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CERTIFICATION COURSES

# Introduction: Sensing & Actuation

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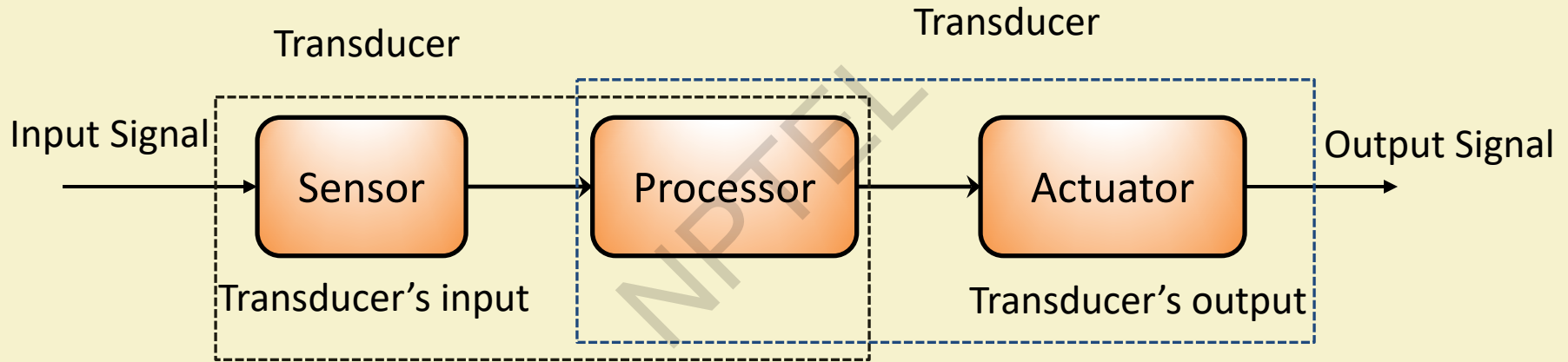
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# Transducer



Source: "Sensor" Online: <https://ielm.ust.hk/dfaculty/ajay/courses/alp/ieem110/lecs/sensors/sensors.html>

# Transducer (Contd.)

## ➤ Transducer:

- Converts a signal from one physical form to another physical form
- Physical form: thermal, electric, mechanical, magnetic, chemical, and optical
- Energy converter
- Example:
  - Microphone : Converts sound to electrical signal
  - Speaker : Converts electrical signal to sound
  - Antenna : Converts electromagnetic energy into electricity and vice versa
  - Strain gauge : Converts strain to electrical

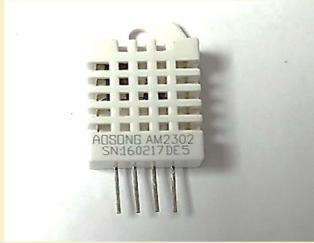
# Definition of Sensor

- The characteristic of any device or material to detect the presence of a particular physical quantity
- The output of sensor is signal, which is converted to human readable form

# Sensor

- Performs some function of input by sensing or feeling the physical changes in the characteristic of a system in response to stimuli
- Input: Physical parameter or stimuli
  - Example: Temperature, light, gas, pressure, and sound
- Output: Response to stimuli

# Sensor (Contd.)



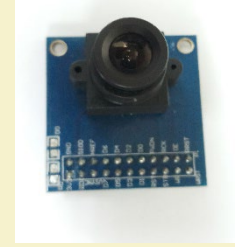
Temperature and Humidity sensor – DH22



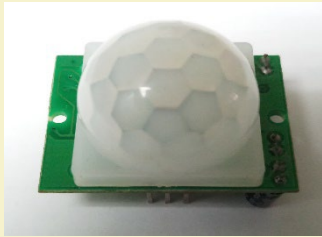
Gas (LPG, CH<sub>4</sub>, and CO) detector sensor - MQ-5



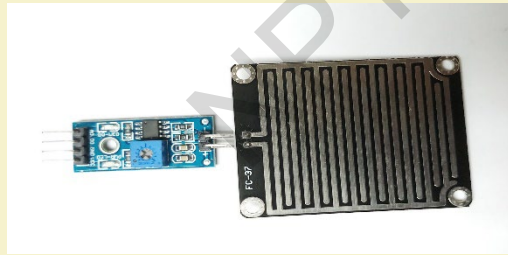
Ultrasonic sensor - HC-SR04



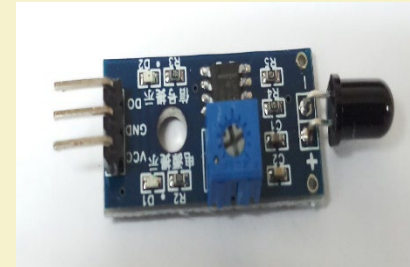
CMOS Camera



PIR sensor



Rain detector sensor



Fire detector sensor

# Sensor Characteristics

- Static characteristics
  - After steady state condition, how the output of a sensor change in response to an input change
- Dynamic characteristics
  - The properties of the system's transient response to an input

# Static characteristics

## ➤ Accuracy

- Represents the correctness of the output compared to a superior system
- The different between the standard and the measured value

## ➤ Range

- Gives the highest and the lowest value of the physical quantity within which the sensor can actually sense
- Beyond this value there is no sensing or no kind of response



# Static Characteristics (Contd.)

## ➤ Resolution

- Provides the smallest change in the input that a sensor is capable of sensing
- Resolution is an important specification towards selection of sensors.
- Higher the resolution better the precision

## ➤ Errors

- The difference between the standard value and the value produced by sensor

# Static Characteristics (Contd.)

## ➤ Sensitivity

- Sensitivity indicates ratio of incremental change in the response of the system with respect to incremental change in input parameter.
- It can be found from slope of output characteristic curve of a sensor

## ➤ Linearity

- The deviation of sensor value curve from a particular straight line

# Sensor Characteristics (Contd.)

- Drift
  - The difference in the measurements of sensor from a specific reading when kept at that value for a long period of time
- Repeatability
  - The deviation between measurements in a sequence under same conditions

Source : "Sensor", Hong Kong University of Science and Technology, online: <https://ielm.ust.hk/dfaculty/ajay/courses/alp/ieem110/lecs/sensors/sensors.html>  
Source: "Repeatability", MIT, Online: <https://ocw.mit.edu/courses/mechanical-engineering/2-693-principles-of-oceanographic-instrument-systems-sensors-and-measurements-13-998-spring-2004/>

# Dynamic Characteristics

How well a sensor responds to changes in its input

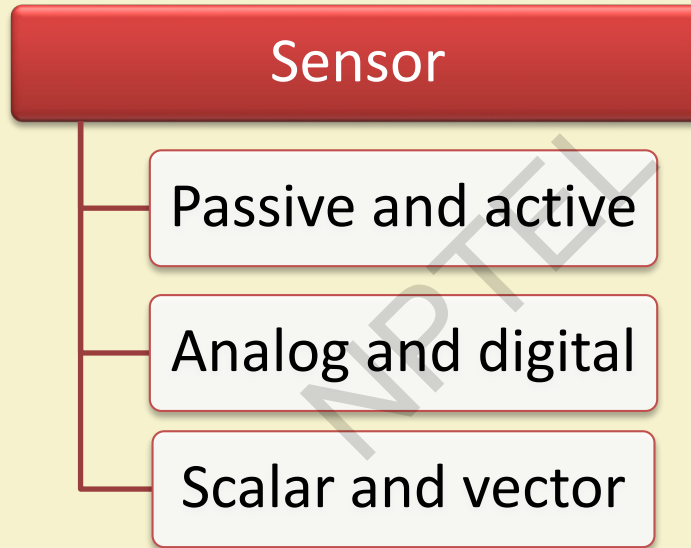
- Zero order system

- Output shows a response to the input signal with no delay
- Does not include energy-storing elements
- Example: Potentiometer measures linear and rotary displacements

# Dynamic Characteristics (Contd.)

- First order system
  - When the output approaches its final value gradually
  - Consists of an energy storage and dissipation element
- Second order system
  - Complex output response
  - The output response of sensor oscillates before steady state

# Sensor Classification



# Passive Sensor

- Cannot independently sense the input
- Example: Accelerometer, soil moisture, water-level, and temperature sensors

# Active Sensor

- Independently sense the input
- Example: Radar, sonar, and laser altimeter sensors



# Analog Sensor

- The response or output of the sensor is some continuous function of its input parameter
  - Example: Temperature sensor, LDR, analog pressure sensor, and Analog Hall effect/Magnetic Sensor
    - A LDR shows continuous variation in its resistance as a function of intensity of light falling on it

# Digital Sensor

- Responses in binary nature
- Designs to overcome the disadvantages of analog sensors
- Along with the analog sensor it also comprises of extra electronics for bit conversion
- Example: Passive infrared (PIR) sensor and digital temperature sensor (DS1620)

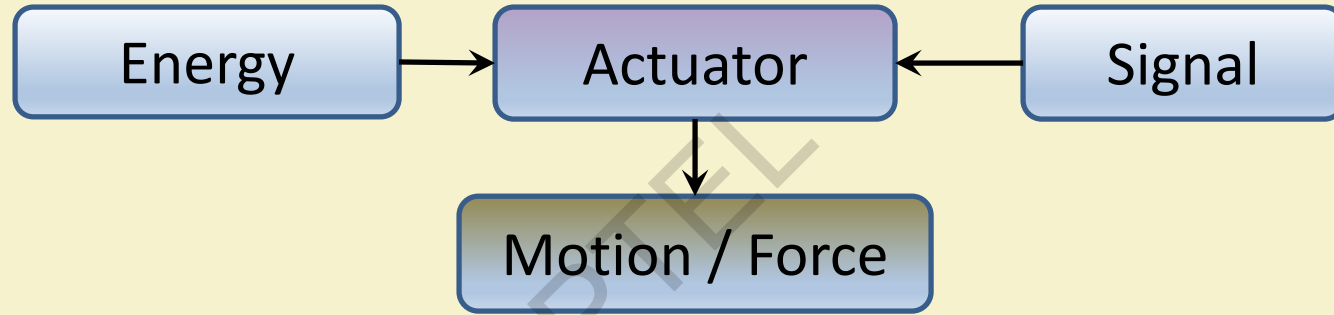
# Scalar Sensor

- Detects the input parameter only based on its magnitude
- The response of the sensor is a function of magnitude of the input parameter
- Not affected by the direction of the input parameter
- Example: Temperature, gas, strain, color, and smoke sensors

# Vector Sensor

- The response of the sensor depends on the magnitude of the direction and orientation of input parameter
- Example : Accelerometer, gyroscope, magnetic field, and motion detector sensors

# Actuator



- An actuator is part of the system that deals with the control action required (mechanical action)
- Mechanical or electro-mechanical devices

# Actuator (Contd.)

- A control signal is input to an actuator and an energy source is necessary for its operation
- Available in both micro and macro scales
- Example: Electric motor, solenoid, hard drive stepper motor, comb drive, hydraulic cylinder, piezoelectric actuator, and pneumatic actuator

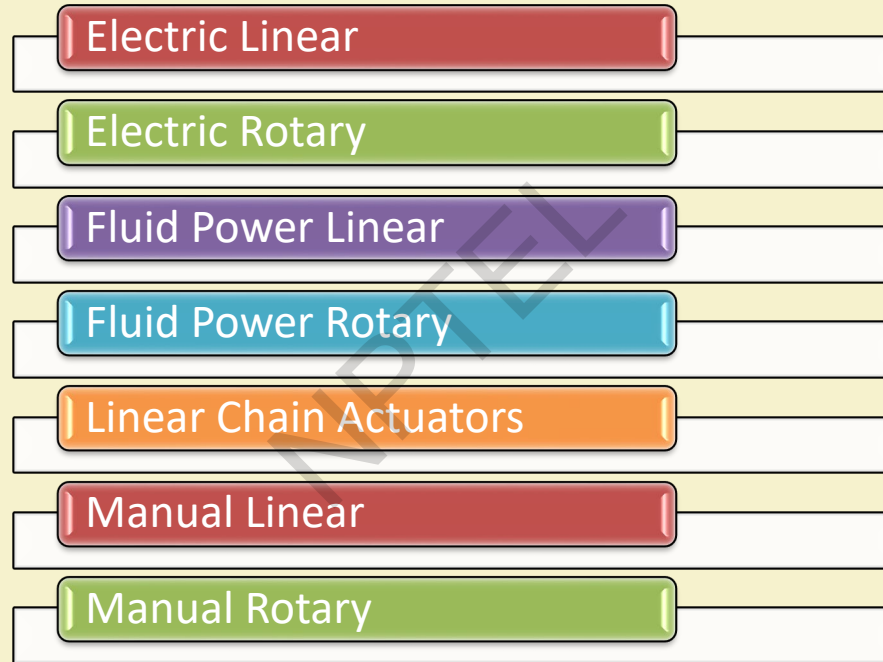


DC Motor



Relay

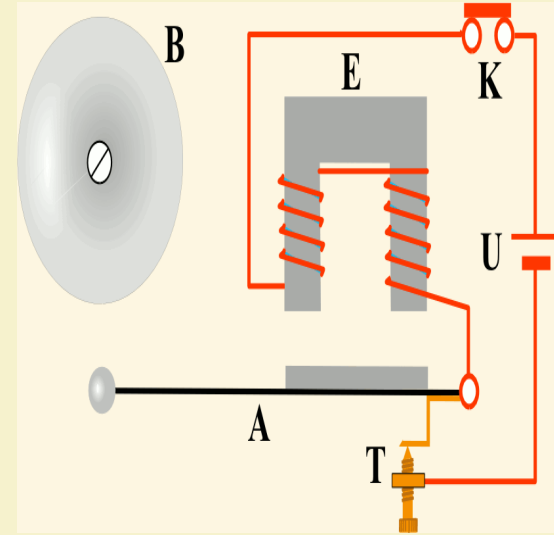
# Classification of Actuators



Source : “Classification of actuators” Online: <https://www.thomasnet.com/articles/pumps-valves-accessories/types-of-actuators>

# Electric Linear Actuator

- Powered by electrical signal
- Mechanical device containing linear guides, motors, and drive mechanisms
- Converts electrical energy into linear displacement
- Used in automation applications including electrical bell, opening and closing dampers, locking doors, and braking machine motions



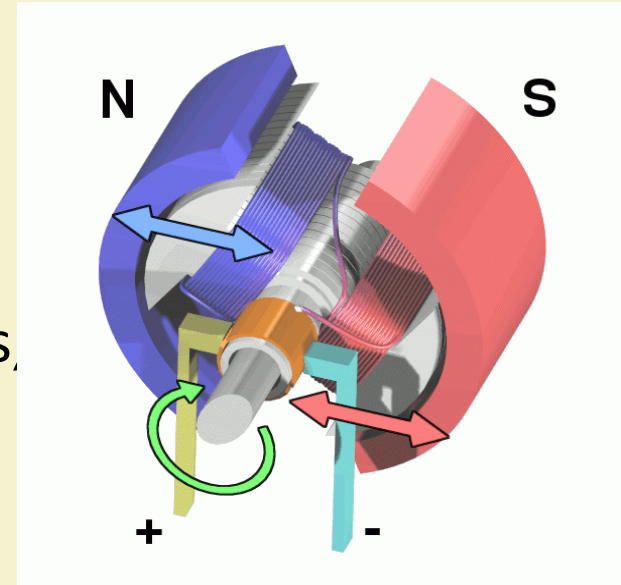
Source: "Electric bell", IOK/ Wikimedia Commons/, Published date: 18 February 2008, Online: [https://commons.wikimedia.org/wiki/File:Electric\\_Bell\\_animation.gif](https://commons.wikimedia.org/wiki/File:Electric_Bell_animation.gif)

Source: "Classification of actuators" Online: <https://www.thomasnet.com/articles/pumps-valves-accessories/types-of-actuators>



# Electric Rotary Actuator

- Powered by electrical signal
- Converts electrical energy into rotational motion
- Applications including quarter-turn valves, windows, and robotics



Source: "Electric motor", Abnormaal / Wikimedia Commons / CC-BY-SA-3.0 Unported/ GFDL. Published date: 21 May 2008, Online: [https://commons.wikimedia.org/wiki/File:Electric\\_motor.gif](https://commons.wikimedia.org/wiki/File:Electric_motor.gif)

Source: "Classification of actuators" Online: <https://www.thomasnet.com/articles/pumps-valves-accessories/types-of-actuators>

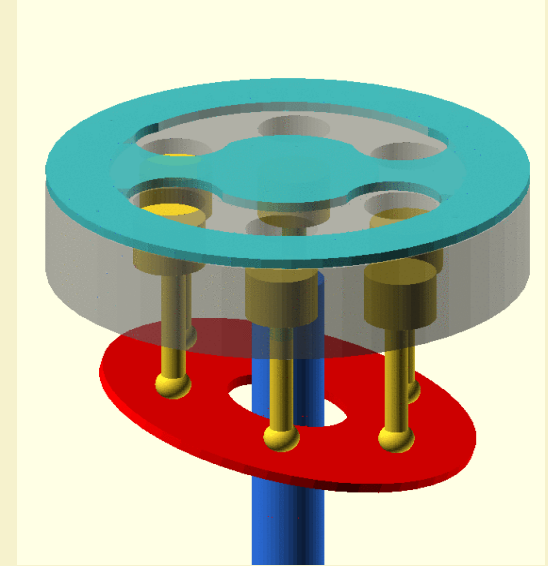
# Fluid Power Linear Actuator

- Powered by hydraulic fluid, gas, or differential air pressure
- Mechanical devices have cylinder and piston mechanisms
- Produces linear displacement
- Primarily used in automation applications including clamping and welding

Source : "Classification of actuators" Online: <https://www.thomasnet.com/articles/pumps-valves-accessories/types-of-actuators>

# Fluid Power Rotary Actuator

- Powered by fluid, gas, or differential air pressure
- Consisting of gearing, and cylinder and piston mechanisms
- Converts hydraulic fluid, gas, or differential air pressure into rotational motion
- Primarily applications of this actuator are opening and closing dampers, doors, and clamping

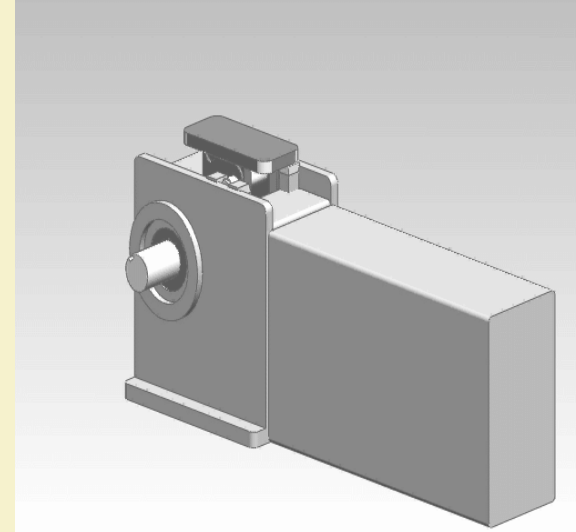


Source: "Axial piston pump", MichaelFrey / Wikimedia Commons / CC-BY-SA-4.0 International/. Published date: 11 August 2017, Online: [https://commons.wikimedia.org/wiki/File:Axialkolbenpumpe\\_-\\_einfache\\_Animation.gif](https://commons.wikimedia.org/wiki/File:Axialkolbenpumpe_-_einfache_Animation.gif)

Source: "Classification of actuators" Online: <https://www.thomasnet.com/articles/pumps-valves-accessories/types-of-actuators>

# Linear Chain Actuator

- Mechanical devices containing sprockets and sections of chain
- Provides linear motion by the free ends of the specially designed chains
- Primarily used in motion control applications



Source: "Rigid chain actuator", Catsquisher/ Wikimedia Commons/, Published date: 11 January 2011, Online: [https://commons.wikimedia.org/wiki/File:Rigid\\_Chain\\_Actuator.gif](https://commons.wikimedia.org/wiki/File:Rigid_Chain_Actuator.gif)

Source: "Classification of actuators" Online: <https://www.thomasnet.com/articles/pumps-valves-accessories/types-of-actuators>

# Manual Linear Actuator

- Provides linear displacement through the translation of manually rotated screws or gears
- Consists of gearboxes, and hand operated knobs or wheels
- Primarily used for manipulating tools and workpieces

Source: "Classification of actuators" Online: <https://www.thomasnet.com/articles/pumps-valves-accessories/types-of-actuators>

# Manual Rotary Actuator

- Provides rotary output through the translation of manually rotated screws, levers, or gears
- Consists of hand operated knobs, levers, handwheels, and gearboxes
- Primarily used for the operation of valves

Source: "Classification of actuators" Online: <https://www.thomasnet.com/articles/pumps-valves-accessories/types-of-actuators>

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# Introduction: IoT Connectivity – Part I

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# Communication Protocols

- The following communication protocols are important for IoT:
  - IEEE 802.15.4
  - Zigbee
  - 6LoWPAN
  - Wireless HART
  - Z-Wave
  - ISA 100
  - Bluetooth
  - NFC
  - RFID

# IEEE 802.15.4



# Introduction to IEEE 802.15.4

- This standard provides a framework meant for lower layers (MAC and PHY) for a wireless personal area network (WPAN).
- PHY defines frequency band, transmission power, and modulation scheme of the link.
- MAC defines issues such as medium access and flow control (frames).
- This standard is used for low power, low cost (manufacturing and operation), and low speed communication between neighboring devices (< ~75m).

Source: What's The Difference Between IEEE 802.15.4 And ZigBee Wireless? Fenzel, L.

# Features of IEEE 802.15.4

- This standard utilizes DSSS (direct sequence spread spectrum) coding scheme to transmit information.
- DSSS uses phase shift keying modulation to encode information.
  - BPSK - 868/915 MHz, data transmission rate 20/40 kbps respectively.
  - OQPSK - 2.4 GHz, data transmission rate 250 kbps.
- DSSS scheme makes the standard highly tolerant to noise and interference and thereby improving link reliability.

Source: What's The Difference Between IEEE 802.15.4 And ZigBee Wireless? Fenzel, L.

## Features of IEEE 802.15.4 (contd.)

- The preferable nature of transmission is line of sight (LOS).
- The standard range of transmission - 10 to 75m.
- The transmission of data uses CSMA-CA (carrier sense multiple access with collision avoidance) scheme.
- Transmissions occur in infrequent short packets for duty cycle (<1 %), thus reducing consumption of power.
- Star network topology and peer-to-peer network topology is included.

Source: What's The Difference Between IEEE 802.15.4 And ZigBee Wireless? Fenzel, L.

# Variants of IEEE 802.15.4

Version	Feature
802.15.4 - 2003	Basic version. The modulation schemes and data rates were fixed for different frequency band – 868, 915 MHz, and 2.4 GHz.
802.15.4 - 2006	Also known as 802.15.4b. Provides <u>higher data rate</u> even on the lower frequency bands. In the 868 MHz, the data transmission rate is up to 100 kb/s while in 915 MHz, the data transmission rate is up to 250 kb/s. Uses OQPSK for all the frequency bands.

Source: Poole, I. IEEE 802.15.4 Technology & Standard.

# Variants of IEEE 802.15.4 (contd.)

Version	Feature
802.15.4 a	<u>Increases range</u> capability. Defines two new physical layers – Direct Sequence ultra-wideband (UWB) – 249.6 - 749.6 MHz (sub-gigahertz band), 3.1 - 4.8 GHz (low band), and 6 - 10 GHz (high band). Chirp spread spectrum (CSS) approach in ISM band at 2.4 GHz.
802.15.4 c	This version provides 780 MHz band in <u>China</u> . It uses either O-QPSK or MPSK (Multiple frequency-shift keying) using data transmission rate 250 kb/s.
802.15.4 d	This version provides 950 MHz band in <u>Japan</u> . It uses either GFSK (Gaussian frequency-shift keying) using data rate 100 kb/s or BPSK using data rate 20 kb/s.

Source: Poole, I. IEEE 802.15.4 Technology & Standard.



# Variants of IEEE 802.15.4 (contd.)

Version	Feature
802.15.4e	Defines MAC developments to IEEE 802.15.4 towards <u>ISA SP100.11a</u> application ( <u>industrial applications</u> ).
802.15.4f	Defines fresh PHYs for 433 MHz frequency band ( <u>RFID applications</u> ), 2.4 GHz frequency band and UWB.
802.15.4g	Defines fresh PHYs for smart utility networks for 902 - 928 MHz band ( <u>smart grid applications</u> , majorly for the energy industry).

Source: Poole, I. IEEE 802.15.4 Technology & Standard.

# Zigbee



# Introduction to Zigbee

- Provides a framework for medium-range communication in IoT connectivity.
- Defines PHY (Physical) and MAC (Media Access Control) layers enabling interoperability between multiple devices at low-data rates.
- Operates at 3 frequencies –
  - 868 MHz (1 channel using data transmission rate up to 20 kbps)
  - 902-928MHz (10 channels using data transmission rate of 40 kbps)
  - 2.4 GHz (16 channels using data transmission rate of 250 kbps).

Source: Agarwal, T. ZigBee Wireless Technology Architecture and Applications.

# Features of Zigbee

- The lower frequency bands use BPSK.
- For the 2.4 GHz band, OQPSK is used.
- The data transfer takes place in 128 bytes packet size.
- The maximum allowed payload is 104 bytes.
- The nature of transmission is line of sight (LOS).
- Standard range of transmission – upto 70m.

Source: Agarwal, T. ZigBee Wireless Technology Architecture and Applications.

# Features of Zigbee (contd.)

- Relaying of packets allow transmission over greater distances.
- Provides low power consumption (around 1mW per Zigbee module) and better efficiency due to
  - adaptable duty cycle
  - low data rates (20 - 250 kbit/s)
  - low coverage radio (10 -100 m)
- Networking topologies include star, peer-to-peer, or cluster-tree (hybrid), mesh being the popular.

Source: Agarwal, T. ZigBee Wireless Technology Architecture and Applications.

# Features of Zigbee (contd.)

- The Zigbee protocol defines three types of nodes:
  - **Coordinators** - Initializing, maintaining and controlling the network. There is one and only one per network.
  - **Routers** - Connected to the coordinator or other routers. Have zero or more children nodes. Contribute in multi hop routing.
  - **End devices** - Do not contribute in routing.
- **Star topology** has no router, one coordinator, and zero or more end devices.
- In **mesh** and **tree** topologies, one coordinator maintains several routers and end devices.

Source: Agarwal, T. ZigBee Wireless Technology Architecture and Applications.

# Features of Zigbee (contd.)

- Each cluster in a cluster-tree network involves a coordinator through several leaf nodes.
- Coordinators are linked to parent coordinator that initiates the entire network.
- ZigBee standard comes in two variants:
  - **ZigBee**
  - **ZigBee Pro** - offers scalability, security, and improved performance utilizing many-to-one routing scheme.

Source: Agarwal, T. ZigBee Wireless Technology Architecture and Applications.

# 6LoWPAN





# Introduction to 6LoWPAN

- 6LoWPAN is IPv6 over Low-Power Wireless Personal Area Networks.
- It optimizes IPv6 packet transmission in low power and lossy network (LLN) such as IEEE 802.15.4.
- Operates at 2 frequencies:
  - 2400–2483.5 MHz (worldwide)
  - 902–929 MHz (North America)
- It uses 802.15.4 standard in unslotted CSMA/CA mode.

Source: Olsson, J. 6LoWPAN demystified.

# Features of 6LoWPAN

- 6LoWPAN converts the data format to be fit with the IEEE 802.15.4 lower layer system.
- IPv6 involves MTU (maximum transmission unit) of 1280 bytes in length, while the IEEE 802.15.4 packet size is 127 bytes.
- Hence a supplementary adaptation layer is introduced between MAC and network layer that provides:
  - Packet fragmentation & packet reassembly
  - Compression of header
  - Routing of data link layer.

Source: Olsson, J. 6LoWPAN demystified.

## Features of 6LoWPAN (contd.)

- Fragmentation is required to fit the intact IPv6 packet into a distinct IEEE 802.15.4 frame ( $> \sim 106$  bytes).
- The fragmentation header allows 2048 bytes packet size with fragmentation.
- Using fragmentation and reassembly, 128-byte IPv6 frames are transmitted over IEEE 802.15.4 radio channel into several smaller segments.
- Every fragment includes a header.

Source: Sulthana, M. R. A Novel Location Based Routing Protocol For 6LoWPAN.

# Features of 6LoWPAN (contd.)

- Header compression reduces the transmission overhead and allows efficient transmission of payload.
- IPv6 addresses are compressed in 6LoWPAN:
  - 8-byte UDP header
  - 40-byte IPv6 header
- Stateless auto configuration allows any device to create the IPv6 address automatically devoid of external dealing using a DHCP server.

Source: Sulthana, M. R. A Novel Location Based Routing Protocol For 6LoWPAN.

# Features of 6LoWPAN (contd.)

- Data link layer routing is classified into two schemes:
  - **mesh-under** - utilizes link layer address to forward data packets.
  - **route-over** - utilizes network layer IP address.
- Provides link layer security (AES-128) from IEEE 802.15.4 such as authentication of link and encryption.

Source: Sulthana, M. R. A Novel Location Based Routing Protocol For 6LoWPAN.

# Wireless HART



# Introduction to Wireless HART

- WirelessHART is based on HART (Highway Addressable Remote Transducer).
- It is the first international industrial wireless standard (IEC 62591), based upon the standard IEEE 802.15.4.
- Functions in the 2.4GHz ISM band using data rate of up to 250 kb/s.
- 11 to 26 channels are supported, with a gap of 5MHz between two adjacent channels.
- The same channel can't be used consecutively.

Source: Feng, A. WirelessHART- Made Easy.

# Features of Wireless HART

- Exploits IEEE 802.15.4 accustomed DSSS coding scheme.
- A WirelessHART node follows channel hopping every time it sends a packet.
- Modulation technique used is offset quadrature phase shift keying (OQPSK).
- Transmission Power is around 10dBm (adjustable in discrete steps).

Source: Feng, A. WirelessHART- Made Easy.



# Features of Wireless HART (contd.)

- Maximum payload allowed is 127 bytes.
- It employs TDMA (time division multiple access) that allots distinct time slot of 10ms for each transmission.
- TDMA technology is used to provide collision free and deterministic communications.
- A sequence of 100 consecutive time slots per second is grouped into a super frame.
- Slot sizes and the super frame length are fixed.

Source: Salman, T. and Jain, R. (2017). A Survey of Protocols and Standards for Internet of Things.

## Features of Wireless HART (contd.)

- The devices support multiple super frames with differing numbers of timeslots.
- At least one super frame is always enabled while additional super frames are enabled and disabled according to the demand of bandwidth.
- For any message, communication occurs in the allotted timeslot and frequency channel.
- Supports both star and mesh topologies.

Source: Salman, T. and Jain, R. (2017). A Survey of Protocols and Standards for Internet of Things.

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# Z-Wave



# Introduction to Z-Wave

- Z-wave is a low power radio communication technology primarily used for home automation and security systems.
- It was designed as a simpler and cheaper alternative to Zigbee for small to medium range connectivity.
- It operates on the unlicensed part of the industrial, scientific and medical (ISM) band: 908.42 MHz in the US & 868.42 MHz in Europe, avoiding any interference with the 2.4Ghz band(Wi-Fi, Bluetooth and others).
- Z-wave uses a Mesh Network Topology to communicate among the devices, supporting up to 232 nodes in a network.

Source: Paul Lamkin. April 26, 2018. Z-Wave explained: What is Z-Wave and why is it important for your smart home

# Features of Z-Wave

- A Z-wave network has 2 device categories: **Controller** and **Slave**
- The **Controller** is a central entity which sets up the Z-wave network and manages other slave devices in the network.
- Each logical Z-wave network has 1 Home (Network) ID and multiple unique Node IDs for the devices in the network.
- The Network ID is of length 4 Bytes and Node ID is of length 1 Byte.
- The nodes can communicate only within their home network
- It offers a data rate of up to 100kbps and an average communication range of 30 meters.

Source: Paul Lamkin. April 26, 2018. Z-Wave explained: What is Z-Wave and why is it important for your smart home



# Features of Z-Wave (contd.)

- It uses source routed network mesh topology using 1 primary controller.
- Z-wave considers only static devices in the network due to its source routed network topology.
- The devices communicate with one another only when they are in range.
- Messages are routed through different nodes in case of any obstruction due to interior layout and other household appliances.
- These obstructions are called radio dead-spots and can be bypassed using a process called **Healing**.

Source: Paul Lamkin. April 26, 2018. Z-Wave explained: What is Z-Wave and why is it important for your smart home

# Application

- Primarily used in Home/Office Automation
- Systems for Smart Energy Management
- System for Smart Security and Surveillance
- Voice control enabled applications
- Appliances automation and control

Source: Applications of Z-wave technology, (March 2018)

# ISA 100.11a



## ➤ Introduction to ISA 100.11a

- ISA 100.11a is a Standard for wireless network technology developed by the International Society of Automation(ISA).
- The primary focus of the technology is the implementation of automation in the industrial environment.
- The protocol stack of ISA 100.11a is in compliance with IoT.
- It is based on the IEEE 802.15.4 protocol along with other wireless networks.

Source: ISA100 Wireless tutorial | What is ISA100 Wireless

# Features of ISA 100.11a

- It supports multiple devices working on different protocols to interact in a single network, simultaneously.
- It is an open standard which enables interoperability and communication between different devices.
- It uses the IPv6 based technology and adds the associated benefits such as increased address space and security.
- 128 bits AES encryption security.
- Hence, it offers essential scalability and reliability for industrial network.
- It supports 2 network topologies for operation: 1)Star and 2)Mesh.
- Uses TDMA/CSMA schemes for resource sharing, collision avoidance.

Source: ISA100 Wireless tutorial | What is ISA100 Wireless?

# Application

- It is primarily used for automation in large scale complex industries.
- Wireless monitoring of the industrial network and devices.
- Process monitoring and control automation in the industrial environment with large and complex setups.

# Bluetooth



# Introduction to Bluetooth

- A short range wireless communication technology.
- Its is aimed at replacing the cables with wireless medium to communicate between portable devices.
- It is based on Ad-hoc technology, also known as Ad-hoc Piconets.
- Network can be established between 2 to 8 Bluetooth devices.

Source: Bluetooth Basics (March 31, 2018)



# Features of Bluetooth

- It is a low cost wireless communication technology.
- Low power consumption.
- Bluetooth technology uses the unlicensed industrial, scientific and medical (ISM) band at 2.4 to 2.485 GHz.
- Supports 1Mbps and 3Mbps data rate for version 1.2 and 2.0, respectively.
- The operating range: 1 meter for Class 3 radios, 10 meters for Class 2 radios, and 100 meters for Class 1 radios.

Source: Bluetooth Basics (March 31, 2018)

# Application

- Bluetooth is suitable for a network of devices with smaller radius.
  - Connectivity with desktop and laptop peripherals
  - Wireless connectivity between mobile phones and other portable devices.
  - Multimedia transfer between devices
  - Automobiles use Bluetooth for connecting with multimedia and navigation devices.
  - GPS devices are connected with the end user.

Source: Tarun Agarwal. April 11, 2016. How does Bluetooth work?

# RFID



# Introduction to RFID

- RFID stands for “radio-frequency identification” .
- An RFID system consists of RFID tag, RFID reader and RFID software.
- RFID tag stores digitally encoded data, which is read by a RFID reader.
- RFID tag data can be read outside the line-of-sight, as compared to traditional barcodes and QR codes.

Source: RFID Radio Frequency Identification Technology Tutorial

# Features of RFID

- RFID tag consists of an integrated circuit and an antenna, covered with a protective material.
- Tags can be classified as passive or active.
- **Active** tags use their own power supply for operation and data transfer.
- **Passive** tags have to be powered by a reader inductively in order to transmit data.

Source: RFID Radio Frequency Identification Technology Tutorial

# Application

- Store product tracking.
- Asset and baggage tracking.
- Supply chain management.
- Livestock tracking and management.
- Automobile tracking.
- Authentication and access control

**NFC**



# Introduction to NFC

- **Near field communication**, or NFC, has been derived from radio-frequency identification (RFID).
- NFC works within close proximity without any physical contact between the devices unlike RFID which has a longer range of communication.
- A NFC device can be any of the two types: 1) Active and 2) Passive.
- An **Active** type of device can both read and transmit data.
- A **Passive** device can only transmit data but cannot read from other NFC devices.

Source: NFC Near Field Communication Tutorial | NFC Tutorial (2016)



# Features of NFC

- NFC operates at 13.56 MHz frequency.
- The communication range of NFC devices is less than 10 centimeters.
- Data rate supported are 106, 212 or 424 Kbps (kilobits per second).
- Two communication modes are supported between two devices: Active-Active or Active-Passive mode.

Source: NFC Near Field Communication Tutorial | NFC Tutorial (2016)

# Application

- Banking and payments using NFC enabled smartphones, transaction cards.
- Tracking goods.
- Data Communication between smart phones.
- Security and authentication using NFC enabled ID cards.
- Low-power home automation systems.

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# Thank You!!





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# Introduction: IoT Networking- Part I

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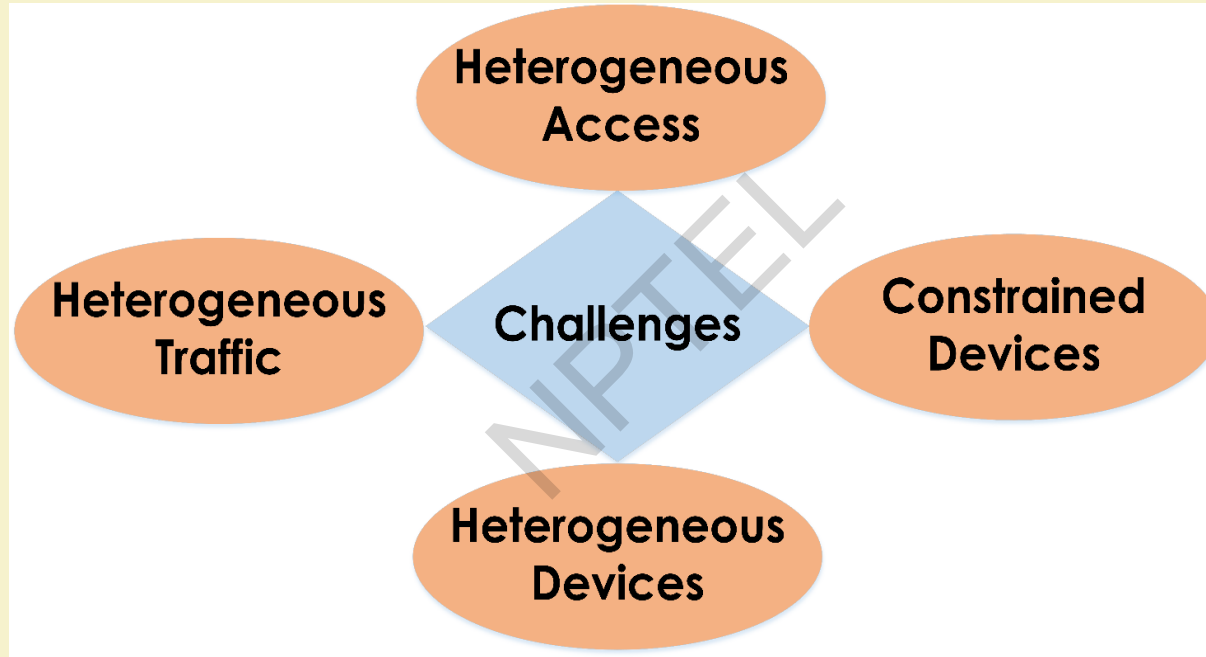
Website: <http://cse.iitkgp.ac.in/~smisra/>

Research Lab: [cse.iitkgp.ac.in/~smisra/swan/](http://cse.iitkgp.ac.in/~smisra/swan/)

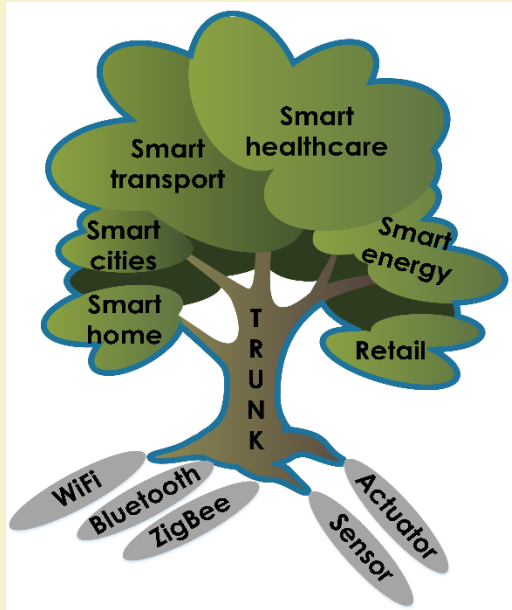
# Introduction

- Characteristics of IoT devices
  - Low processing power
  - Small in size
  - Energy constraints
- Networks of IoT devices
  - Low throughput
  - High packet loss
  - Tiny (useful) payload size
  - Frequent topology change
- Classical Internet is not meant for constrained IoT devices.

# Introduction



# Introduction



- Analogy
  - Roots - Communication Protocol and device technologies
  - Trunk- Architectural Reference Model (ARM)
  - Leaves – IoT Applications
- Goal
  - To select a minimal set of **roots** and propose a potential **trunk** that enables the creation of a maximal set of the **leaves**.

**Source:** FhG, I. M. L., et al. "Internet of things-architecture iot-a deliverable d1. 3–updated reference model for iot v1. 5."



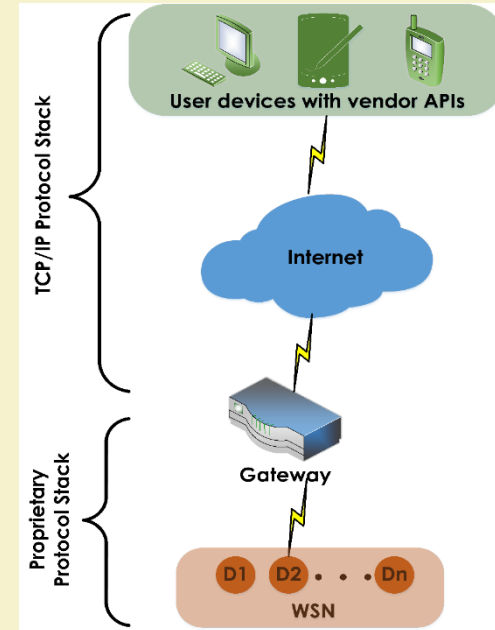
# Enabling Classical Internet for IoT Devices

- Proprietary non-IP based solution
  - Vendor specific gateways
  - Vendor specific APIs
- Internet Engineering Task Force (IETF) IP based solution
  - Three work groups
    - IPv6 over Low power Wireless Personal Area Networks (6LoWPAN)
    - Routing Over Low power and Lossy networks (ROLL)
    - Constrained RESTful Environments (CoRE)

**Source:** I. Ishaq, et al. , "IETF standardization in the field of the internet of things (IoT): a survey", J. of Sens. and Act. Netw. 2, vol. 2 (2013): 235-287.

# Proprietary non-IP based solution

- Drawbacks
  - **Limited flexibility to end users:** vendor specific APIs
  - **Interoperability:** vendor specific sensors and gateways
  - **Limited last-mile connectivity**



**Source:** I. Ishaq, et al. , "IETF standardization in the field of the internet of things (IoT): a survey", J. of Sens. and Act. Netw. 2, vol. 2 (2013): 235-287.

# IETF IP based solution

## ➤ Three work groups

- IPv6 over Low power Wireless Personal Area Networks (6LoWPAN)
  - By header compression and encapsulation it allows IPv6 packets to transmit and receive over IEEE 802.15.4 based networks.
- Routing Over Low power and Lossy networks (ROLL)
  - New routing protocol optimized for saving storage and energy.
- **Constrained RESTful Environments (CoRE)**
  - Extend the Integration of the IoT devices from network to service level.

# Constrained RESTful Environments (CoRE)

# CoRE

- Provides a platform for applications meant for constrained IoT devices.
- This framework views sensor and actuator resources as web resources.
- The framework is limited to applications which
  - Monitor basic sensors
  - Supervise actuators
- CoAP includes a mechanism for **service discovery**.

# CoRE: Service Discovery

- IoT devices (act as mini web servers) register their resources to **Resource Directory (RD)** using **Registration Interface (RI)**.
- RD, a logical network node, stores the information about a specific set of IoT devices.
- RI supports Representational State Transfer (REST) based protocol such as HTTP (and CoAP- optimized for IoT).
- IoT client uses **Lookup interface** for discovery of IoT devices.

# IoT Network QoS



# IoT Network QoS

- Quality-of-service (QoS) of IoT network is the ability to guarantee intended service to IoT applications through controlling the heterogeneous traffic generated by IoT devices.
- QoS policies for IoT Network includes
  - Resource utilization
  - Data timeliness
  - Data availability
  - Data delivery

**Source:** Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.



# Resource utilization

- Requires control on the storage and bandwidth for data reception and transmission.
- QoS policies for resource utilization:
  - **Resource limit policy**
    - Controls the amount of message buffering
    - Useful for memory constrained IoT devices
  - **Time filter policy**
    - Controls the data sampling rate (interarrival time) to avoid buffer overflow
    - Controls network bandwidth, memory, and processing power

**Source:** Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

# Data timeliness

- Measure of the **freshness** of particular information at the receiver end
- Important in case of healthcare, industrial and military applications
- Data timeliness policies for IoT network include
  - **Deadline policy**
    - Provides maximum interarrival time of data
    - Drops the stale data; notify the missed deadline to the application end
  - **Latency budget policy**
    - Latency budget is the maximum time difference between the data transmission and reception from source end to the receiver end.
    - Provides priority to applications having higher urgency

**Source:** Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

# Data availability

- Measure of the amount of valid data provided by the sender/producer to receiver/consumer
- QoS policies for data availability in IoT network include
  - **Durability policy**
    - Controls the degree of data persistence transmitted by the sender
    - Data persistence ensures the availability of the data to the receiver even after sender is unavailable
  - **Lifespan policy**
    - Controls the duration for which transmitted data is valid
  - **History policy**
    - Controls the number of previous data instances available for the receiver.

**Source:** Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

# Data delivery

- Measure of successful reception of reliable data from sender to receiver
- QoS policies for data delivery include
  - **Reliability policy**
    - Controls the reliability level associated with the data distribution
  - **Transport priority**
    - Allows transmission of data according to its priority level

**Source:** Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

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# Introduction: IoT Networking - Part 2

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# Requirements of IoT Network

- Coverage
- High throughput
- Low latency
- Ultra reliability
- High power efficiency

# MQTT

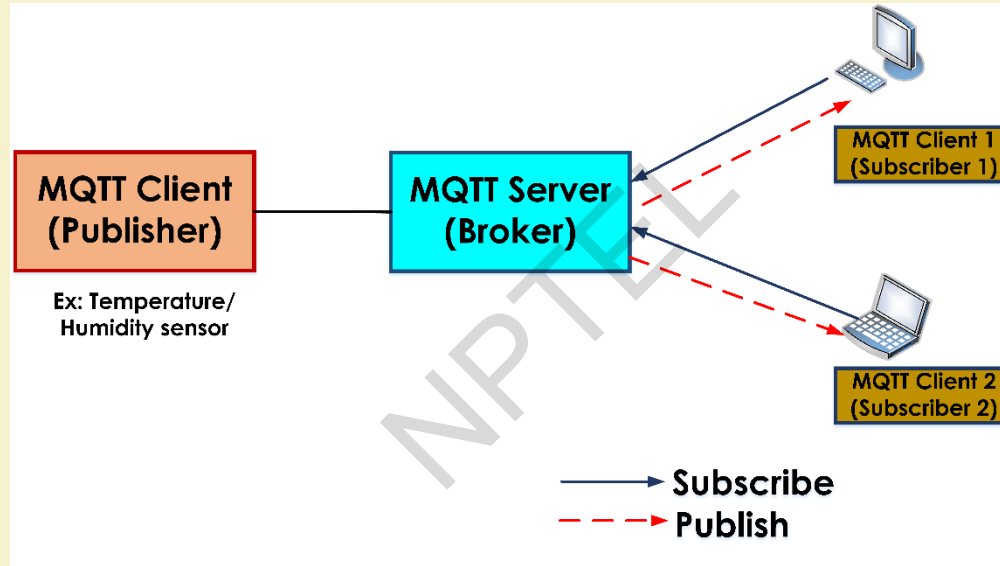




# MQTT

- Message Queue Telemetry Transport
- Introduced by IBM and standardized by Organization for the Advancement of Structured Information Standards (OASIS) in 2013
- Works on Publish/Subscribe framework on top of TCP/IP architecture
- Advantages
  - Reliable, Lightweight, and cost-effective protocol

# MQTT Publish/Subscribe Framework



**Source:** Hanes, D, et al. (2017), "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things", Cisco Press.

# MQTT QoS

- QoS of MQTT protocol is maintained for two transactions
  - First transaction: Publishing client → MQTT Server
  - Second transaction: MQTT Server → Subscribing Client
- Client on each transaction sets the QoS level
  - For the first transaction, publishing client sets the QoS level
  - For second transaction, client subscriber sets the QoS level

**Source:** Hanes, D, et al. (2017), "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things", Cisco Press.

# MQTT QoS Levels

- Supports 3-level of QoS
- **QoS 0:**
  - Also known as “at most once” delivery
  - Best effort and unacknowledged data service
  - Publisher transmits the message one time to server and server transmits it once to subscriber
  - No retry is performed

**Source:** Hanes, D, et al. (2017), "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things", Cisco Press.

# MQTT QoS Levels

## ➤ QoS 1:

- Also known as “at least once” delivery
- Message delivery between the publisher, server and then between server and subscribers occurs at least once.
- Retry is performed until acknowledgement of message is received

## ➤ QoS 2:

- Also known as “exactly once” delivery
- This QoS level is used when neither packet loss or duplication of message is allowed
- Retry is performed until the message is delivered exactly once

# CoAP



# CoAP

- Constrained Application Protocol
- CoAP was designed by IETF Constrained RESTful Environment (CoRE) working group to enable application with lightweight RESTful (HTTP) interface
- Works on Request/Response framework based on the UDP architecture, including Datagram Transport Layer Security (DTLS) secure transport protocol

**Source:** Hanes, D, et al. (2017), "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things", Cisco Press.

# CoAP

- CoAP defines four types of messages
  - CON: Conformable
  - NON: Non-conformable
  - RST: Reset
  - ACK: Acknowledgement
- For conformable type message, the recipient must explicitly either acknowledge or reject the message.
- In case of non-conformable type message, the recipient sends reset message if it can't process the message.

**Source:** Hanes, D, et al. (2017), "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things", Cisco Press.



# CoAP

- Utilizes GET, PUT, OBSERVE, PUSH, and DELETE messages requests to retrieve, create, initiate, update, and delete subscription respectively.
- Supports caching capabilities to improve the response time and reduce bandwidth consumption.
- Uses IP multicast to support data requests sent to a group of devices.
- Specialized for machine-to-machine (M2M) communication.

**Source:** Hanes, D, et al. (2017), "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things", Cisco Press.

**XMPP**



# XMPP

- Extensible Messaging and Presence Protocol
- Supports Publish/Subscribe messaging framework on top of TCP protocol
- The communication protocol is based on Extensive Markup Language (XML).
- Uses Datagram Transport Layer Security (DTLS) secure transport protocol

**Source:** Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

# XMPP

- XMPP model is decentralized, no central server is required.
- Advantages of XMPP
  - Interoperability: Supports interoperability between heterogeneous networks
  - Extensibility: Supports privacy lists, multi-user chat, and publish/subscribe chat status notifications
  - Flexibility: Supports customized markup language defined by different organizations according to their needs

**Source:** H. Wang et. al., "A Lightweight XMPP Publish/Subscribe Scheme for Resource-Constrained IoT Devices," IEEE Access, vol. 5, pp. 16393-16405, 2017.

**AMQP**



# AMQP

- Advance Message Queuing Protocol
- Optimized for financial applications
- Binary message-oriented protocol on top of TCP
- Supports Publish/Subscribe framework for both
  - Point-to-point (P2P)
  - Multipoint communication

**Source:** Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

# AMQP

- Uses token-based mechanism for flow control
  - Ensures no buffer overflow at the receiving end
- Message delivery guarantee services:
  - At least once: Guarantees message delivery but may do so multiple times
  - At most once: Each message is delivered once or never
  - Exactly once: No message drop and delivered once one

**Source:** Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

**IEEE 1888**





# IEEE 1888

- Energy-efficient network control protocol
- Defines a generalized data exchange protocol between network components over the IPv4/v6-based network.
- Universal Resource Identifiers (URIs) based data identification
- Applications: Environmental monitoring, energy saving, and central management systems.

**Source:** Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

# DDS RTPS



# DDS RTPS

- Distributed Data Service Real Time Publish and Subscribe
- Supports Publish/Subscribe framework and on top of UDP transport layer protocol.
- Data-centric and binary protocol
- Data is termed as “topics”.
- The users/listeners may subscribe to their particular topic of interest

**Source:** Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

# DDS RTPS

- A single topic may have multiple speakers of different priorities
- Supports enlisted QoS for data distribution
  - Data persistence
  - Delivery deadline
  - Reliability
  - Data freshness
- Applications: Military, Industrial, and healthcare monitoring

**Source:** Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

# Thank You!!

