




ISTITUTO SUPERIORE MARIO BOELLA

WIRELESS TECHNOLOGIES FOR THE INTERNET OF THINGS

MIRKO FRANCESCHINIS

Workshop on Scientific Applications
for the Internet of Things (IoT)
16-27 March 2015, ICTP – Trieste

I S M B
Istituto Superiore Mario Boella

Pervasive Technologies

ABOUT ME

- 2000 – Telecommunication Engineering Master Degree at Politecnico di Torino
- 2003 – Communication Engineering PhD Degree at Politecnico di Torino
- 2004 – Research Grant on Wireless Networks at Politecnico di Torino
- [2005 - Today] – Researcher @ ISMB in the Pervasive Technologies (PerT) Area, mainly working on low-power wireless networks
- ISMB PerT Area
  - IoT Objects and Platforms
  - Pervasive Secure Networks
  - IoT Service Management

OUTLINE

- Part I – Basics and Short Overview
- Part II – Wireless technologies pre-IoT (autonomously existing)
  - RFID / NFC
  - WSN (IEEE 802.15.4 and “sons”)
  - UWB
  - Bluetooth / BLE
  - Technologies comparison
- Part III – Integration efforts in IoT through IPv6
  - 6LoWPAN
  - 6tisch
  - IPv6 over BLE

BASICS

- **Wireless** communication
  - Transfer of **information** between two or more points **not connected** by an electrical conductor
  - Refers to any type of communication operated **without** the use of **wires**
  - Different wireless technologies, according to the physical phenomenon
    - **Radio**, by means of **electromagnetic signals**
    - Free-space optical communication, uses **light** propagating in **free space**
    - **Infrared**, electromagnetic radiation with longer wavelengths than visible light
    - Ultrasonic, transmission and reception of **acoustic waves**
    - **Electromagnetic induction**, for short-range RFid tags
    - …

BASICS

- Frequency band
  - Light and radio use the electromagnetic spectrum for signals propagation
  - Public resource regulated by national organizations
  - Wireless communication spans the spectrum from 9 kHz to 300 GHz
- Radio communication range
  - The received signal power depends on
    - Transmission power
    - Distance among transmitter and receiver
    - Propagation environment and frequency band (reflections, interference)
    - Antennas' gain

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

  - RSSI = Received Signal Strength Indicator, measured at the receiver
  - LQI = Link Quality Indicator, based also on RSSI

BASICS

- Bit rate
  - Defined as the number of bits that physically can flow on the wireless medium
  - Measured in [bit/s]
  - Depends on Physical layer specifications, included modulations
  - Also known as transmission speed
  - Not to be confused with data rate or throughput/goodput
    - Each layer contributes to end-to-end delay
    - Transmission delay relates to bit rate and is just one responsible for latency

VERY SHORT OVERVIEW

- **First generation**: key role in extending **communications** potentialities among **people**
  - '**Anywhere, anytime, anyone**' paradigm
  - Main communication technologies
    - Cellular, from first generation (ETACS, '80s) to GSM, UMTS and nowadays LTE
    - WiMax, long-range wireless access to broadband networks (IEEE 802.16)
    - WiFi , short-range wireless access to broadband networks (IEEE 802.11)
    - …

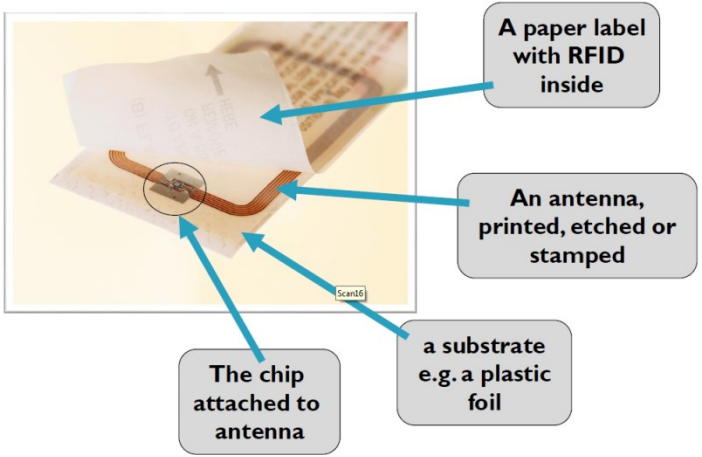
VERY SHORT OVERVIEW

- **Second generation**: new role in **communications** among **objects**
  - Favored by **reduction** of **cost, size, weight** and **energy consumption**
  - '**Anywhere, anytime, anything**' paradigm -> leading to **IoT concept**
  - Wireless technologies existing **independently of IoT**
    - RFID / NFC
    - WSN (IEEE 802.15.4 + ZigBee / WirelessHART / ISA100)
    - UWB
    - Bluetooth / BLE
  - Wireless technologies as **integration** efforts in **IoT** through **IPv6**
    - 6LoWPAN
    - 6tisch
    - IPv6 over BLE

RADIO FREQUENCY IDENTIFICATION – RFID

- Principle of functioning
  - One or more **reader**(s)
  - Several **tags**
    - characterized by a **unique identifier (ID)**
    - applied to '**products**' (objects, persons or animals)
  - **(Active) readers** trigger tag transmission by **generating** a **query**
  - **(Passive,** through **energy induction) tags** in surrounding area reply by announcing **their IDs**
  - Purpose: automatic **identification** and **tracking** of tags/objects

RFID tag

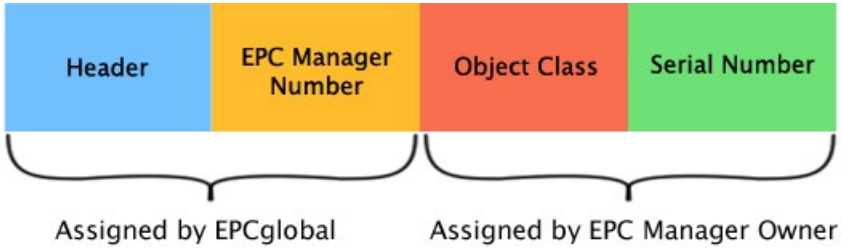


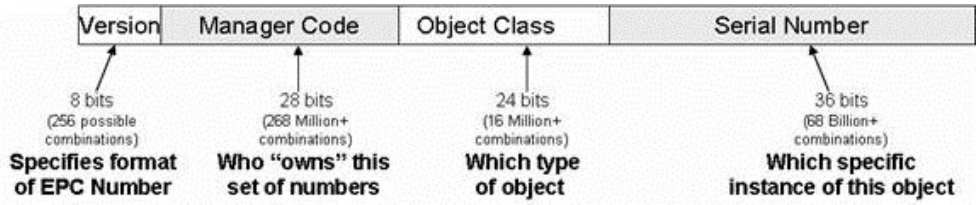
RADIO FREQUENCY IDENTIFICATION – RFID

- Main technical features
  - Radio communication **range**: a **few meters**
  - Extremely **reduced** tags **dimensions**: up to 0.4 mm x 0.4 mm x 0.15 mm
  - Several **application scenarios**, just a few examples
    - Logistics
    - Manufacturing
    - Waste management
    - E-health
  - **Frequency bands**
    - LF @ 124–135 kHz
    - UHF @ 860–960 MHz
    - … but even MF @ 13.56 MHz, HF and SHF @ different bands

RADIO FREQUENCY IDENTIFICATION – RFID

- RFID standardization
  - Main bodies
    - ISO and other recognized standardization bodies
    - EPCglobal (the most prominent industry standards for RFID)
  - Standards involve
    - The definition of communication protocols between the involved entities
    - The data structures and format





NEAR-FIELD COMMUNICATION – NFC

- Principle of functioning
  - Built on top of **existing RFID standards** @ 13.56 MHz, enabling two-way communication between end-points
    - Same physical technology as RFID
  - An **active initiator** generates an RF field powering a **passive target**
  - NFC communication either by a modulated **electric field**, or a modulated **magnetic field**, but not by radio (electromagnetic waves)

NEAR-FIELD COMMUNICATION – NFC

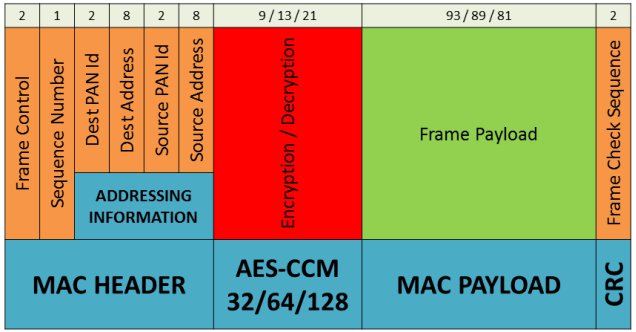
- Main technical features
  - Communication **range**: **10 cm** or less (difficult to eavesdrop on)
  - Extremely **reduced size**: typically **embedded** in smartphones and cards
  - **Bit rate**: from 106 kbps to 424 kbps
  - Applications
    - **Contactless payment systems**
    - Electronic identity documents
    - Access control
    - File sharing
  - **Frequency bands**: 13.56 MHz

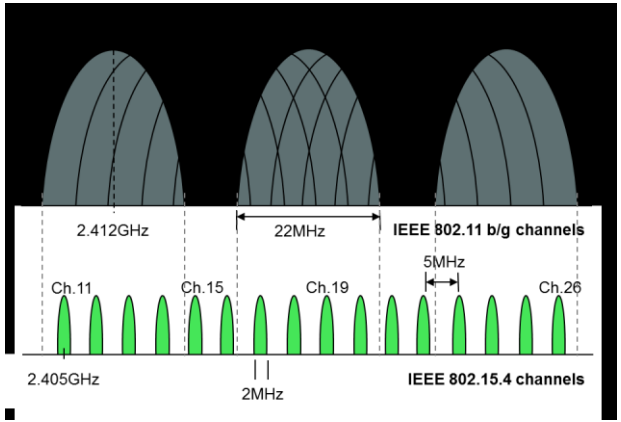
WIRELESS SENSOR NETWORKS – WSN

- Principle of functioning (standardized solution)
  - **IEEE 802.15.4** standardizes **PHY** and **MAC** layers
    - PHY features: radio (de)activation, transmit/receive packets on the medium, energy detection (ED), link quality indication (LQI), clear channel assessment (CCA)
    - MAC (alternative) functioning modes: 'Beacon-enabled' and 'Non beacon-enabled'
    - MAC protocol based on CSMA, TDMA optional for beacon-enabled mode
  - General purpose standard
  - Defines full-function devices (**FFD**) and reduce-function devices (**RFD**)
  - **Self-configuring**, **self-healing** capabilities (intelligent nodes)
  - **Mesh topologies** supported through multi-hop routing
    - Demanded to **NWK** layer, not in charge of IEEE 802.15.4

WIRELESS SENSOR NETWORKS – WSN

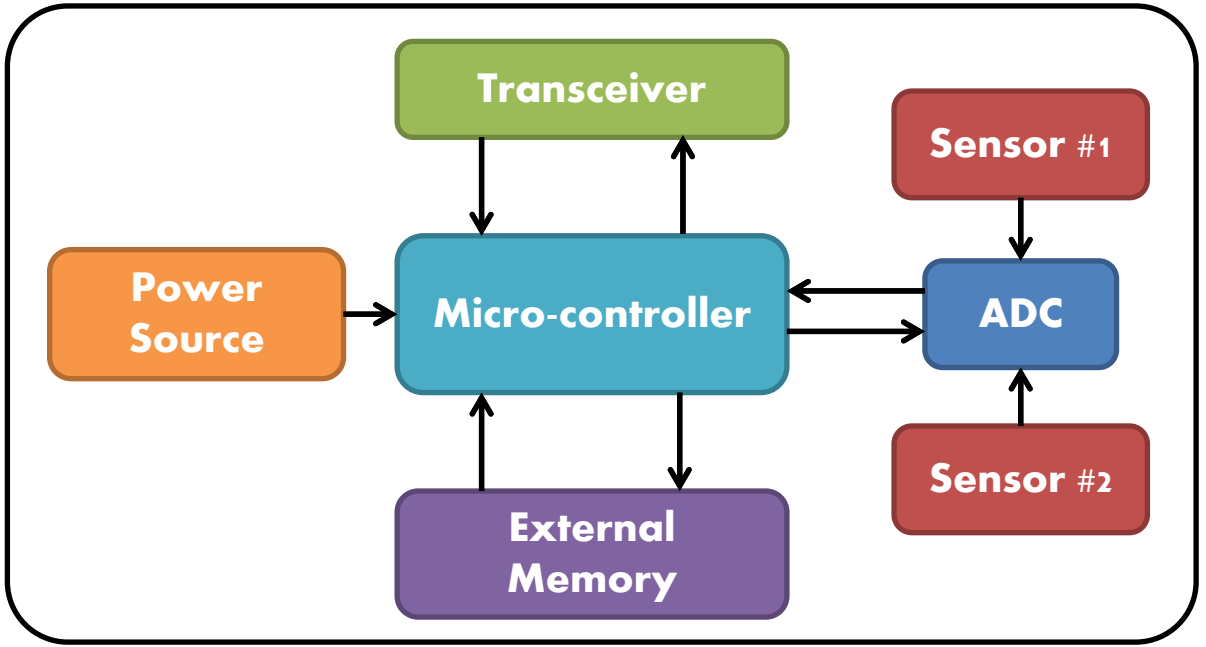
- Some technical features
  - Communication **range**: **10-50 meters** (point-to-point, without multi-hop)
  - **Typical size**: some cm^2
  - **Bit rate**: 250 kbps
  - Optional support for security and data integrity
  - **Applications**
    - basically (large-scale) monitoring in a large set of heterogeneous domains
    - metering
  - **Frequency bands**: 433 MHz, 868 MHz, and ISM worldwide band @ 2.4 GHz





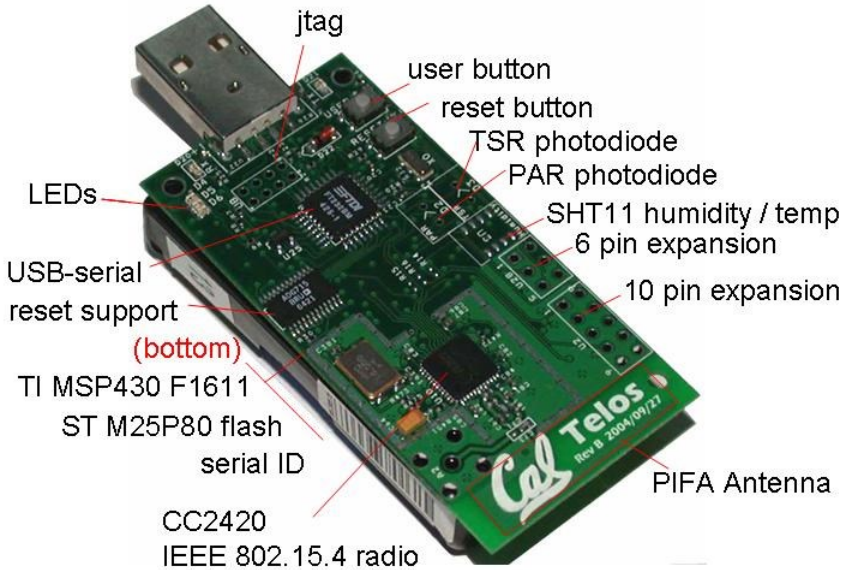
WIRELESS SENSOR NETWORKS – WSN

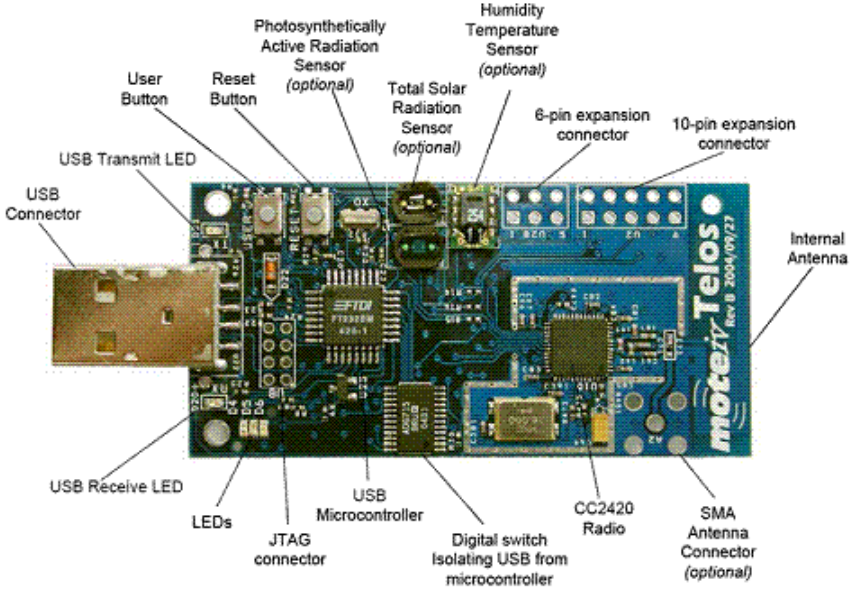
- Typical sensor node architecture



WIRELESS SENSOR NETWORKS – WSN

- Examples of WSN platforms: **Xbow Telos**



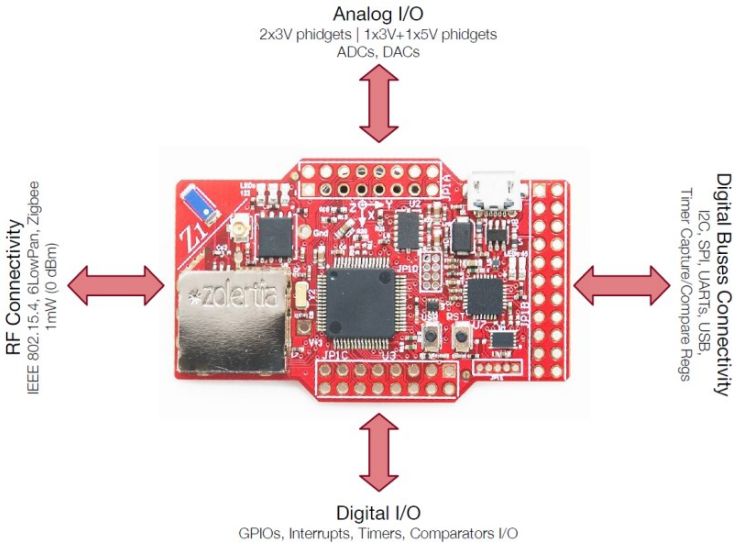


WIRELESS SENSOR NETWORKS – WSN

- Examples of WSN platforms: **Xbow Telos**
  - IEEE 802.15.4 compliant RF transceiver
  - 2.4 GHz ISM band
  - 250 kbps data rate
  - Integrated onboard antenna
  - 8 MHz TI MSP430 MCU with 10kB RAM
  - 1MB external flash for data logging
  - Programming and data collection via USB
  - Integrated light, temperature and humidity sensors
  - Runs TinyOS operating system

WIRELESS SENSOR NETWORKS – WSN

- Examples of WSN platforms: **Zolertia Z1**



IC	Operating Range	Current Consumption	Notes
MSP430f2617	1.8V to 3.6V	0.1µA 0.5µA 0.5mA < 10mA	OFF Mode Standby Mode Active Mode @1MHz Active Mode @16MHz
CC2420	2.1V to 3.6V	<1µA 20µA 426µA 18.8mA 17.4mA	OFF Mode Power Down IDLE Mode RX Mode TX Mode @ 0dBm
ADXL345	1.8V to 3.6V	0.1µA 40uA to 145uA	Standby Active Mode
M25P16	2.7V to 3.6V	1µA 4mA to 15mA	Deep Power Down Active Mode
TMP102	1.4V to 3.6V	1µA 15µA	Shutdown Mode Active Mode

WSN - ZIGBEE

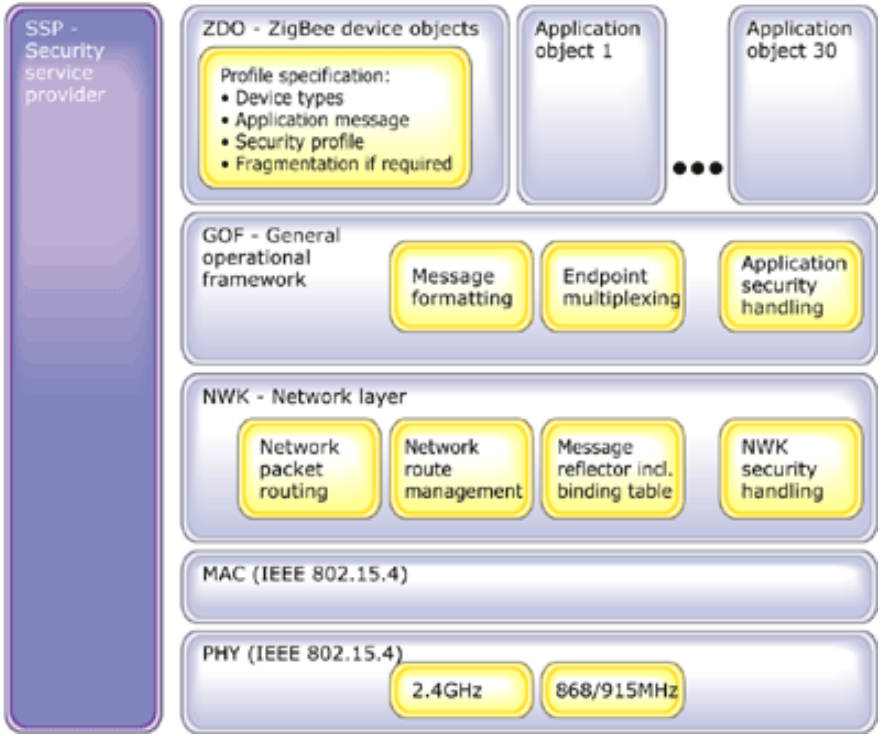
- Different **industrial** standards are built on top of IEEE 802.15.4
  - **ZigBee**
    - Developed by **ZigBee Alliance**, public standard, proprietary implementations (e.g., Z-Stack by Texas Instruments)
    - General purpose (i.e., multiple application domains)
    - Defines roles of **Coordinator**, **Router**, **End Device**
    - Defines

      NWK layer (basically, routing)

      APP layer (ZigBee profiles such as **Home Automation, Smart Energy, Health Care, Building Automation**)
    - Further support for security

WSN - ZIGBEE

- ZigBee stack architecture



WSN – WIRELESSHART

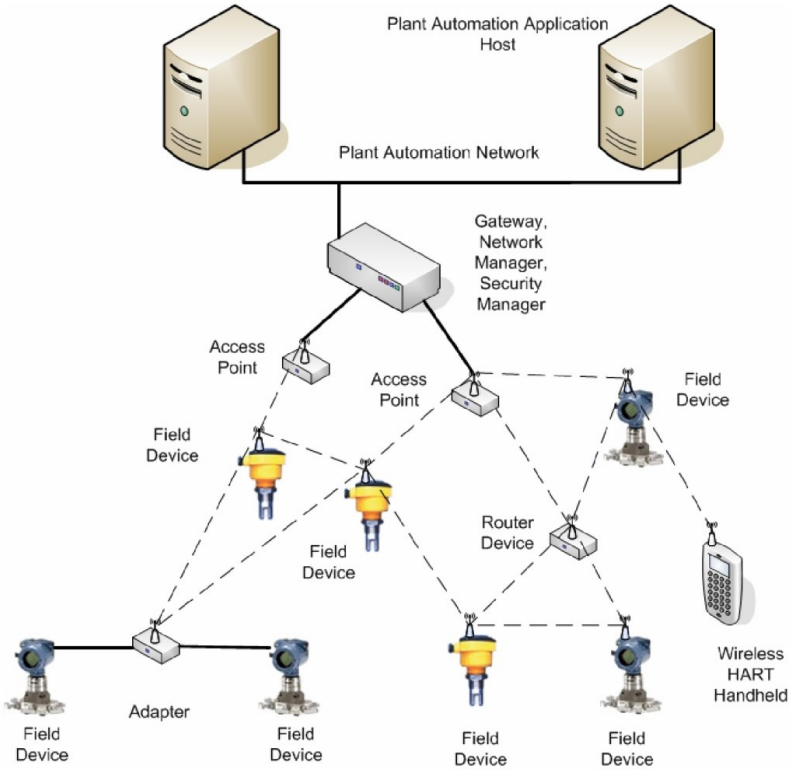
- Different **industrial** standards are built on top of IEEE 802.15.4
  - **WirelessHART**
    - Developed by **HART Communication Foundation**
      - HART standard has existed for more than 20 years
      - WirelessHART introduced to bring wireless technology to industrial field
      - HART and WirelessHART share the same application layer
    - Designed to meet the requirements of industrial automation (manufacturing processes)
      - ISA100.11a similar to WirelessHART
    - Includes features to support **reliable communication** links
    - **Synchronization** achieved through TDMA approach for **guaranteed delays**
    - **Frequency Hopping** suitable for industrial **harsh environments**
    - **Enhanced security**, network and data protection

WSN – WIRELESSHART

- WirelessHART **layers**
  - **PHY**: based on the IEEE 802.15.4-2006 2.4GHz DSSS
  - Datalink (**LLC**): error detection and security
  - Datalink (**MAC**)
    - TDMA (10 ms timeslots) combined with CSMA
    - Channel hopping and TDMA as frequency diversity against interferers and multipath fading effects
  - **NWK**: routing and end-to-end security
  - **Transport**: supports end-to-end packet reception
  - **APP**: device commands, device responses, status reporting

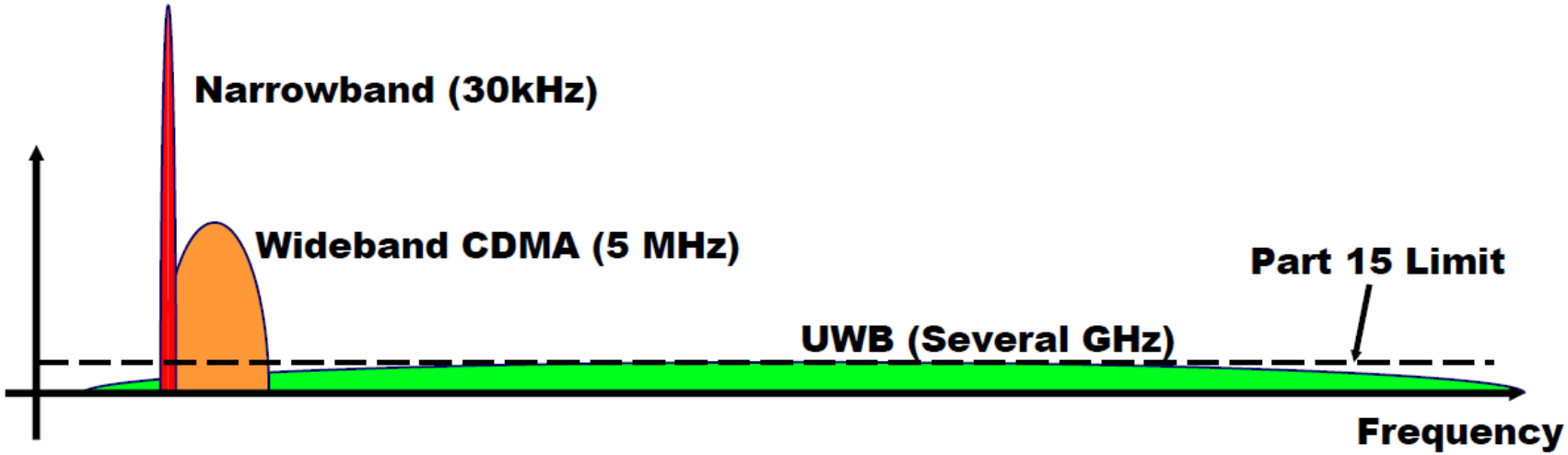
WSN – WIRELESSHART

- WirelessHART **devices**
  - **Field device**: basic device for field sensing or actuating functions
  - **Router device**: serves as pckt routers
  - **Adapter**: binds wired HART devices into the mesh
  - **Handheld device**: carried by mobile users
  - **Access points**: connect field devices to the gateway
  - **Gateway** / **Network Manager**: bridge to the host applications (unique)



ULTRA-WIDEBAND – UWB

- Principle of functioning
  - Extremely wide spread spectrum where RF energy is spread over gigahertz of spectrum
  - Short pulses transmission in time (1 ns) / high band occupancy in frequency



ULTRA-WIDEBAND – UWB

- **UWB properties**
  - Extremely difficult to be detected by unintended users
    - Highly secure
  - Non-interfering with other communication systems
    - Effect of noise for other systems
  - Both LoS and non-LoS
    - Signals can transparently pass through walls and doors
  - High multipath immunity
  - Common architecture for two main (heterogeneous) application fields: data communication and localization/tracking
  - Low-cost, low-power, nearly all-digital and single chip architecture

ULTRA-WIDEBAND – UWB

- UWB in 802.15 standards
  - **IEEE 802.15.3a**
    - IEEE 802.15.3 amendment for **applications** involving **imaging** and **multimedia**
    - Max data rate 480 Mb/s
    - Range ≤10 m
  - **IEEE 802.15.4a**
    - IEEE 802.15.4 amendment for **WSN applications** with higher performance
      - Higher precision ranging and location capability (1 m accuracy)
      - Longer range [20;100] m
      - Scalability for bit rates (110 kb/s, 851 kb/s, 6.81 Mb/s, 27.24 Mb/s)
      - Higher aggregate throughput
      - Lower power consumption
    - Same MAC layer as IEEE 802.15.4

ULTRA-WIDEBAND – UWB

- Main technical features
  - **Ultra-low-power** energy **consumption**
  - **Robustness** to **interference** (jammers) and **multipath**
  - Very accurate **ranging capabilities** (< 1 m)
  - **Bit rates**: 110 kbps, 851 kbps (mandatory), 6.81 Mbps, 27.24 Mbps
  - **Applications**: accurate **localization/tracking** in various fields (e.g., space)
  - **Frequency bands**: IR-UWB [250;750] MHz; [3.1;10.6] GHz; CSS-UWB 2.4 GHz

BLUETOOTH

- Principle of functioning
  - Piconet
    - **One Master** governing the piconet (clock synchronization for slave nodes and frequency hopping sequence)
    - Up to **seven slaves**
    - Alternate slotted transmissions
  - Scatternet
    - Several piconets connected together into one wider network
    - Envisioned to overcome the scalability limitations by extending
      the number of nodes
      the covered area
    - Rarely used

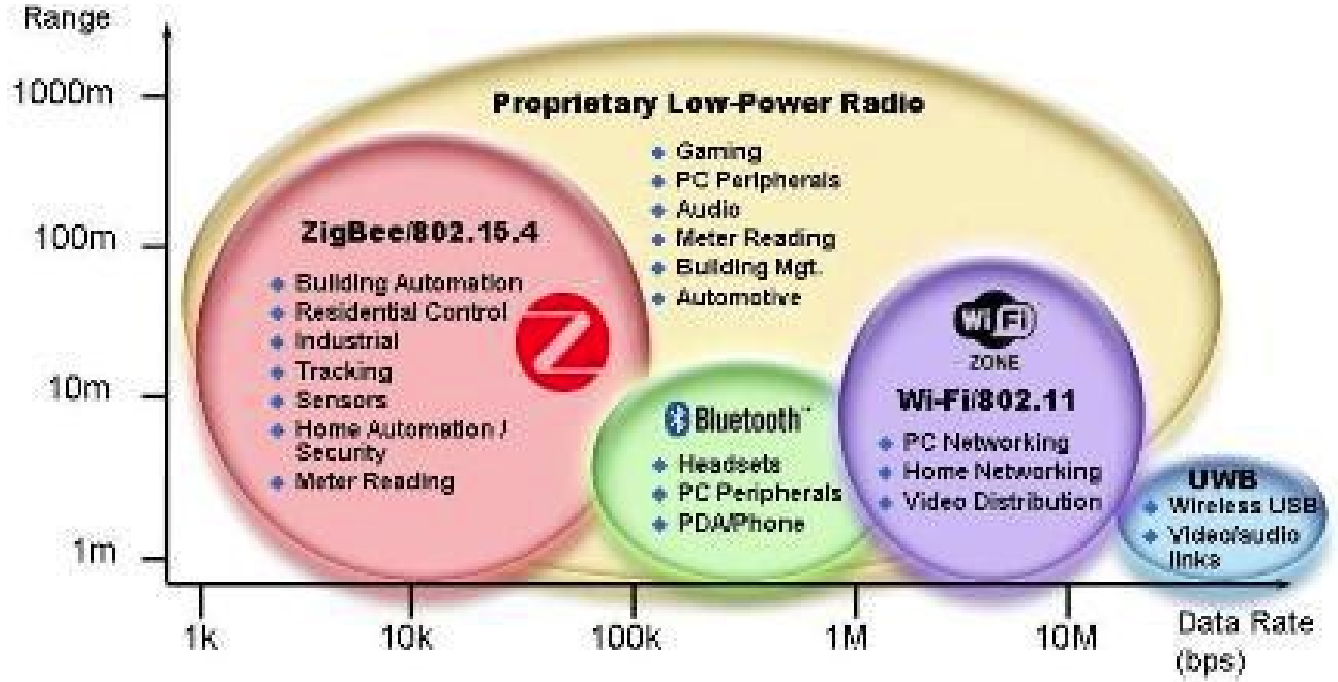
BLUETOOTH

- Main technical features
  - Communication **range**: **tens-hundreds meters**, comparable with WiFi
  - **Reduced size**: typically dongle size, or embedded in mobile phones / PCs
  - **Bit rate**: up to **some Mbps**
  - **Applications**
    - **cable** (RS-232) **replacement**
    - short-range **communication** between **PCs** / **mobile phones** and devices (**mouse**, **hands-free headset**); …
  - **Frequency bands**: ISM band @ 2.4 GHz
  - Multiple versions (1.0, 1.1, 1.2, 2.0, 2.1, 3.0, the most recent is 4.0 in 2010) and characterization

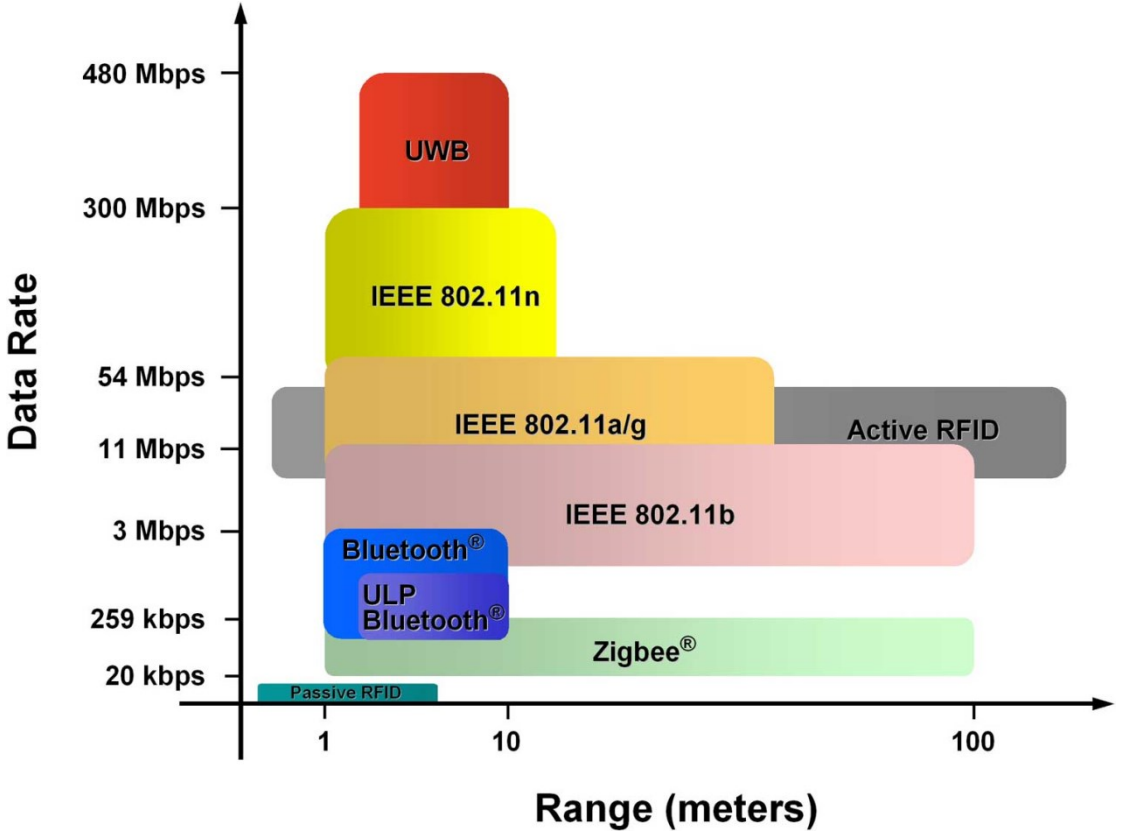
BLUETOOTH

- Bluetooth Low Energy (**BLE**)
  - Follows the trend of low-energy for IoT devices and applications
  - Not backward compatible
  - Novel applications in many fields and industries
    - **Healthcare**
    - **Fitness**
    - **Security**
    - **Home entertainment**

TECHNOLOGIES IN THE ISM 2.4GHZ BAND



TECHNOLOGIES IN THE ISM 2.4GHZ BAND



TECHNOLOGIES IN THE ISM 2.4GHZ BAND

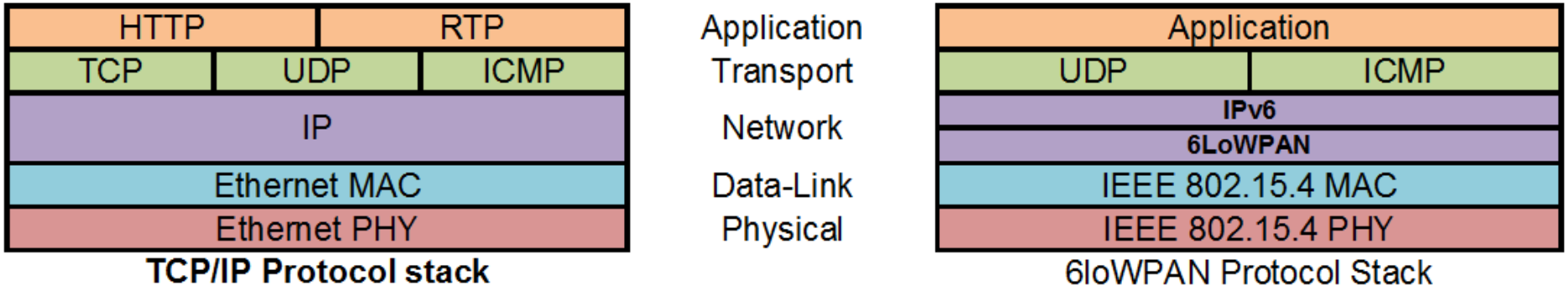
	WSN 802.15.4	UWB	2.4 GHz WiFi
Data rate	Low, 250 kbps @2.4GHz And 20 kbps @868MHz	Medium, 1Mbit/s mandatory and up to 27 Mbps for 802.15.4a	High, 11 Mbps for 802.11b and 100+ Mbps for 802.11n
Transmission distance	Short, < 30 meters	Short, < 30 meters	Long, up to 100 meters
Location accuracy	Very Low, tens of meters	High, < 50 cm	Low, several meters
Power consumption	Low, 1 mW	Low, 30 mW	High, 500 mW – 1 W
Multipath performance	Poor	Good	Poor
Interference resilience	Low	High with high complexity receivers, low with simplest receivers	Medium
Interference to other systems	Very Low	Low	High
Complexity and cost	Low – medium complexity while having low cost	Low - medium - high are possible	High

INTEGRATION IN IPV6

- **Shared principle**: to bring **already existing** wireless **communication technology** under the **TCP/IP domain**, i.e., to connect constrained devices directly to the Internet
- The reason: the Internet, along with its TCP/IP stack, is the **current** worldwide network
- The means: **IPv6 addressing**, which exponentially extends the number of addresses
- Multiple challenges!
  - E.g., adaptation of packet format and sizes
- Main efforts: 6LoWPAN, 6tisch, 6lo, IPv6 over BLE

6LOWPAN

- **6LoWPAN** (IPv6 over Low power Wireless Personal Area Networks)
  - **Adaptation layer** for adopting IPv6 protocol in IEEE 802.15.4-based devices
  - Enables the transmission of IPv6 datagrams over IEEE 802.15.4 wireless links



6LOWPAN

- **6LoWPAN** (IPv6 over Low power Wireless Personal Area Networks)
  - The problems
    - 1) Maximum transmission unit (**MTU**) for an IPv6 packet: **1280 bytes**
    - 2) Maximum **MAC frame size** defined in IEEE 802.15.4: **127 bytes**

      102 bytes for payload (**25 bytes** frame overhead), **81** considering security

      40 bytes for **IPv6 header** → only **41 bytes** for upper layers

      4-8 bytes for **UDP header** → only **33 bytes** for APP layer
  - The solution (6LoWPAN adaptation layer)
    - 1) **Packet fragmentation and reassembly**
    - 2) **Header compression** of IPv6 and Transport layer protocol

6LOWPAN

- **6LoWPAN** (IPv6 over Low power Wireless Personal Area Networks)
  - **IPv6 routing** in **6LoWPANs**
    - The goals: border nodes of the WSN should be able to
      route IPv6 packets into the WSN nodes from outside, and
      route inside packets towards outside IP network
    - **RPL** (Routing Over Low power Lossy networks) algorithm

IETF WORKING GROUPS

- Internet Drafts (ID)
  - Working documents published by the IETF
    - Typically, drafts for RFCs
    - Alternatively, works in progress not intended for publication as RFCs
  - Valid for six months only (unless replaced by an updated version or unless under official request to be published as an RFC)
- Requests for Comments (RFC)
  - Publication of the IETF and the Internet Society
  - In the form of a memorandum describing methods, behaviors, research, or innovations applicable to the working of the Internet-connected systems
  - IETF adopts some of the proposals published as RFCs as Internet standards

6TISCH

- **6TiSCH** (IPv6 over the TSCH mode of IEEE 802.15.4e)
  - TimeSlotted Channel Hopping (TSCH)
    - Standard for industrial automation and process control
    - Inheritance from WirelessHART and ISA100.11a
  - IETF Working Group, currently no RFCs but 6 IDs
    - 6TiSCH Operation Sublayer (6top) Interface
    - An Architecture for IPv6 over the TSCH mode of IEEE 802.15.4e
    - 6TiSCH Resource Management and Interaction using CoAP
    - Minimal 6TiSCH Configuration
    - Terminology in IPv6 over the TSCH mode of IEEE 802.15.4e
    - Using IEEE802.15.4e TSCH in an IoT context: Overview, Problem Statement and Goals

6LO

- **6lo** (IPv6 over Networks of Resource-constrained Nodes)
  - IETF Working Group, 3 RFCs and several IDs
    - RFC 7388: Definition of Managed Objects for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs), October 2014
    - RFC 7400: 6LoWPAN-GHC: Generic Header Compression for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs), November 2014
    - RFC 7428: Transmission of IPv6 Packets over ITU-T G.9959 Networks, February 2015

IPV6 OVER BLE

- **IPv6 over BLE**: recent and ongoing ID
- Born within the 6LoWPAN WG
- Title: “Transmission of IPv6 Packets over Bluetooth Low Energy”
- Dates back to February 2013

THANKS FOR YOUR ATTENTION !

Mirko Franceschinis

Researcher

Pervasive Technologies (PerT) Reasearch Area

+39 011 227615

franceschinis@ismb.it

