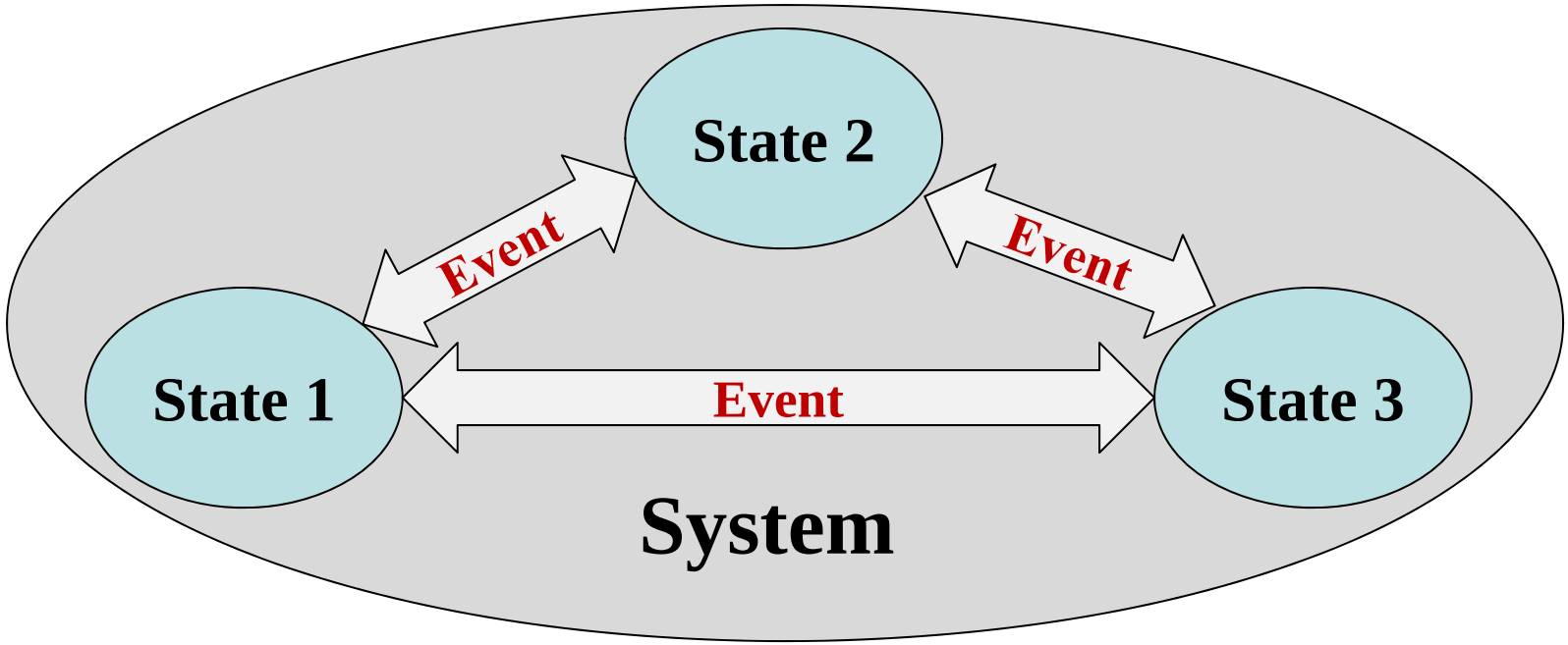
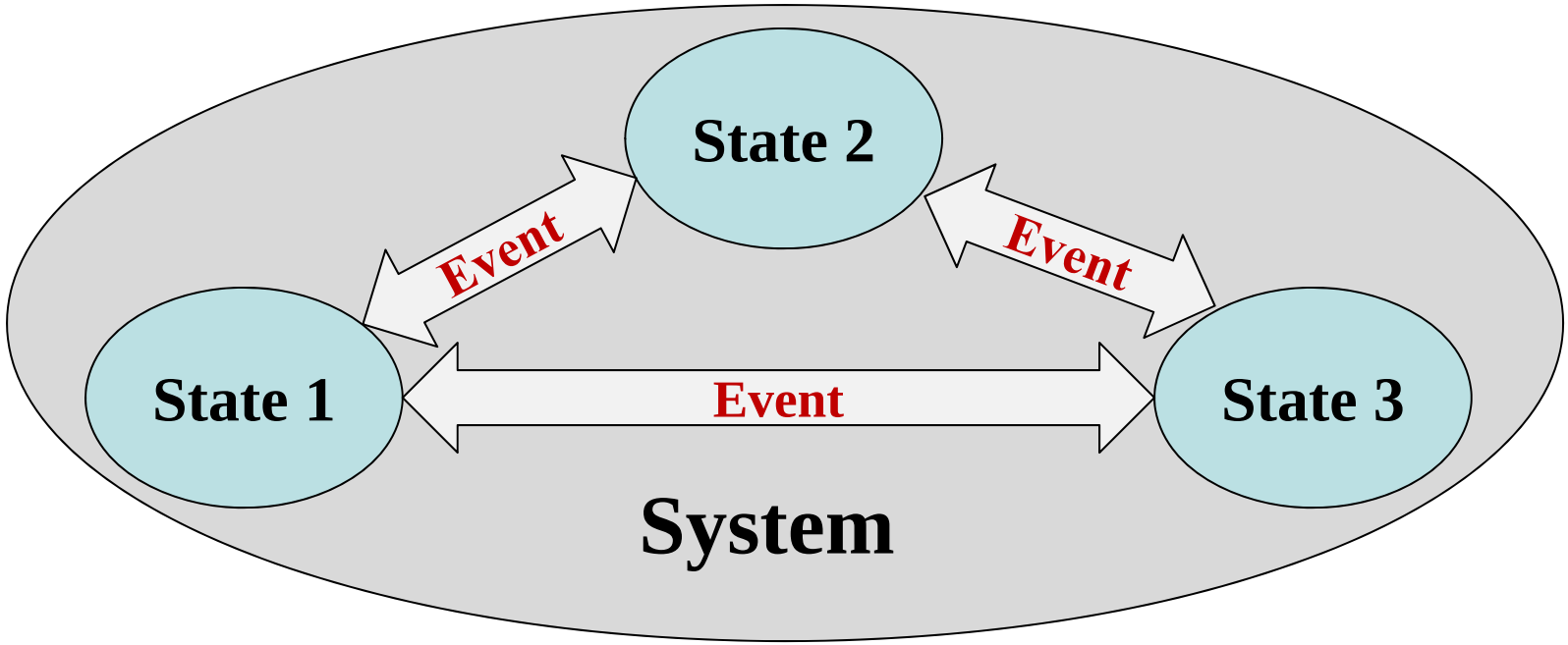
Monitoring and control concept

- To monitor or monitoring generally means to be aware of the state of a system
  - A system can be described as a collection of states
  - Each state is described by a batch of conditions
  - The change of state is typically triggered by an event
  - The monitoring aims to detect the system status



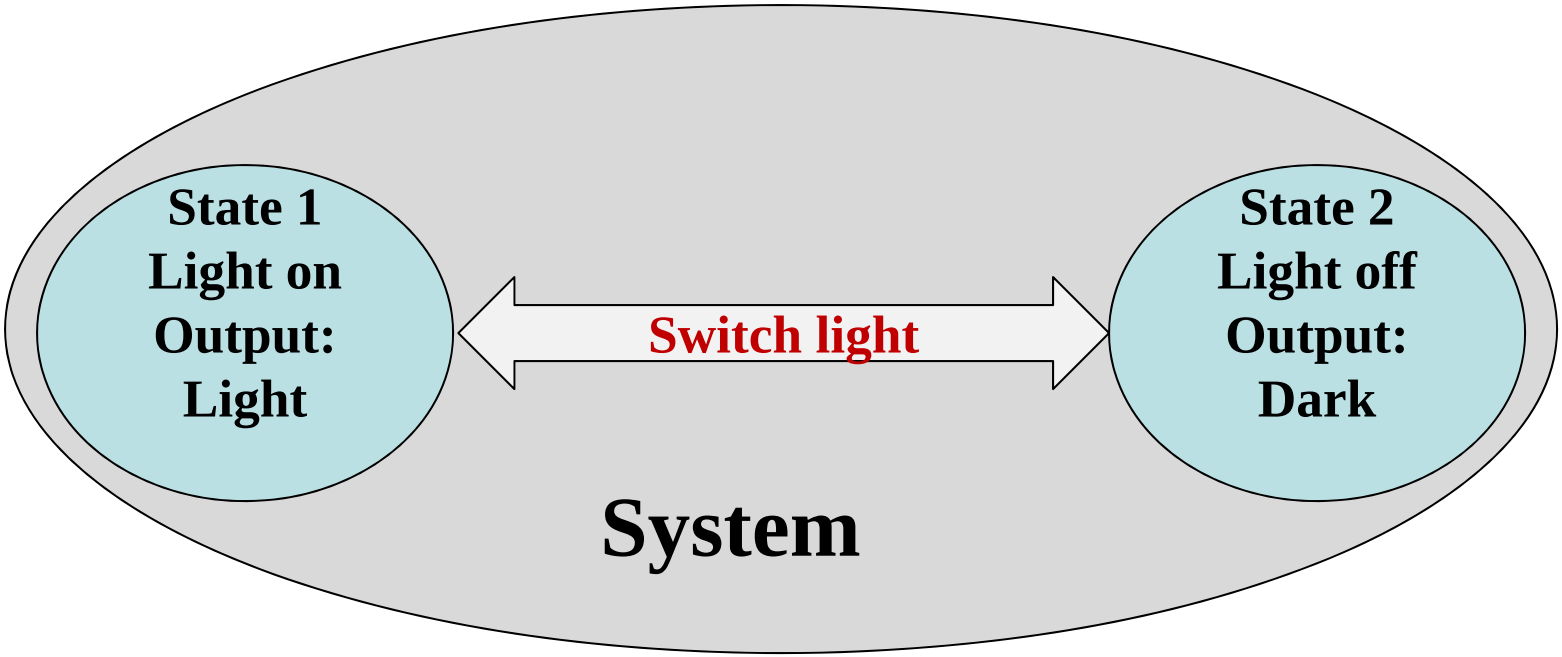
Monitoring and control concept

- To control generally means to force a system to reach a predefined state
  - The control can trigger events (called input) to reach the desired state
  - An output of a system is a condition that we want to control
  - A system is fully controllable if the triggered events can bring the system to have the desired output

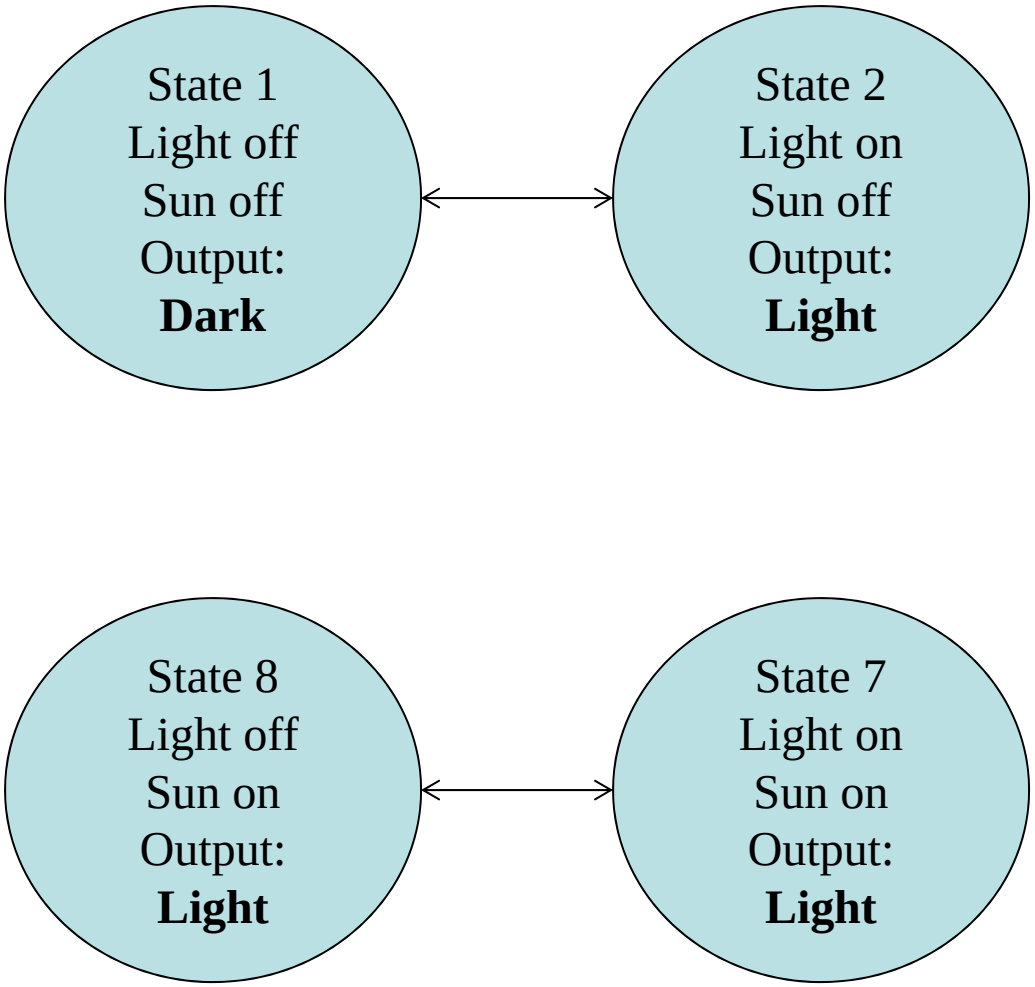


Monitoring and control concept

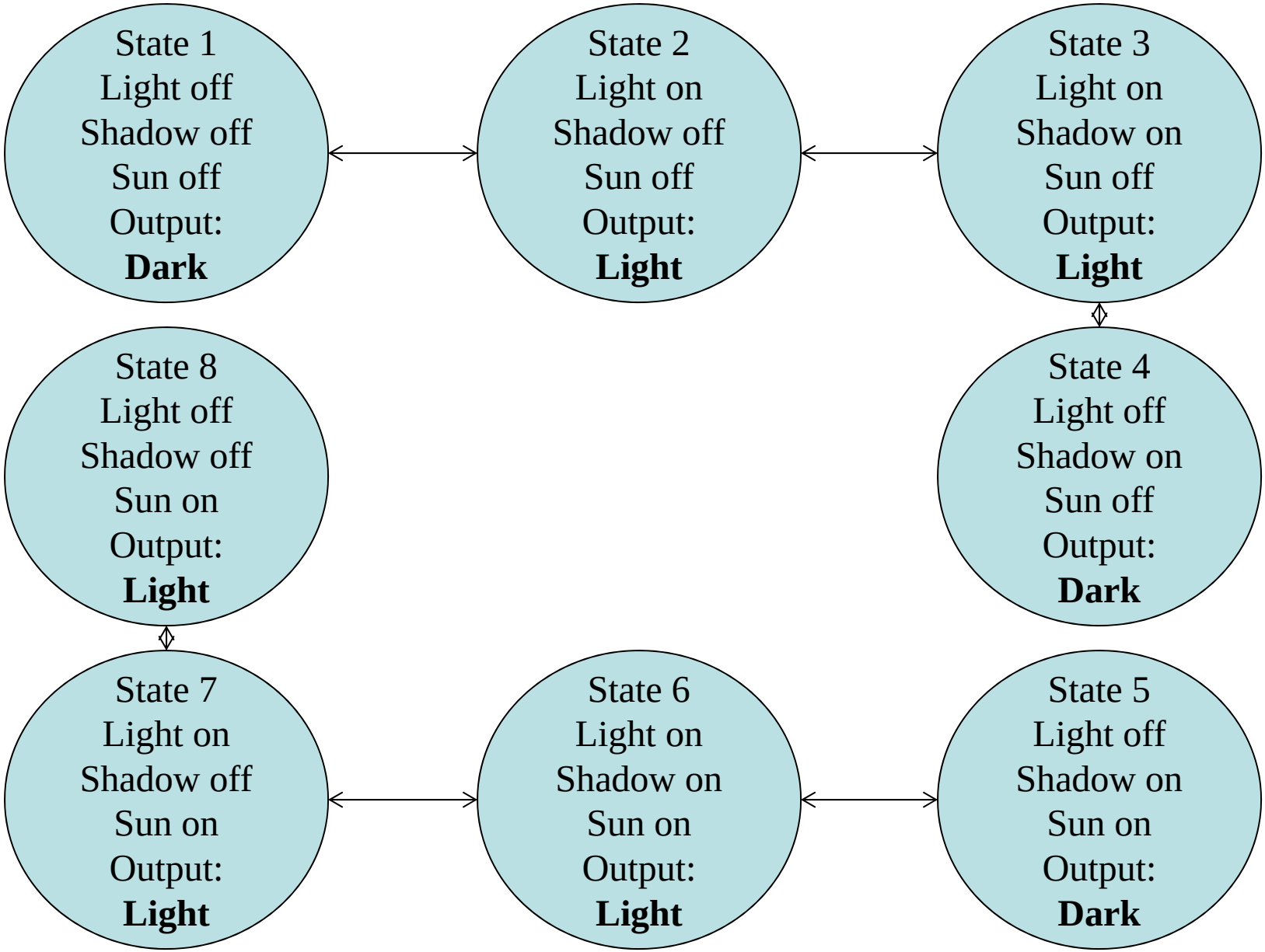
- Example: Lighting control
  - In a room without windows it is possible to control the lighting acting only to the light switch (fully controllable)
  - In a room with windows we can not control the lighting only acting to the light switch (the system is partially controllable)
  - Adding the possibility to act to the shadowing we can completely control the system



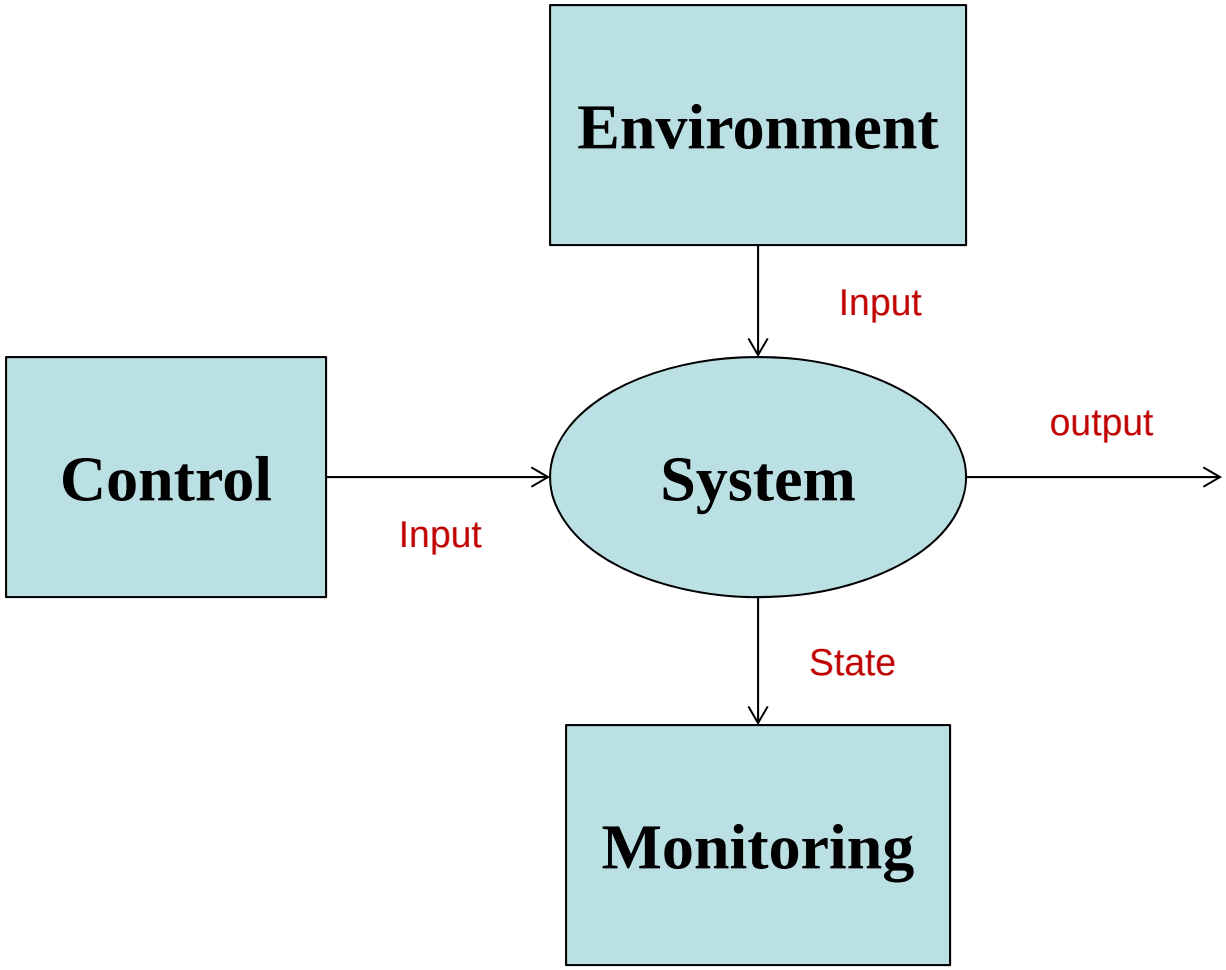
Monitoring and control concept



Monitoring and control concept

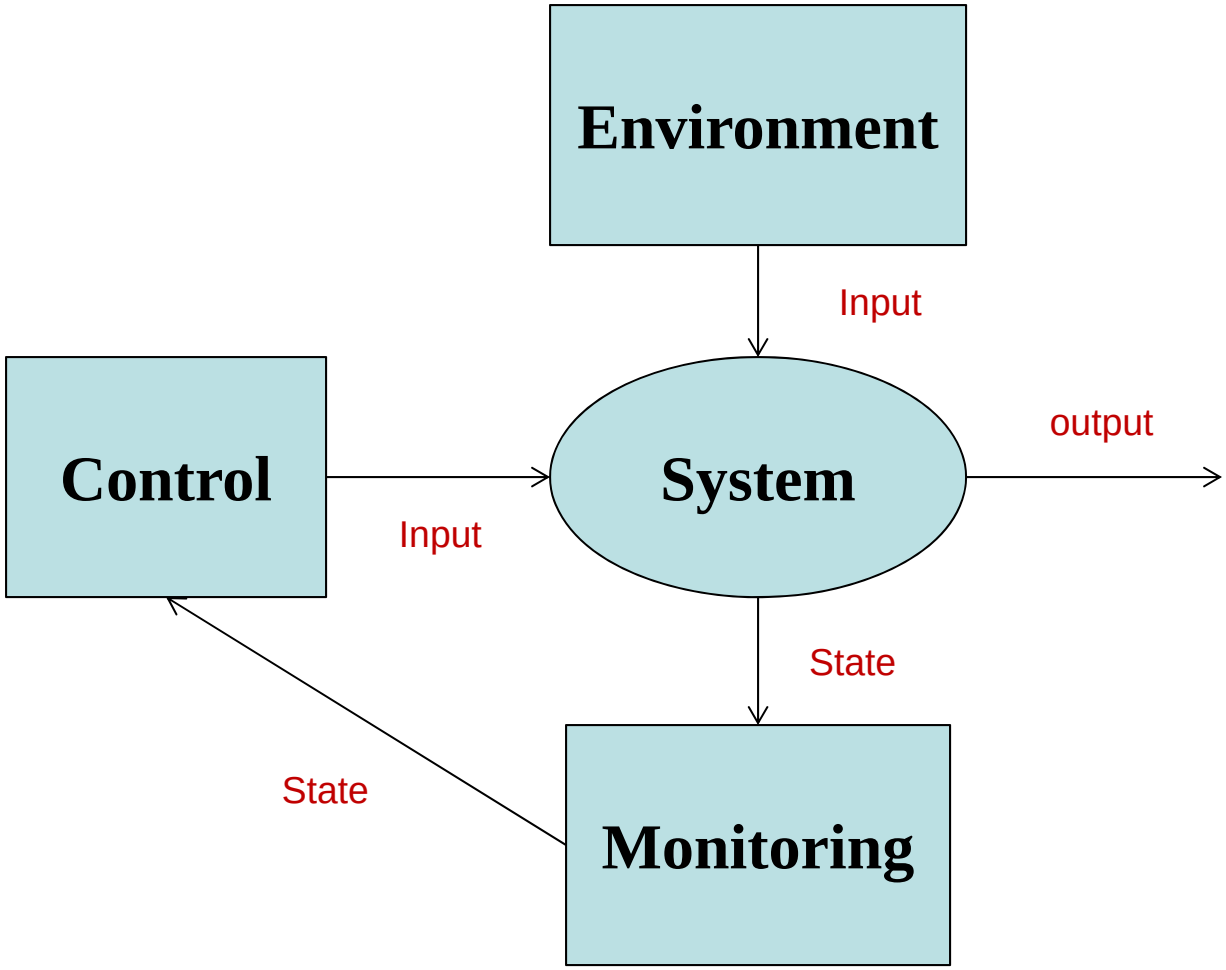


Monitoring and control concept



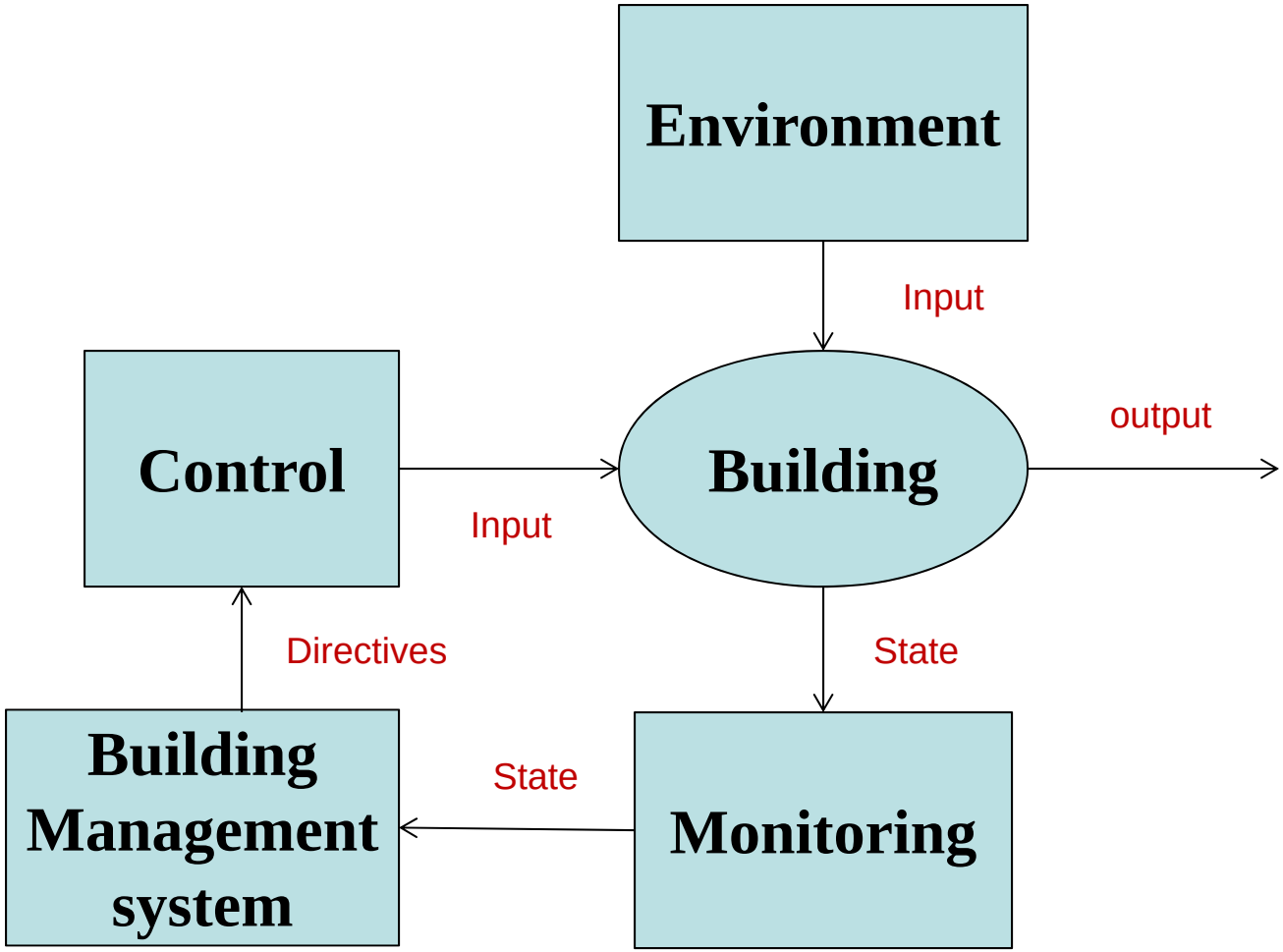
- Open loop control system

Monitoring and control concept



- Closed loop control system

Monitoring and control concept



- Smart building: monitoring and control

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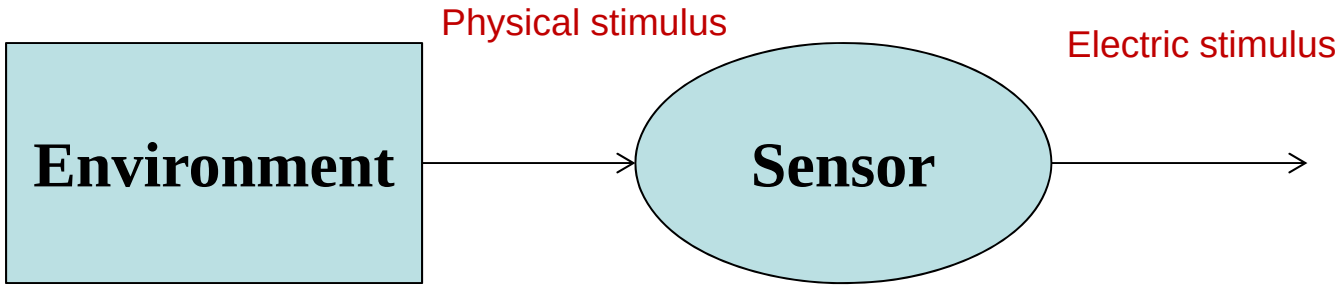
Sensors

- Sensor is a device that convert a physical stimulus (as heat, light, sound, pressure, magnetism, or a particular motion) to an electric stimulus



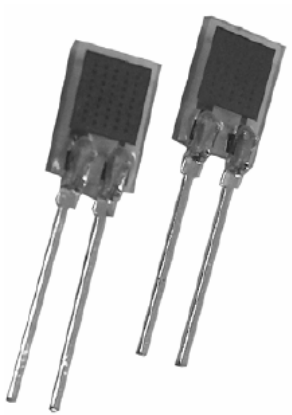
- The electric stimulus could be:
  - Voltage (e.i. Light sensors, microphone, gas sensors)
  - Current (e.i gas sensors, current sensors)
  - Resistance (temperature sensors, gas sensors, pressure sensors)
  - Capacitance (humidity sensors, acceleration sensors)
  - Frequency (velocity sensors, wind sensors)
- The sensor could need power supply or not
  - Microphone (self powered)
  - Temperature (need power supply)

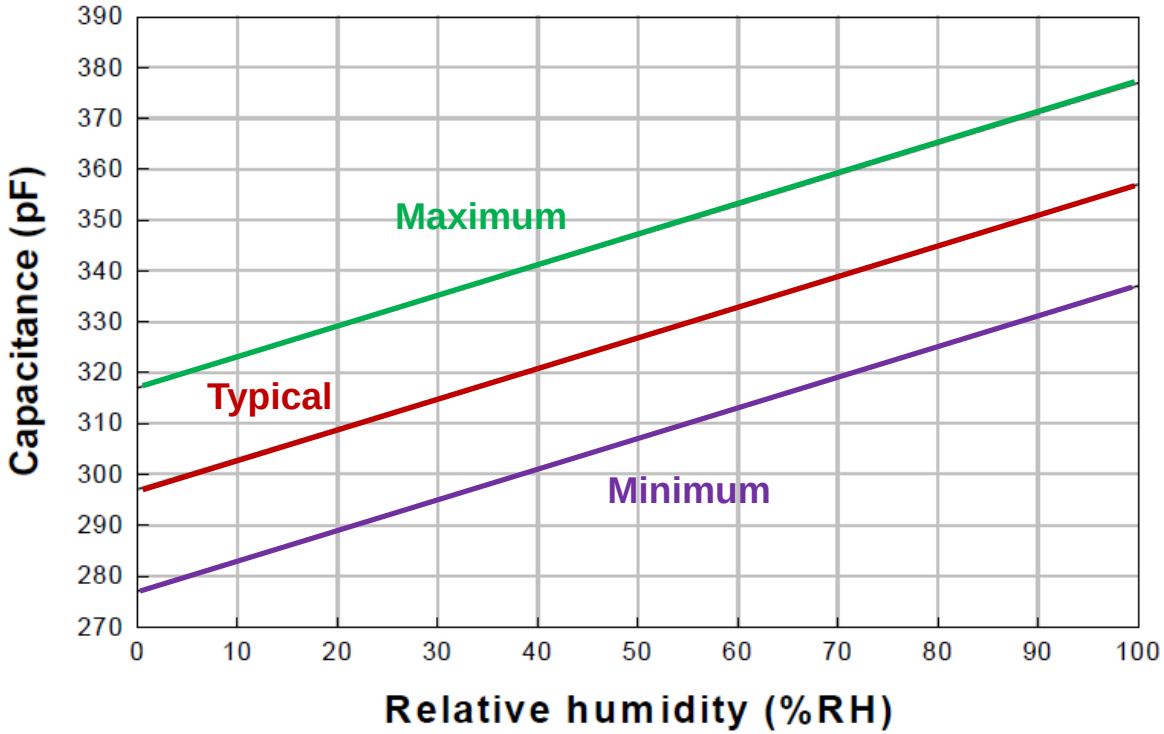
Sensors

- Sensor characteristics
  - Conversion characteristics, the function that convert the physical entity amount in the electrical stimulus amount (linear, quadratic, un linear etc.)
  - Sensitivity, the capability to convert a certain amount of physical entity in a corresponding electrical amount.
  - Range, the maximum and minimum amount of physical quantity that the sensor can detect.
  - Resolution, is the degree to which repeated measurements under unchanged conditions show the same results
  - Accuracy, is the degree of closeness of measurements to the physical entity true value.
  - Tolerance, is the degree to which repeated measurements under unchanged condition with different entity of the same sensor show the same results. (Usually due to production variability)
  - Response time, the time required to the sensor to go at equilibrium with the surrounding environment.
  - Reading time, the time required to the sensor to collect the measurement

Sensors

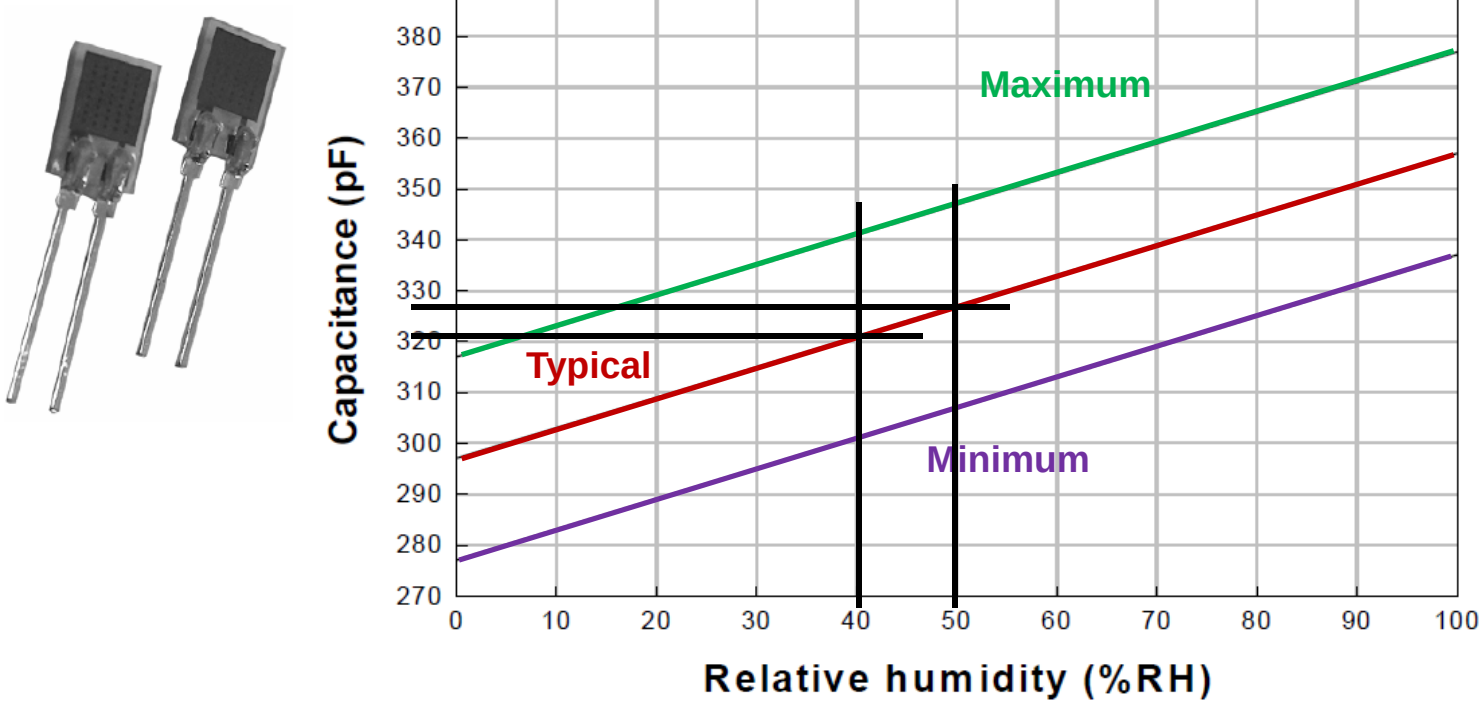
- Sensor characteristics example
  - Conversion characteristics, the function that convert the physical entity amount in the electrical stimulus amount (linear, quadratic, un linear etc.)
- Humidity sensor (linear)





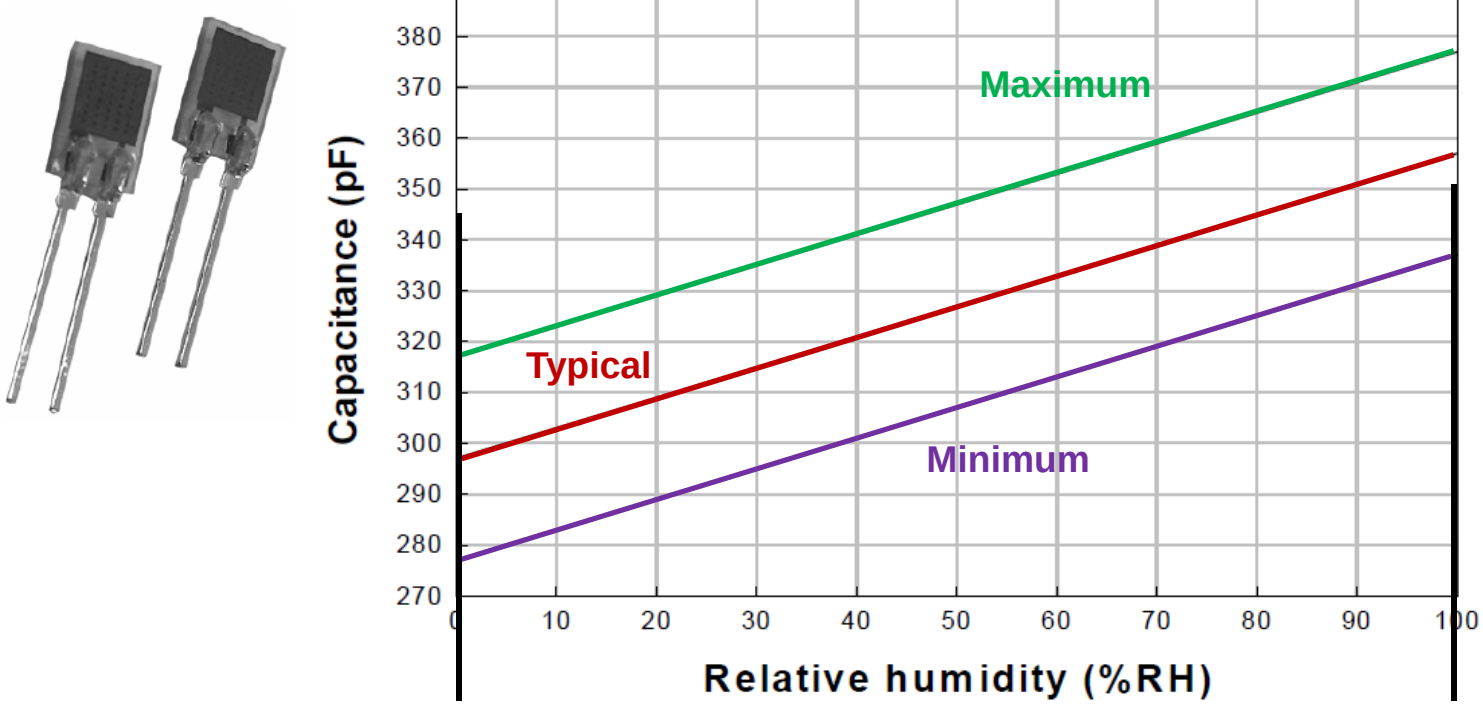
Sensors

- Sensor characteristics example
  - Sensitivity, the capability to convert a certain amount of physical entity in a corresponding electrical amount.
- Humidity sensor: 0.6 pF/%RH



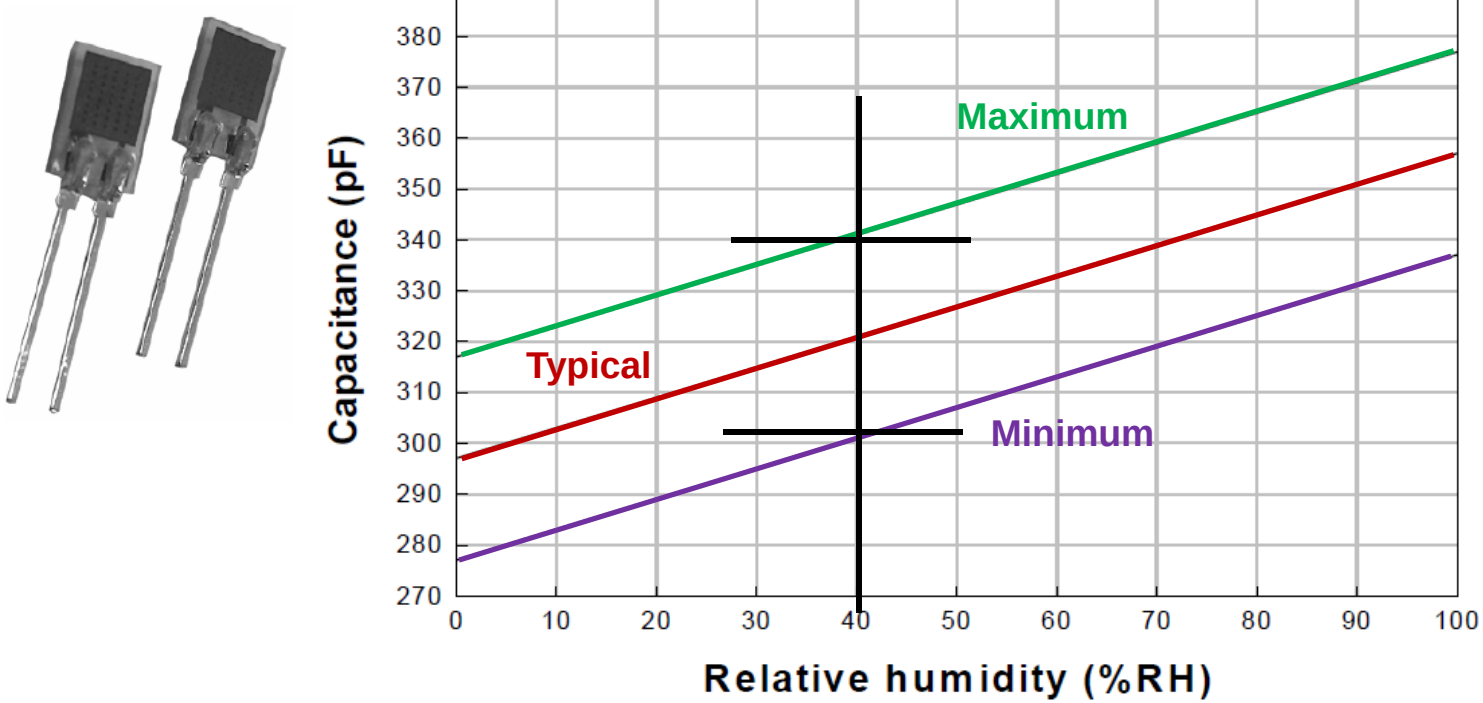
Sensors

- Sensor characteristics example
  - Range, the maximum and minimum amount of physical quantity that the sensor can detect.
- Humidity sensor: 0 to 100% RH



Sensors

- Sensor characteristics example
  - Tolerance, is the degree to which repeated measurements under unchanged condition with different entity of the same sensor show the same results. (Usually due to production variability)
- Humidity sensor: ±20pF



Sensors

- Sensor characteristics example
  - Response time, the time required to the sensor to go at equilibrium with the surrounding environment.
- Humidity sensor: 15sec

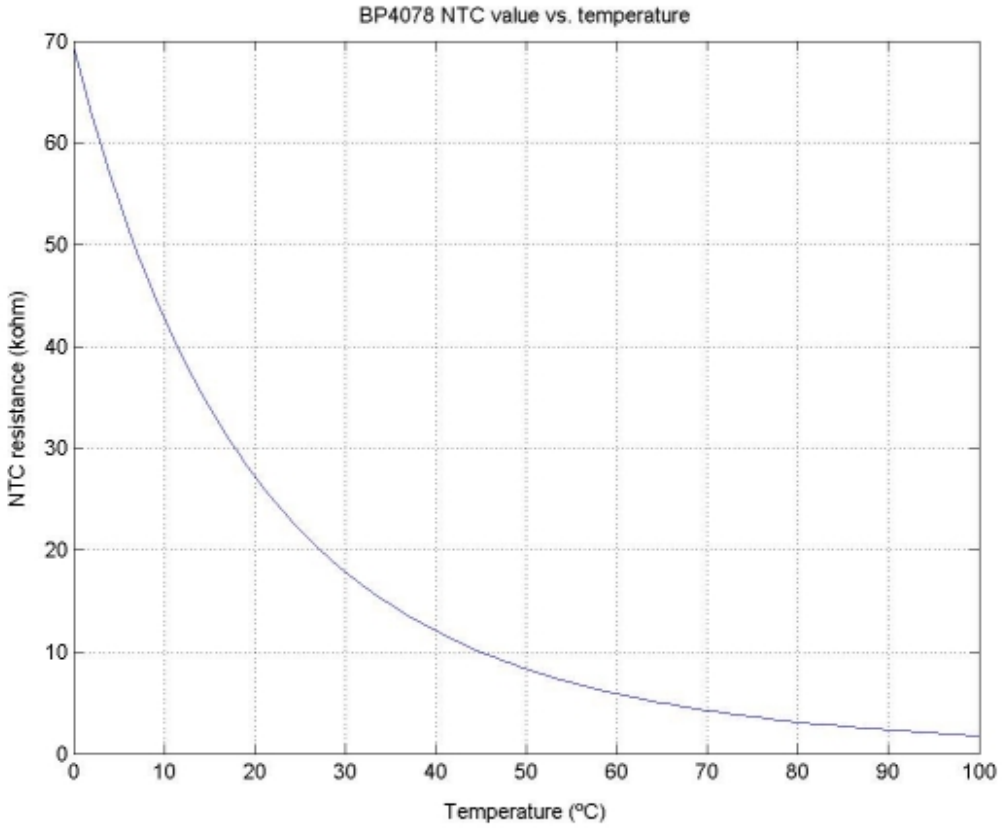
SPECIFICATIONS (T_A= 25 °C [77 °F], Input Voltage = 1 V_{RMS}, Frequency = 20 kHz)

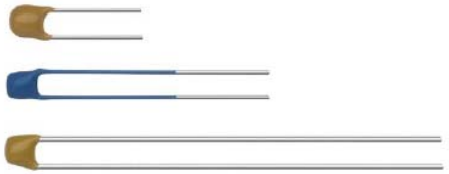
Characteristic	Min.	Typ.	Max.	Unit	Note
Normal capacitance	310	330	350	pF	at 55% RH
Sensitivity	0.55	0.60	0.65	pF/%RH	10% RH to 95% RH
Humidity hysteresis	–	±2	–	%RH	–
Linearity	–	±2	–	%RH	–
Response time	–	15	–	sec	30% RH to 90% RH
Temperature coefficient	0.15	0.16	0.17	pF/°C	5 °C to 70 °C [41 °F to 158 °F]
Long-term stability (drift)	–	0.2	–	%RH/year	–
Operating temperature range	-40 [-40]	–	120 [248]	°C [°F]	–
Operating humidity range	0%	–	100%	RH	–
Operating frequency range	1	–	100	kHz	–

- Note: the measurement can be affected from others physical quantity. The humidity sensor is sensitive to the temperature!
- Note: the humidity sensor is affected by log term stability drift due to wear out process.

Sensors

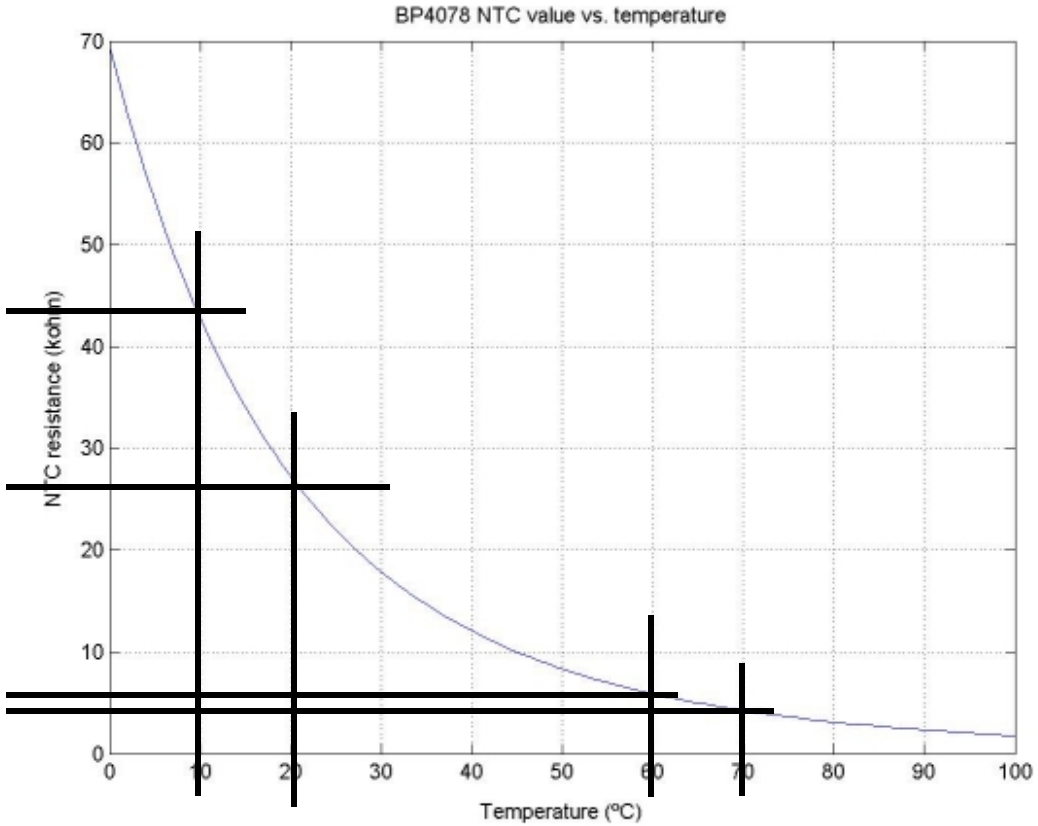
- Sensor characteristics example
  - Conversion characteristics, the function that convert the physical entity amount in the electrical stimulus amount (linear, quadratic, un linear etc.)
- Temperature sensor NTC (no linear)

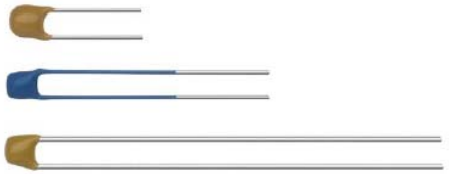




Sensors

- Sensor characteristics example
  - Sensitivity, the capability to convert a certain amount of physical entity in a corresponding electrical amount.
- Temperature sensor NTC: change with the temperature





Sensors

- Sensor characteristics example
  - Resolution, is the degree to which repeated measurements under unchanged conditions show the same results
  - Accuracy, is the degree of closeness of measurements to the physical entity true value.
- Temperature sensor digital (Sensirion SHT21)

Parameter	Condition	min	typ	max	Units
Resolution [1]	14 bit		0.01		°C
	12 bit		0.04		°C
Accuracy tolerance [2]	typ		±0.3		°C
	max	see Figure 3			°C
Repeatability			±0.1		°C
Operating Range	extended [4]	-40		125	°C
		-40		257	°F
Response Time [7]	τ 63%	5		30	s
Long Term Drift			< 0.04		°C/yr

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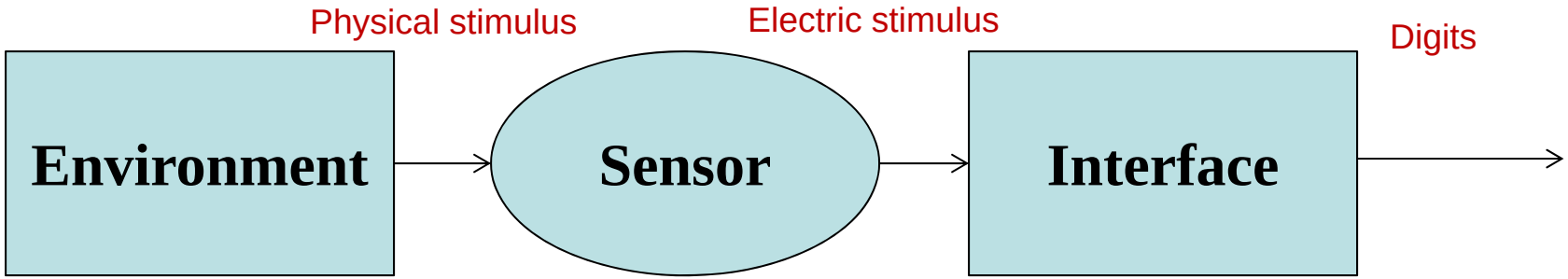
Sensors interfacing and data acquisition

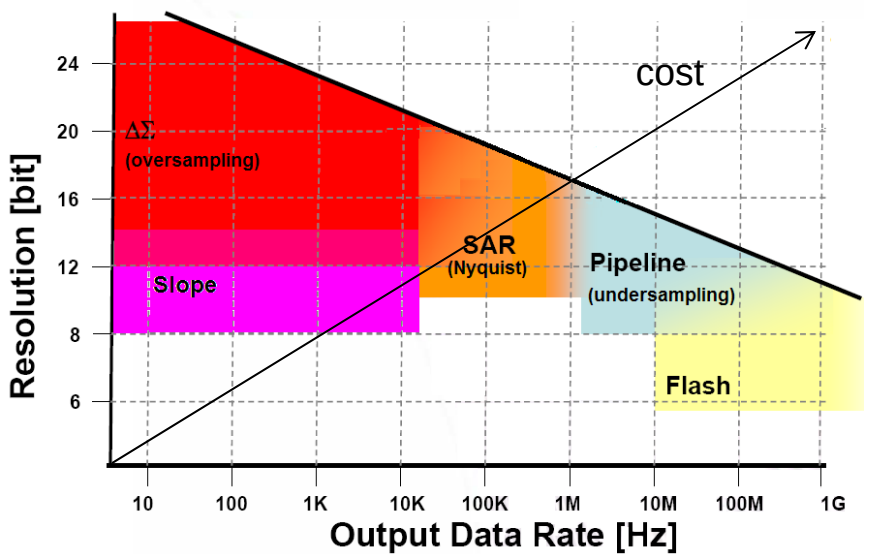
- Sensor interface is usually an electronic circuit that provides the power supply to the sensor (if needed); filters the signals to eliminate unwanted noise; amplifies the signal and converts it in a form more suitable to be transmitted.

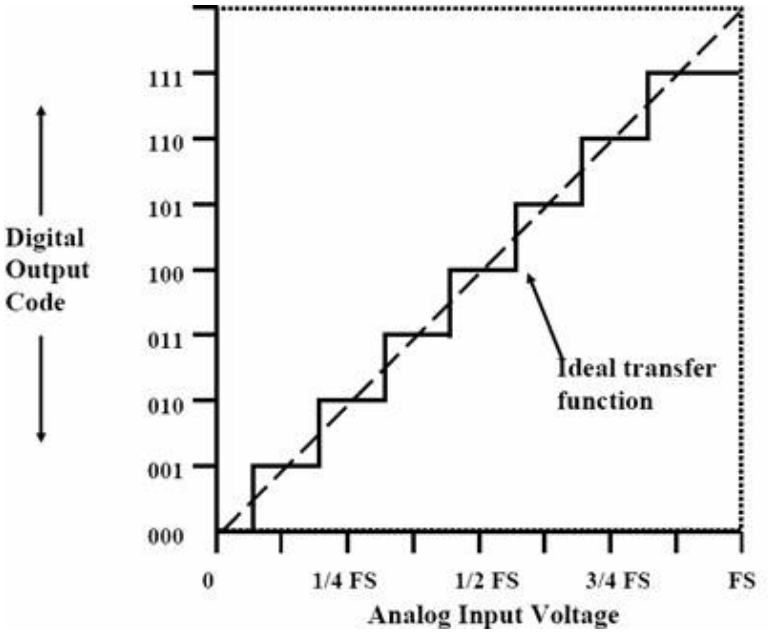


- The interface:
  - It is usually responsible of the sensor resolution, which is essentially due to the signal noise ration capability of the circuit.
  - More close is the interface to the sensor and better signal noise ratio it is possible to achieve at minor cost.
  - The modern interfaces have an Analog to Digital Converter (ADC) that convert the electric signal in binary code string.
  - If the sensor and the interfacing with ADC are built in the same package than it is a digital sensor. (e.i. SHT21)
  - Digital sensors usually provides directly the measure of the physical quantity not the measure of the electric quantity

Sensors interfacing and data acquisition

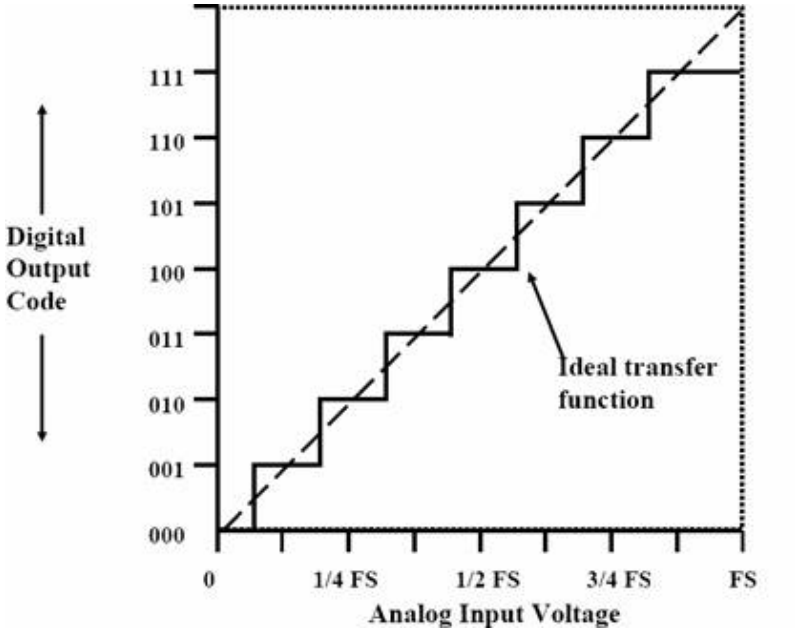
- Analog to Digital Conversion (ADC)
  - Analog to Digital converter is a circuit that typically translate a voltage in a binary digital string (or binary number)
  - The ADC main characteristics are:
    - Resolution, how many binary digits has the output string
    - Sample rate, how many string can the ADC take at each second





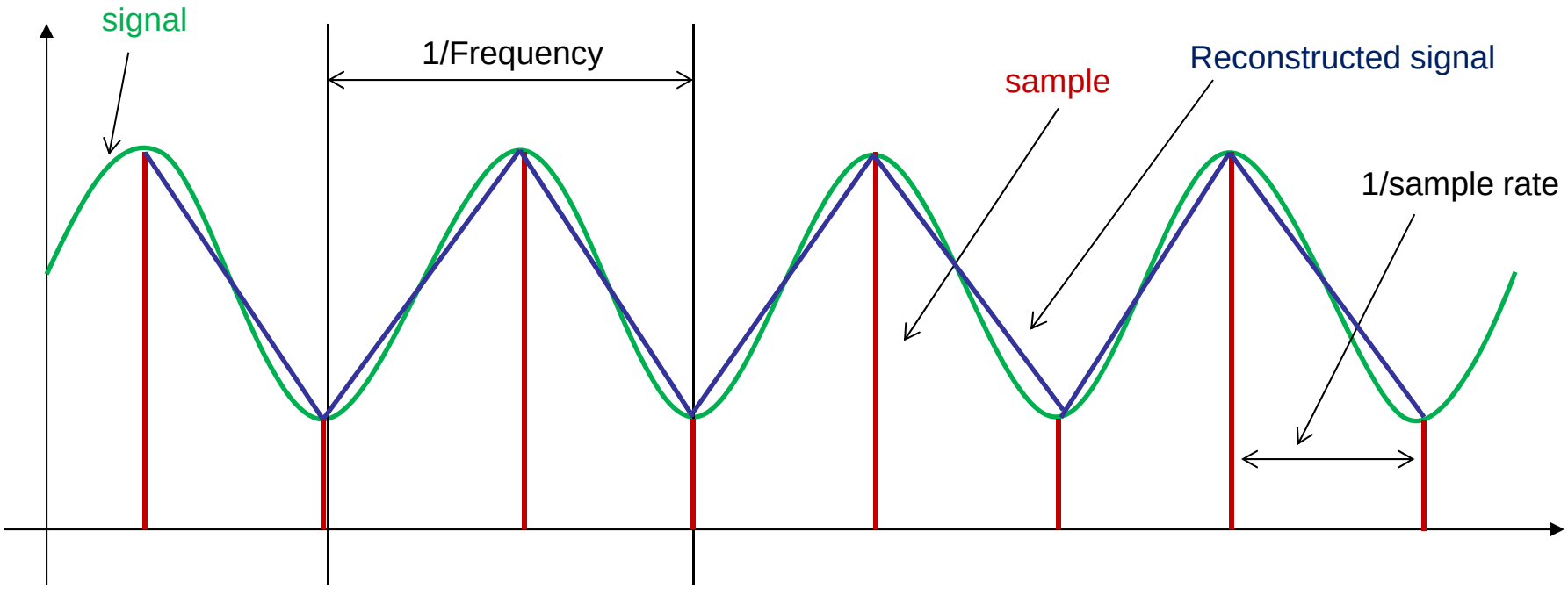
Sensors interfacing and data acquisition

- Analog to Digital Conversion (ADC) resolution
  - An ADC can represent the entire range of signal input using the number of binary digits express in the resolution. Than if we have a 8 bits ADC it means that the entire range is divided in $2^8 = 256$ segments (signal quantization). Therefore the smallest number representable is a 1/256 of the maximum value.
  - E.i. If we have a linear temperature sensor raging from 0 to 100ºC and we interface it with an 8 bit ADC, the minimum detectable temperature variation would be 100/256=0,39ºC
  - The ADC resolution typically range from 8 bit to 24 bit



Sensors interfacing and data acquisition

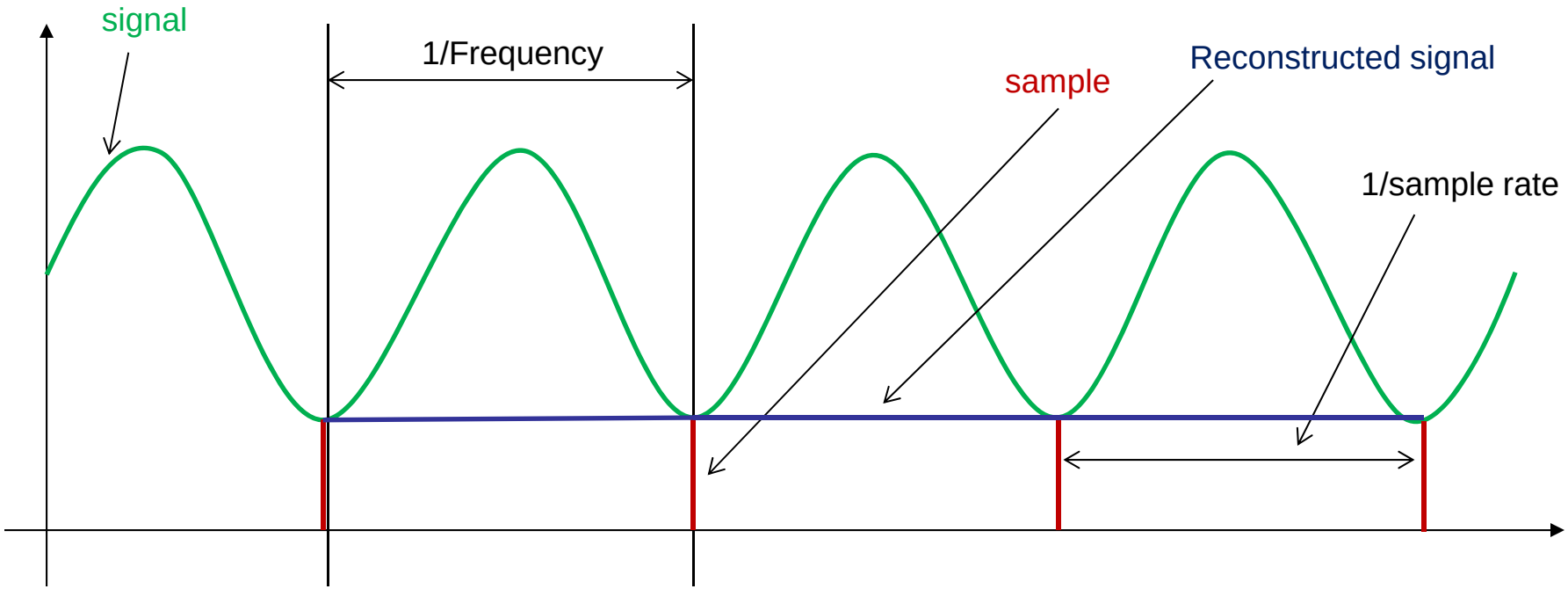
- Analog to Digital Conversion (ADC) sample rate
  - The sample rate is important to have da correct temporal representation of the signal
  - The Shannon theory explain that a signal as to be converted in digital form with at least double sample rate of the maximum frequency
  - E.i. music is sampled at 44,1Khz because we can hear till 20Khz



Sample rate = 2 * frequency

Sensors interfacing and data acquisition

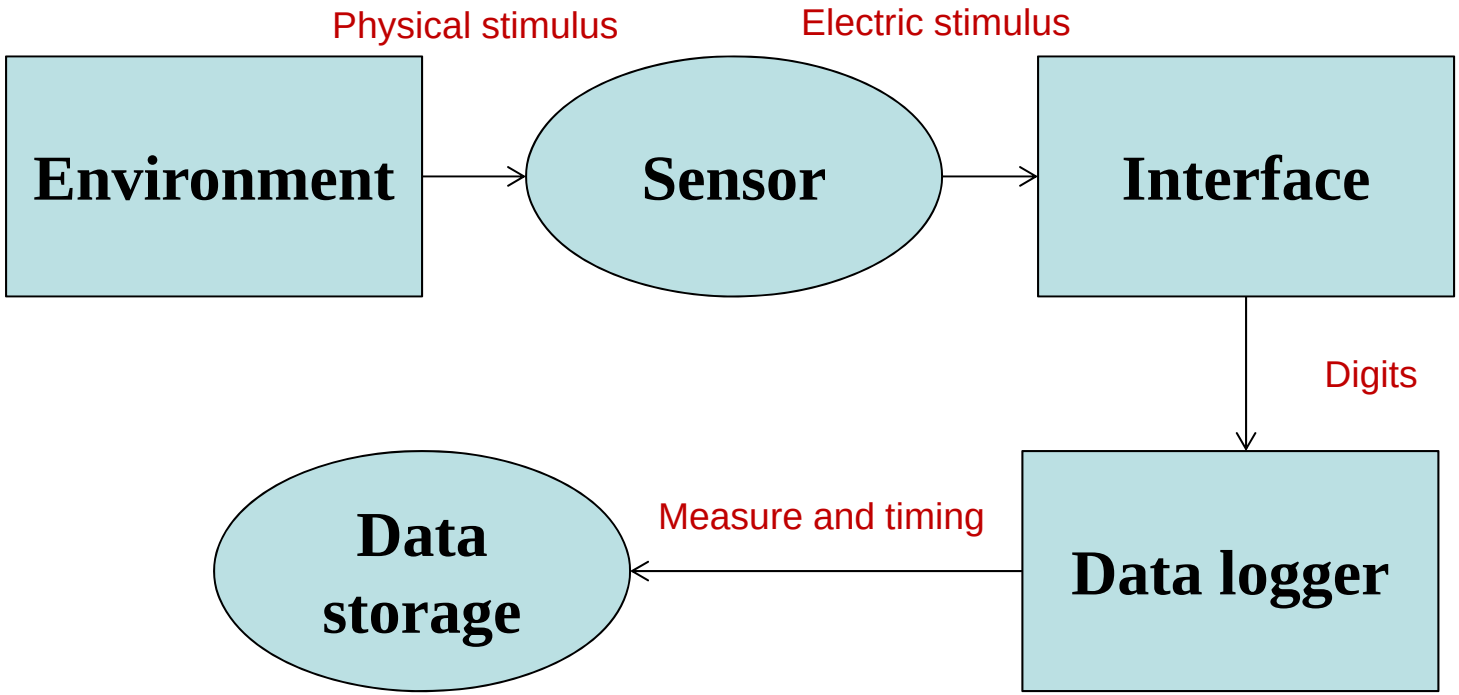
- Analog to Digital Conversion (ADC) sample rate



Sample rate = frequency

Sensors interfacing and data acquisition

- Data logger



- A data logger collect the sensor information in a data storage with the timing information of the acquisition
  - Off the shelf there are data logger that have analog and digital interfaces to collect data from digital and analog sensors.
  - The analog interface main component is ADC, then it is characterized by digital resolution and sample rate as the ADC.

Sensors interfacing and data acquisition

- Commercial data logger

  - There are commercial data logger with analog channel design to measure electric quantity as voltage, current, resistance, capacitance, etc.
  - Most of the data loggers can be connected to a PC to program them and to show the data collected to the user
  - Moreover there are software to elaborate the data in the way to obtain directly the value of the measured physical entity

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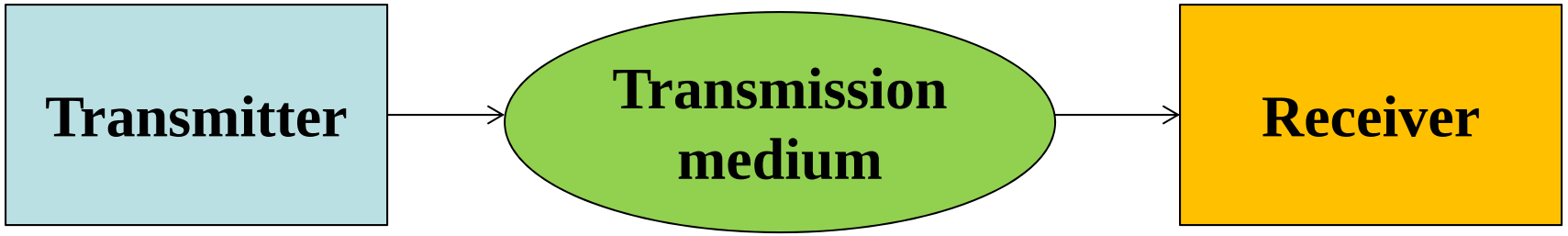
Data transmission

- Transmission is the process to send information from a transmitter to a receiver throw a communication channel



- Transmitter is the electronic circuits that convert the digital data to a energy waves able to propagate throw the transmission medium (modulation)
- Receiver is the electronic circuits that convert the energy waves present in the transmission medium to a digital data (Demodulation)
- Transceiver is a transmitter and receiver in the same electronic circuit
- Data transmissions speed is characterized by the bit per second (bps), a byte is composed of eight bits.

Data transmission

- Transmission medium is the physical material that permit the propagation of energy waves.
  - Data transmission typically use electromagnetic waves able to propagate in: Air, cables, optic fiber.
- Transmission media usually used are:
  - Air: Radio communication with a modulation that permit the division of the media with several radio channels. Each channel has is own carrier wave at fixed frequency.
  - Cables: communication with a modulation that can divide the media with one or several radio channels.
    - The cable can have two or more wires. Two wires make a transmission line.
    - If a communication is done with one transmission line is called serial.
    - If a communication is done with more transmission lines is called parallel.
  - Power line: The power line is used as transmission line with more than one radio channels; the AC power goes in the lower frequency channel meanwhile the information goes to the higher frequency channel

Data transmission

- Transmission can be:

- Simplex one user to one or more users (television, Radio).
  - It use one radio channel and/or one transmission line

- Half duplex bidirectional but one user at time (Walkie - talkie).
  - It use one radio channel and/or one transmission line

- Full duplex bidirectional two user contemporarily (telephone).
  - It use two radio channel and/or two transmission line

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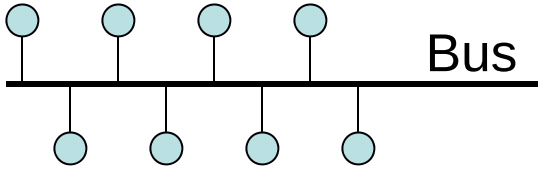
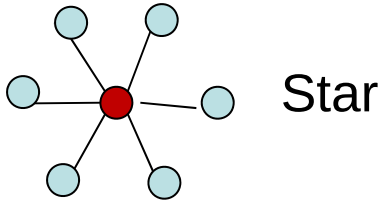
Network infrastructure and protocol

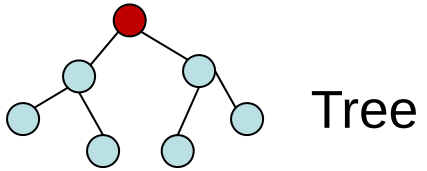
- Network is a collection of transceiver interconnected each others
- The network can have different topology
- Bus topology
  - Each transceiver is connected to the same transmission line and can communicate with every other transceiver



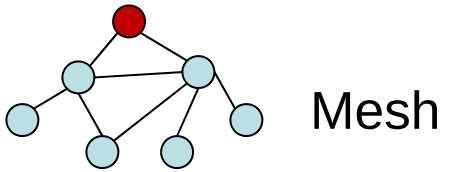
- Star topology
  - Each transceiver is connected to a dedicated transmission line and can communicate directly only with the center star transceiver



- Tree topology
  - Each transceiver (called also node) is connected to more dedicated transmission lines and can communicate directly with their parent and children



- Mesh topology
  - Each transceiver (called also node) is connected to a more dedicated transmission line and can communicate directly with several nodes

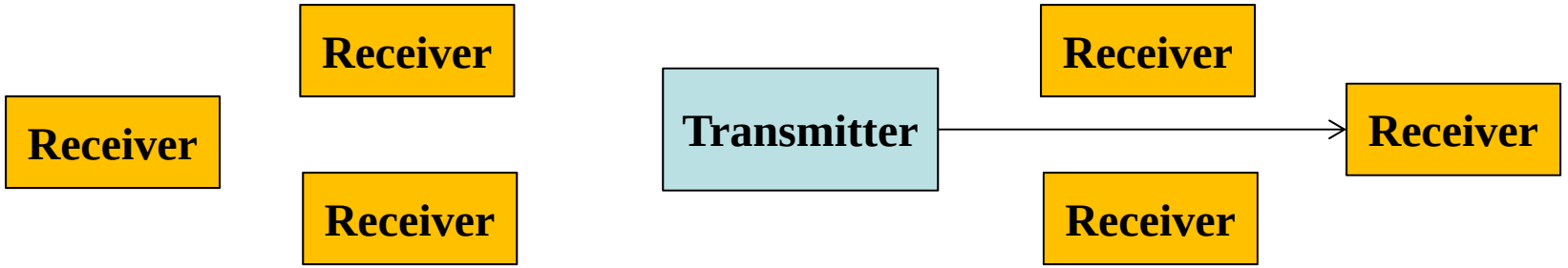


Network infrastructure and protocol

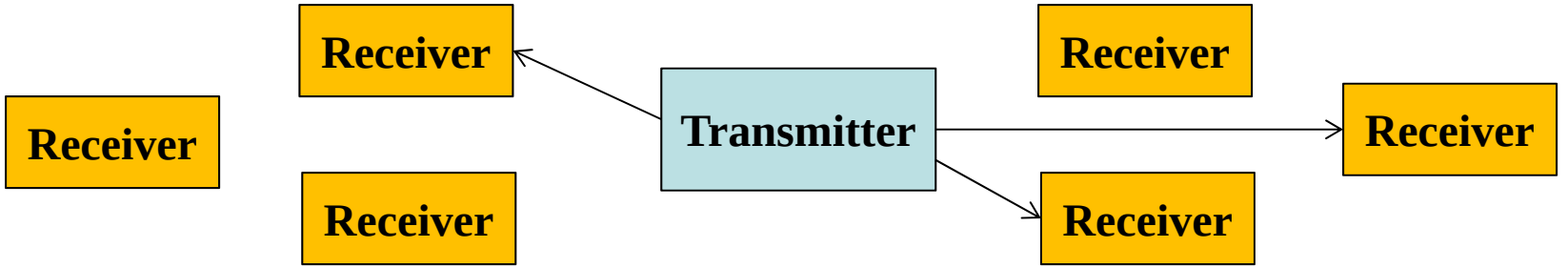
- Protocol is a collection of rules that each components of the network should respect to permit the communication and the execution of the services that the network will provide
- The protocol define:
  - Transmission data packet, that contain addressing information, command and data.
  - Commands (to manage and control the network)
  - Addressing rules
  - Network services
  - Network hierarchy
  - Modulation type
  - Physical characteristic of the transmission
  - The transmission medium

Network infrastructure and protocol

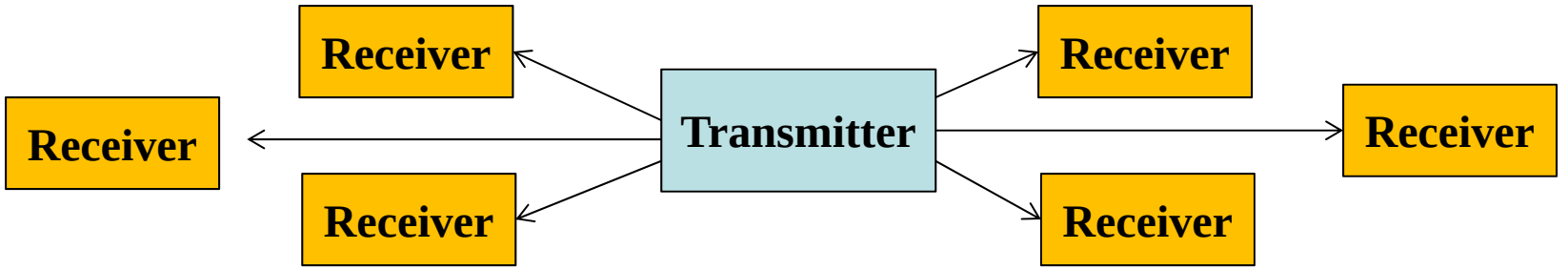
- Routing and addressing can be:



- Unicast one user to one in a network (point to point)



- Multicast one user to many users (point to multipoint)



- Broadcast one to all (point to all)

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X10

- Standard introduced by the Pico Electronics in the 1975 with the aim to integrate at low cost lighting devices with controls devices.
- Use power line transmission.
- Still highly used, especially in the USA.

- It is typically constituted by a *Controller* and a certain amount of receivers, connected to power plugs.

- The transmission is typical unidirectional from the Controller to the receivers.

- The pretocol has been extended for bidirectional comunication but there are not many device able to do that (called Two-way)

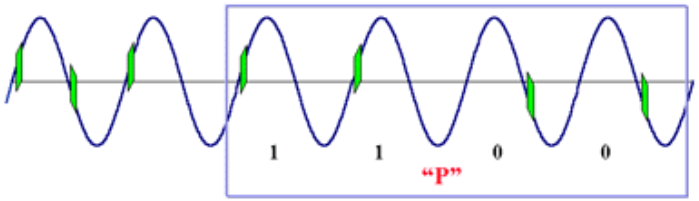
- It is possible to build a network up to 256 receivers.

X10

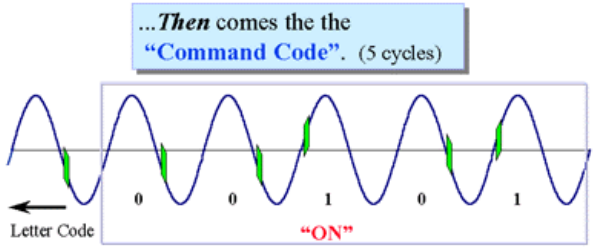
- Most used controller is the Marmitek CM11
- The data packet is composed by a start code and addressing field
- The start code is 1110.
- The addressing is composed by an house code and key code.
- The key codes can be an unit code or function code

HOUSE CODES					KEY CODES					
	H1	H2	H4	H8		D1	D2	D4	D8	D1
A	0	1	1	0	1	0	1	1	0	0
B	1	1	1	0	2	1	1	1	0	0
C	0	0	1	0	3	0	0	1	0	0
D	1	0	1	0	4	1	0	1	0	0
E	0	0	0	1	5	0	0	0	1	0
F	1	0	0	1	6	1	0	0	1	0
G	0	1	0	1	7	0	1	0	1	0
H	1	1	0	1	8	1	1	0	1	0
I	0	1	1	1	9	0	1	1	1	0
J	1	1	1	1	10	1	1	1	1	0
K	0	0	1	1	11	0	0	1	1	0
L	1	0	1	1	12	1	0	1	1	0
M	0	0	0	0	13	0	0	0	0	0
N	1	0	0	0	14	1	0	0	0	0
O	0	1	0	0	15	0	1	0	0	0
P	1	1	0	0	16	1	1	0	0	0
					All Units Off	0	0	0	0	1
					All Lights On	0	0	0	1	1
					On	0	0	1	0	1
					Off	0	0	1	1	1
					Dim	0	1	0	0	1
					Bright	0	1	0	1	1
					All Lights Off	0	1	1	0	1
					Extended Code	0	1	1	1	1
					Hail Request	1	0	0	0	1
					Hail Acknowledge	1	0	0	1	1
					Pre-Set Dim	1	0	1	X	1
					Extended Data (analog)	1	1	0	0	1
					Status=on	1	1	0	1	1
					Status=off	1	1	1	0	1
					Status Request	1	1	1	1	1

X10

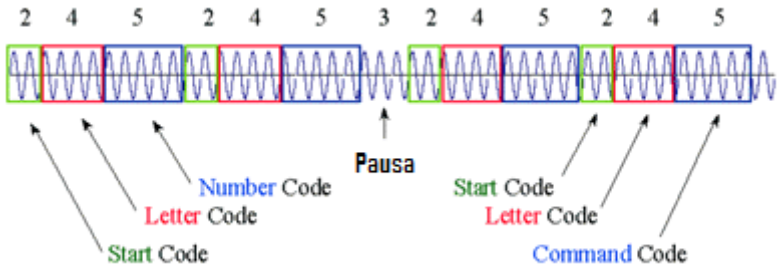


A = 0110	E = 0001	I = 0111	M = 0000
B = 1110	F = 1001	J = 1111	N = 1000
C = 0010	G = 0101	K= 0011	O = 0100
D = 1010	H = 1101	L = 1011	P = 1100



On = 00101	All Lts On = 00011	Bright = 01011
Off = 00111	All Units Off = 00001	Dim = 01001

....and there are 9 other commands but they are rarely used.



X10

- The producer offer devices that the address can be configure with a mechanical switch, or with proprietary bus commands.

Drawback

- Not compability between X10 for the USA market and the Eurpean market
- Low data rate
- Attenuation due to older appliance (as CRT monitor)
- Crosstalking between two near X10 network
- Sensitivity to the discharge lamps noise

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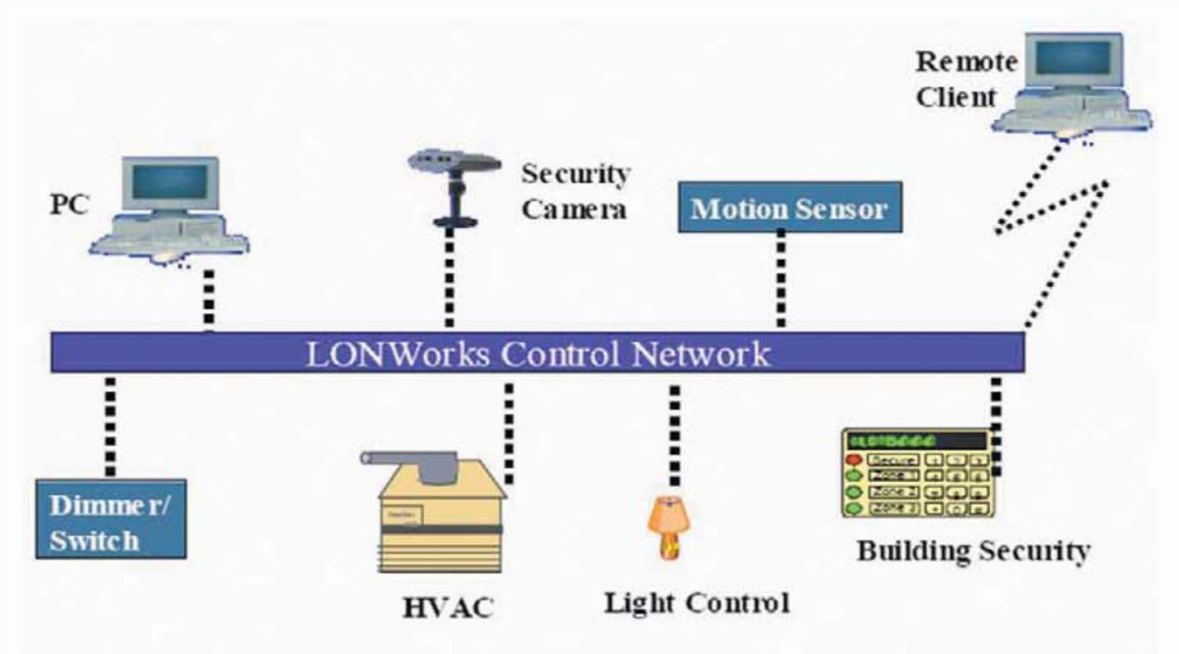
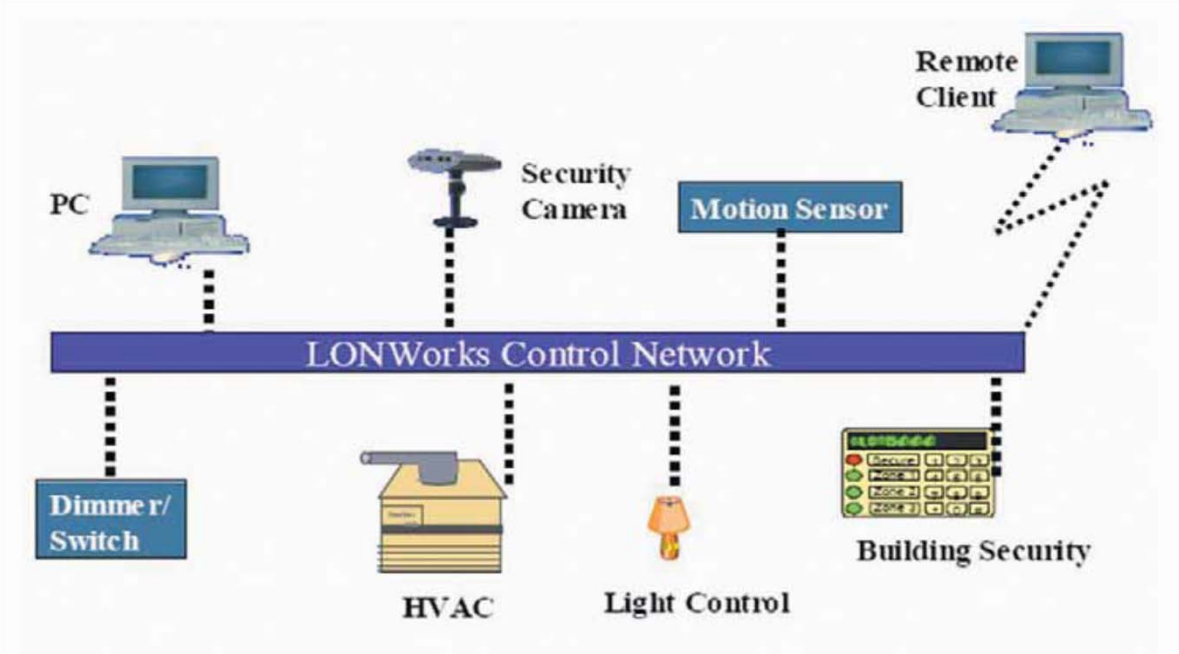
LonWork



- LonWork has been developed by Echelon as a communication technology that use the same protocol to interconnect devices connected to a different transmission medium, as twisted pair, power line, optic fiber and TCP/IP.
- Lon means Local Operating Network and identify network for transmit sensor and actuators status and data.

LonWork



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LonWork

- The comunication is based to the protocol LonTalk, which address different media
- LonWork rapidally spreaded in the building automation for HAVC (heating, ventilation, air conditioning), lighting, access control and fire allarm.
- LonWork has gained consideration in industrial sector and for the realizzation of smart metering
- In the last years LonWork is used for managing energy efficiency in smart building and reduce the mainteinance building cost

LonWork

- The fundamental concept of the LonWork is to put the intelligence directly where the function is implemented, than in the sensors and actuators.

- The LonWork network is based upon three fundamental units:
  - LONTalk
  - Neuron Chip
  - LSN (Lonwork netowork service) that is the network operative system.

- Neuron chip is the Lonwork transceiver that automatically manage the protocol and permit an easy realization of lonwork device. Then a producer can realize a Lon device using the neuron chip without know anything about the Lon protocol.

LonWork

Off the shelf are present LonWork trasceiver for:

- twisted pair cables
- Power line
- Radio transceiver for 400-470Mhz and 900Mhz

- Lonwork can manage huge network and provide a network infrastructure to realize all type off addressing (unicast, multicast, broadcast)

- The data packet is light and there is a priority police to permit the delivery in time of urgent data.

LonWork

- The addressing is divided in domain, sub network, nodes to simplify the routing. Can be defined
- 2^{48} Domain
- 127 sub-network in a domain
- 127 nodes in each sub-network.

- LonWork has network variables, that can be configure at installation time. It is possible to associate to a sensor output a variable which could be readed by an actuator automatically, using the binding process. The tool ICELAN provide all the support to do that.

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KNX

- KNX is based up three precedent european standard.
- It is sutable for the creation of smart building thank its capability to excahnge information between switch, actuators, motors and HAVC.

- KNX use different transmission media as:
  - Twisted pair
  - Powerline
  - RF at 868Mhz

- The comunication it is based to data points.
- A data point is a control variable of the system.
- A data point is inside a group object that is the functional system unit

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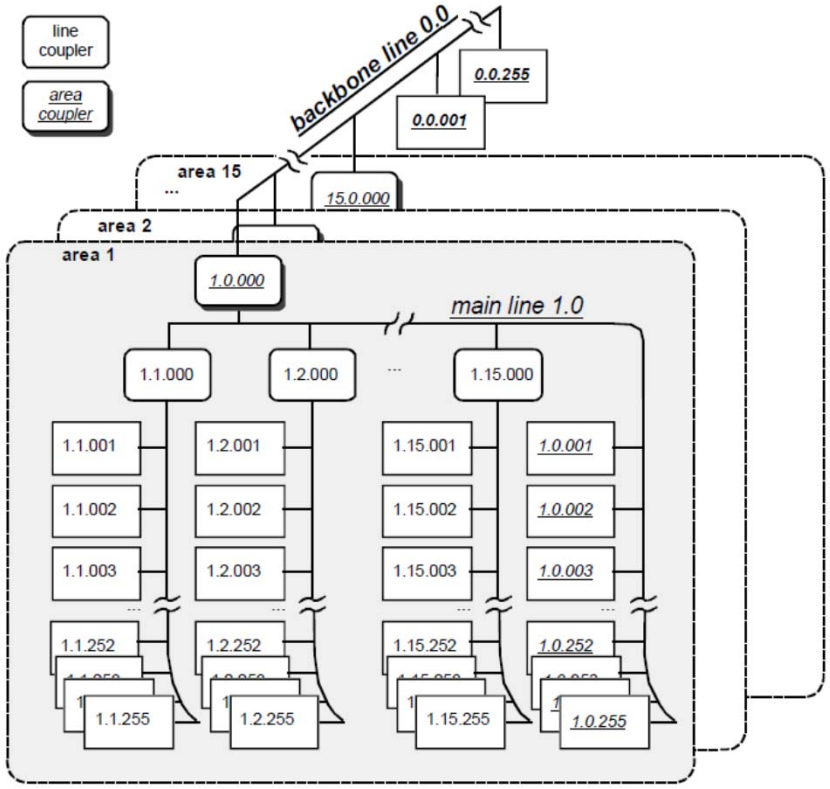
KNX

- A device can read and write a data point.
- Then if a switch can write is status and a relay actuator can read the value, than the actuator can know when turn on or off the light in relation of the switch state.

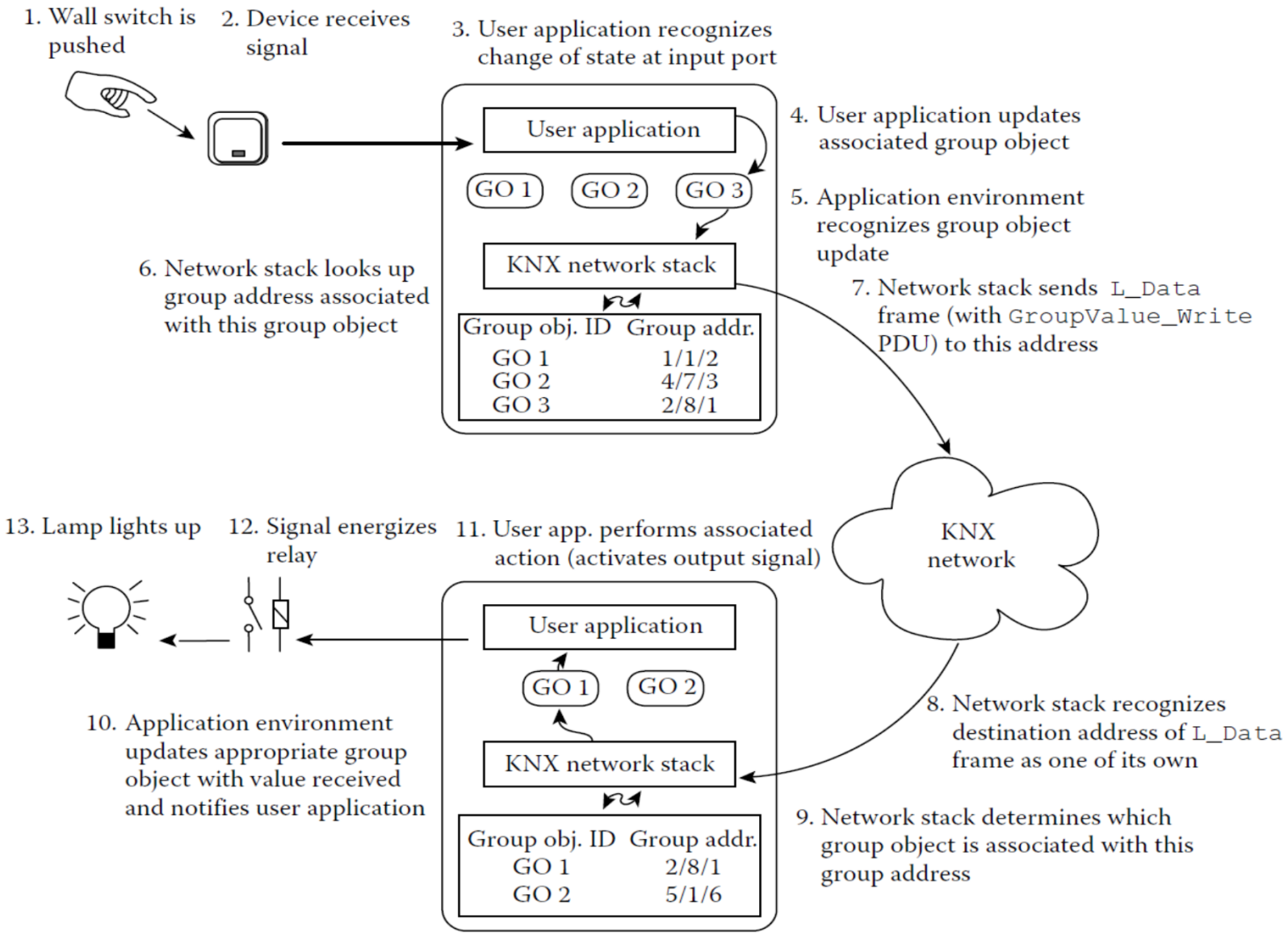
- KNX is the bridge to permit the single node to write and read datapoints, creating the system

KNX

- Each device must have a logical address that identify univocally the device.
- The logical address is compose: 255 deivices in 15 main lines, insides at 15 areas and everytingh connected with the backbone line.
- The gruop object has its own obejct address
- More group object can be associated to the same object address (multicast)
- Gruop address the same structure of logical address

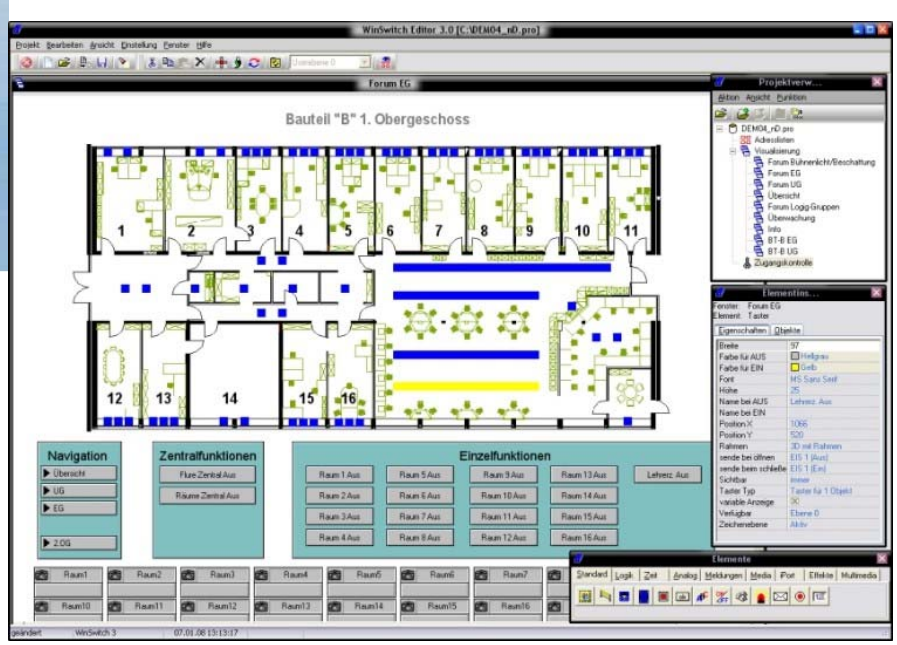


KNX


1. Wall switch is pushed
2. Device receives signal
3. User application recognizes change of state at input port
User application
GO 1
GO 2
GO 3
KNX network stack
Group obj. ID Group addr.
GO 1 1/1/2
GO 2 4/7/3
GO 3 2/8/1
4. User application updates associated group object
5. Application environment recognizes group object update
6. Network stack looks up group address associated with this group object
7. Network stack sends L_Data frame (with GroupValue_Write PDU) to this address
KNX network
8. Network stack recognizes destination address of L_Data frame as one of its own
9. Network stack determines which group object is associated with this group address
User application
GO 1
GO 2
KNX network stack
Group obj. ID Group addr.
GO 1 2/8/1
GO 2 5/1/6
10. Application environment updates appropriate group object with value received and notifies user application
11. User app. performs associated action (activates output signal)
12. Signal energizes relay
13. Lamp lights up

KNX

- In the market there are a lot of KNX devices, as sensors, actuators,
- Supervisor systems



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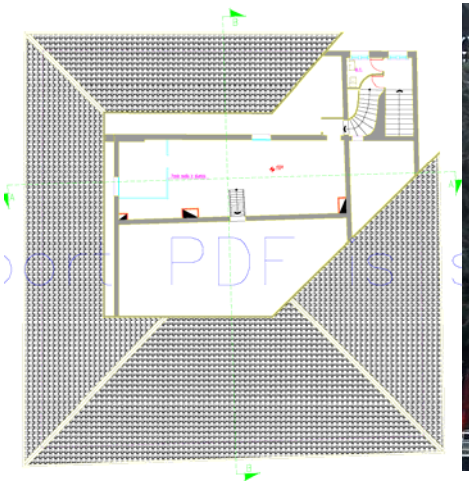
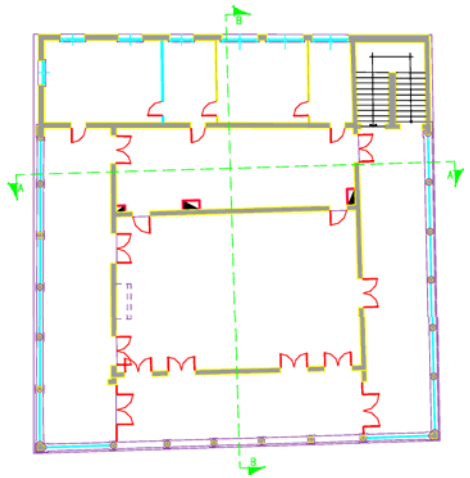
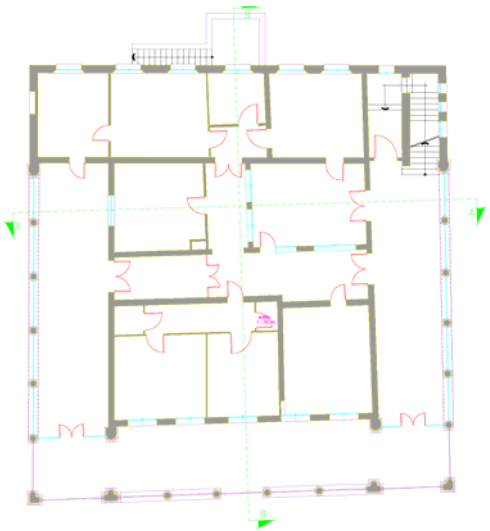
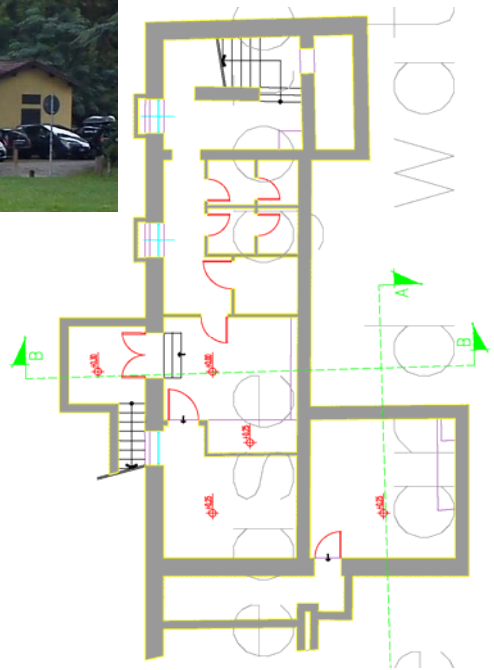
Palazzina della Viola









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Wireless sensor node used

- 32Mhz 32Mbit microprocessor
- 2.4Ghz radio transceiver
- Zigbee Pro compliant
- Aggressive power management (sleep mode 8µA) for long battery life
- MicroSD card for local data logging
- On board sensors
  - Temperature (0.01°C resolution)
  - Humidity (0.04°C resolution)
  - Light sensor (0.23 lx resolution)
  - 3-axis accelerometer (1mg resolution)
  - Gas sensor interface (10% resolution)
    - VOC, CO, NHx, O3, NH4
- Analog input with 12bit resolution and 300khz sample rate
- 10 digital input/output
- 1 UART (convertible to RS232, RS422, USB)
- 1 I2C (used to communicate with IC sensors)
- 1 SPI (used to communicate with fast IC sensors and external Analog Digital converter)
- 3V 1.5W fully controlled DC output power supply for both external sensors and expansion board

Ad hoc developed wireless protocol

Main characteristics

- WSN fully configurable with multi-hop radio link capable to operate for years.
- Each device can be configured either by USB or remotely with radio link to:
  - Set the device ID, PAN ID, radio channel
  - Check the list of neighbor device with radio link quality
  - Select the network parent device in order to build up a network custom tree
  - Check sensor state (disable/enable), sample time and batteries voltage, check network parameters.
- The network coordinator uses the USB to:
  - Set each node sensor state (enable/disable)
  - Set sample time
  - Provide data collected from every device connected to the network
  - Set date

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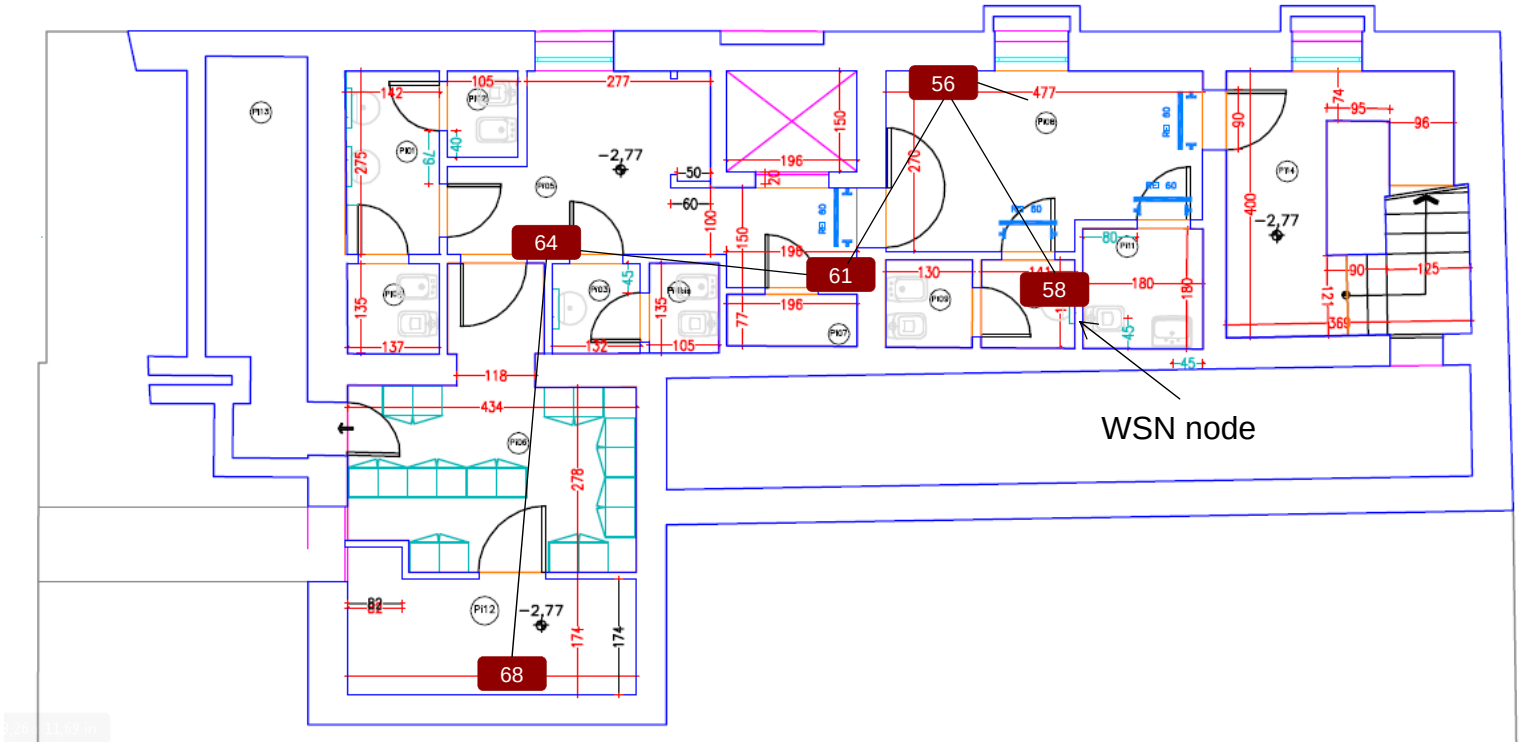
Deployment



ID	Address
56	11
58	89
61	8a
64	451
68	2289

Underground floor

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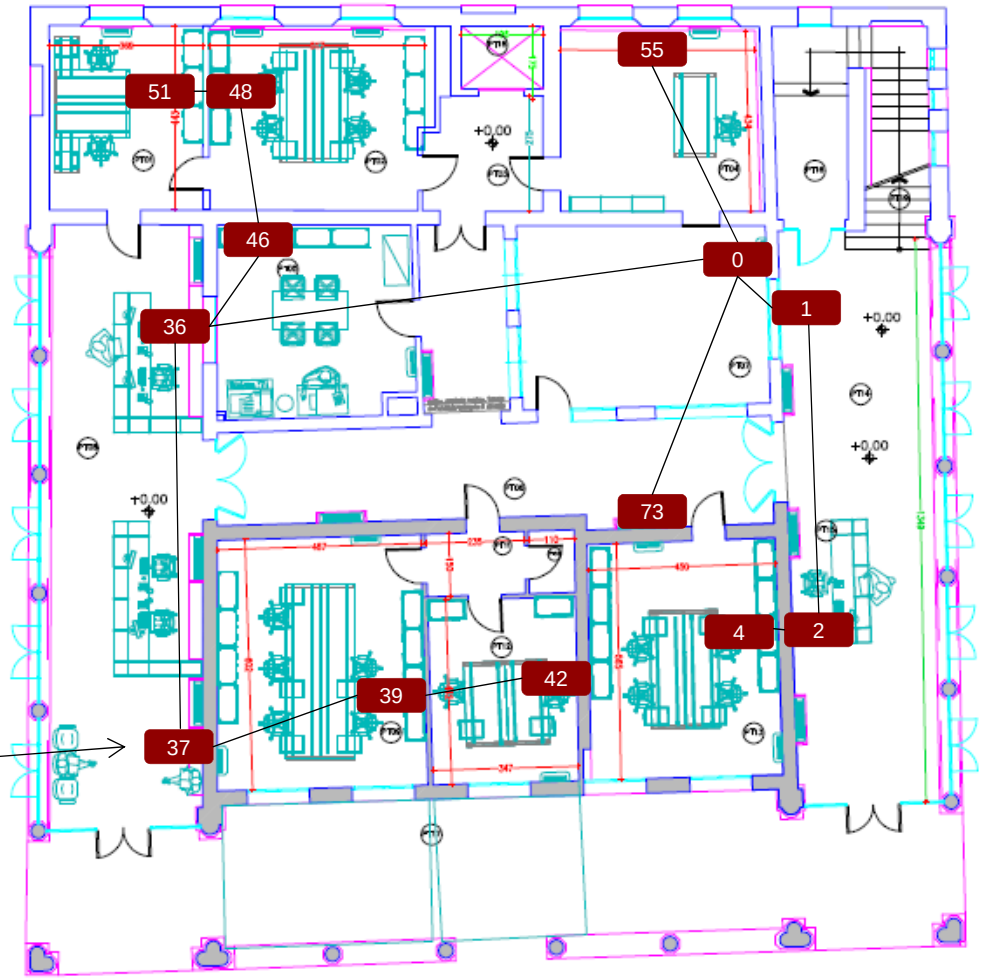
Deployment

Ground floor



WSN node

ID	Address
0	0
1	1
2	9
4	49
36	3
37	19
39	c9
42	649
46	1a
48	d1
51	689
55	2
73	7

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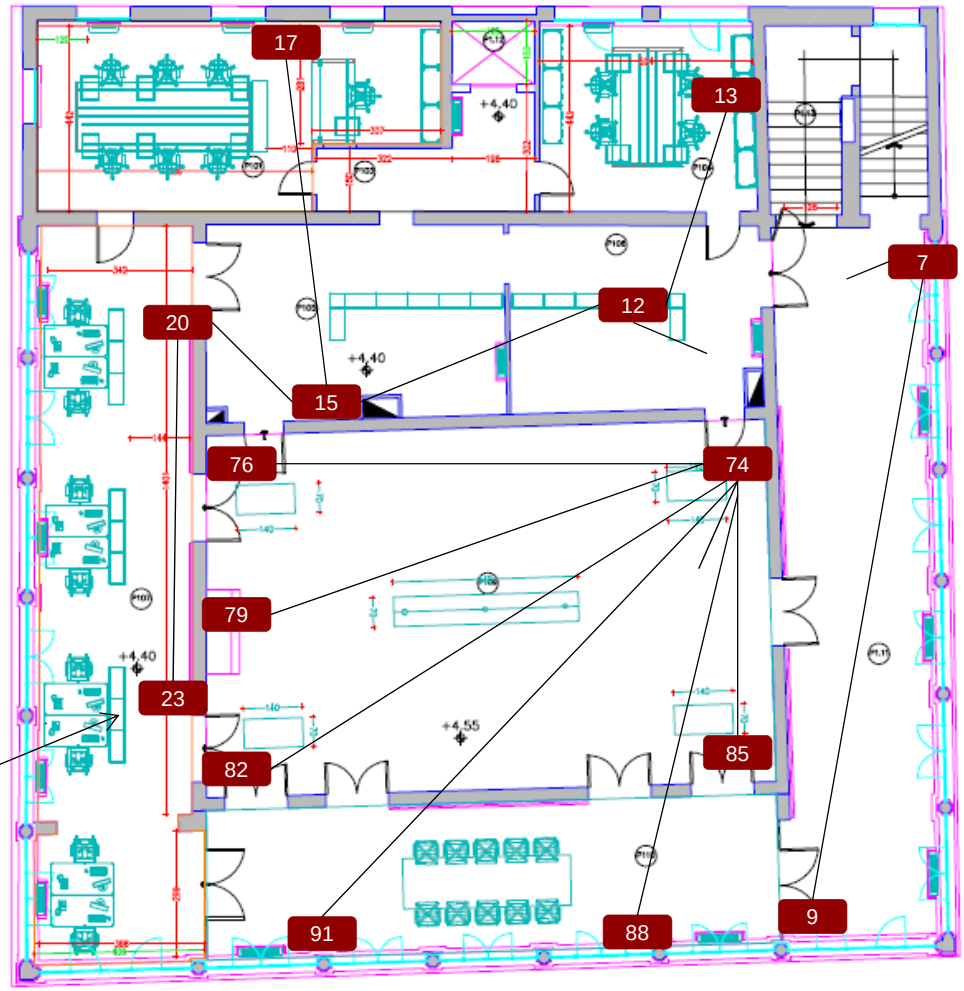
Deployment

First floor



ID	Address
7	a
9	51
12	4
13	21
15	22
17	111
20	112
23	891
74	39
76	1c9
79	1ca
82	1cb
85	1cc
88	1cd
91	1ce

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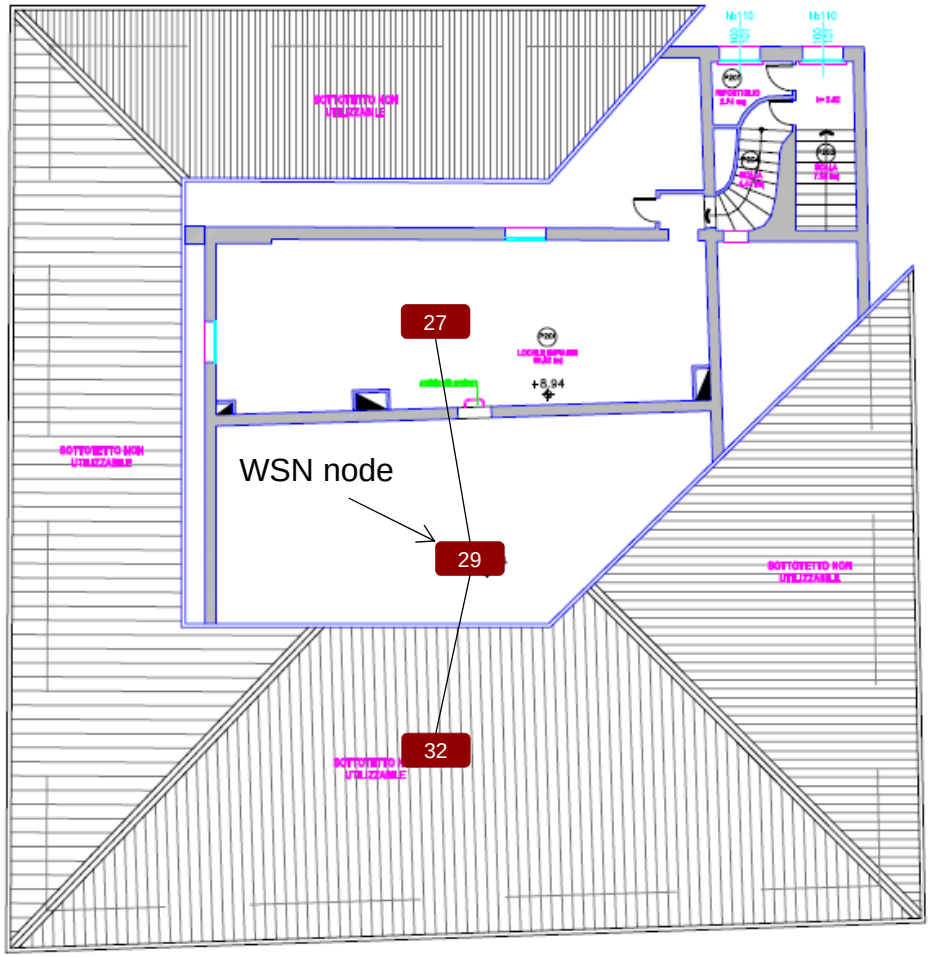
Deployment

Attic floor



ID	Address
27	23
29	119
32	8c9

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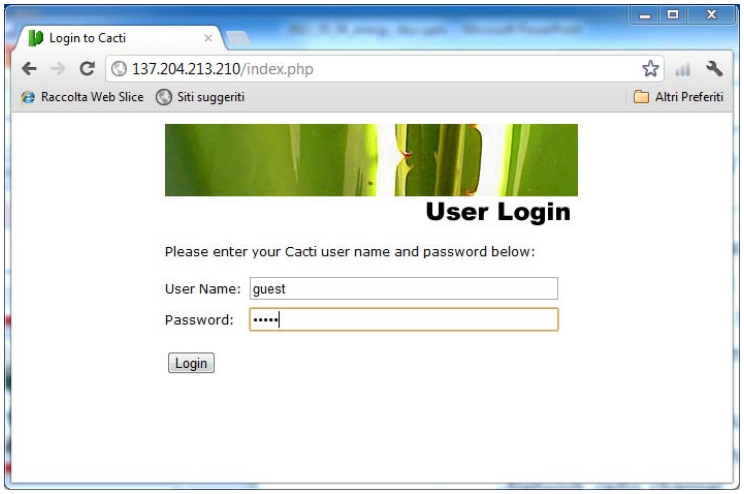
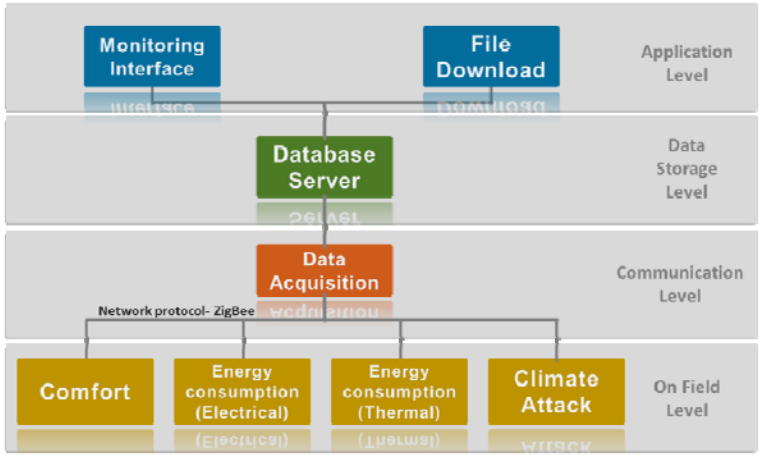
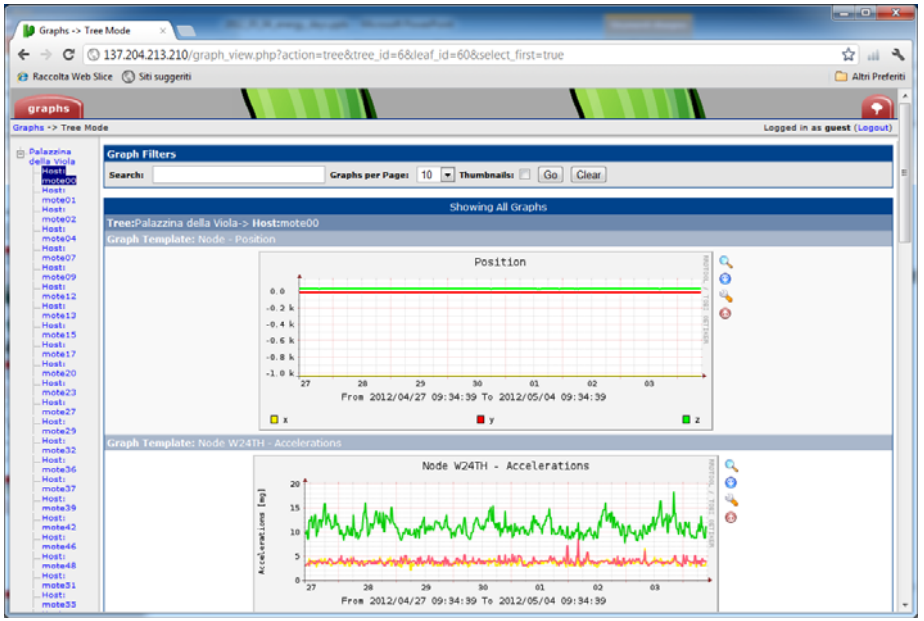
User Interface developed



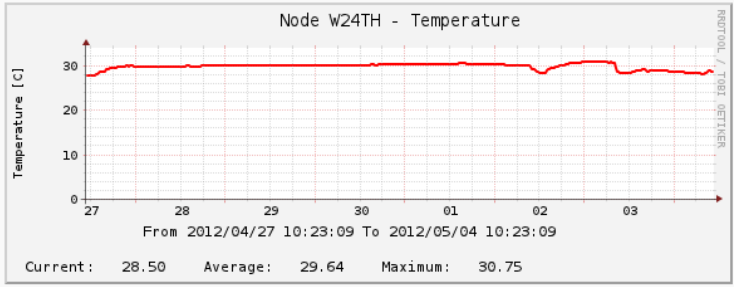
The data are sent to a web server.
The web server is accessible at the page:
137.204.213.210
User:guest
Password:guest

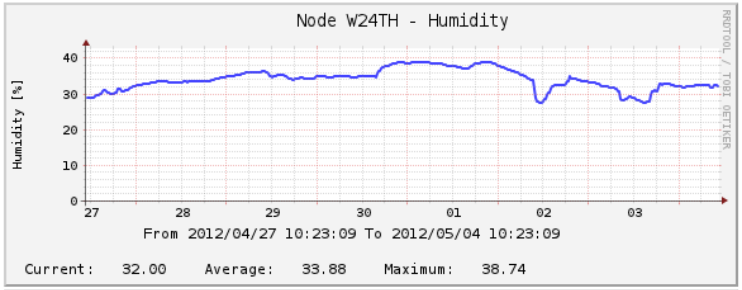




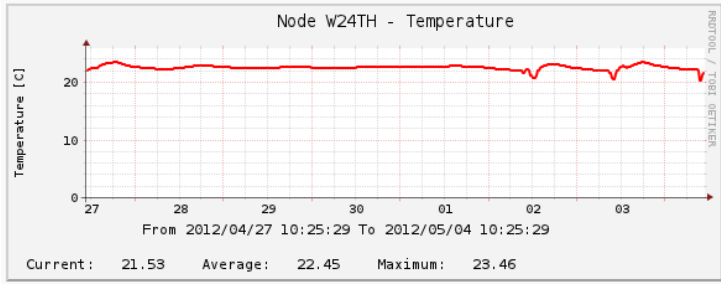
Data collected sample

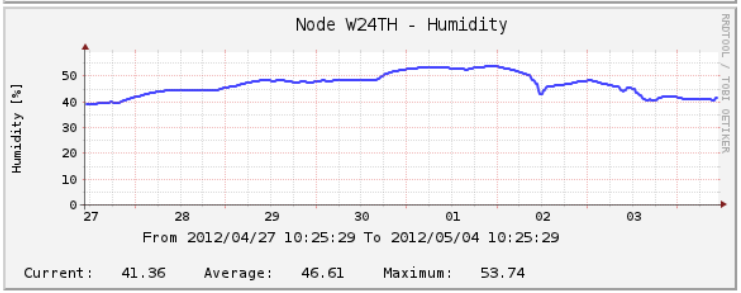
- Underground



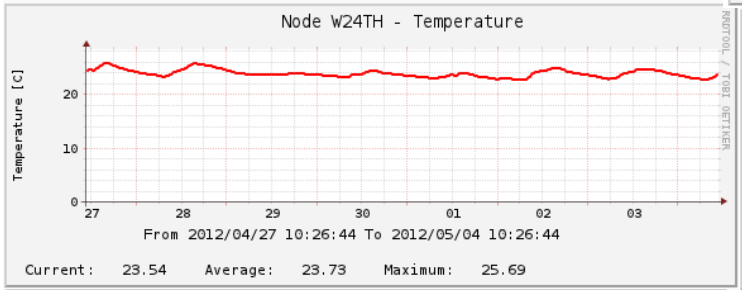


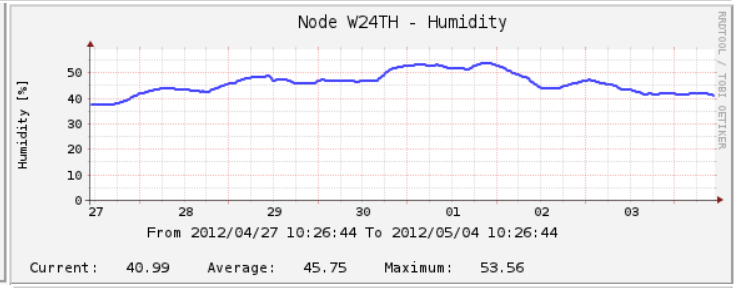
- Ground floor





- First floor





- Attic floor