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Introduction: Sensing & Actuation

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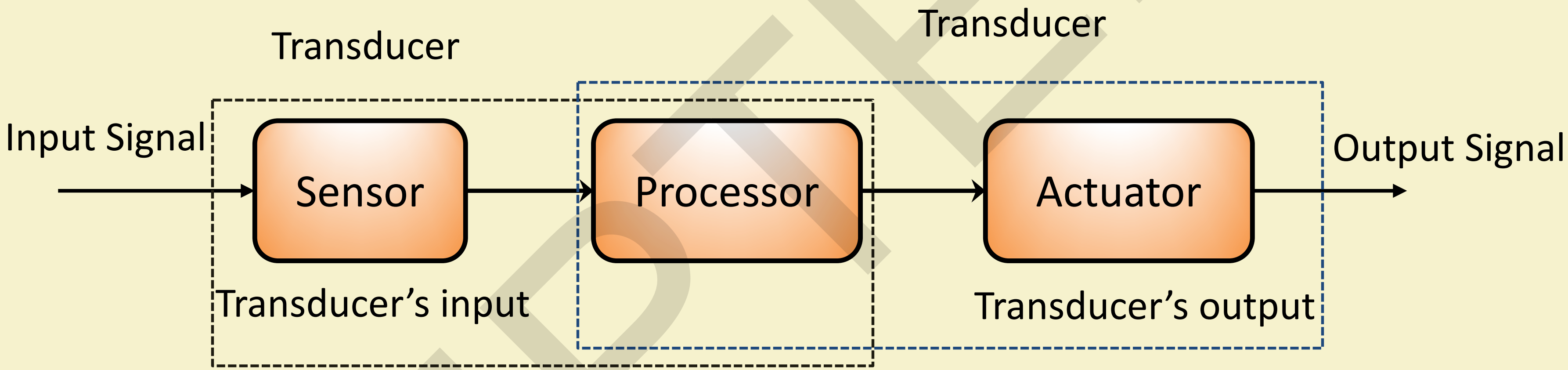
Transducer



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

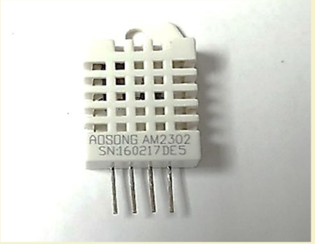
Definition of Sensor

- The characteristic of any device or material to detect the presence of a particular <u>physical quantity</u>
- 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.)

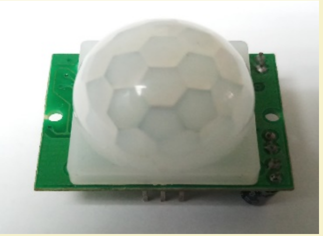


Temperature and Humidity sensor – DH22

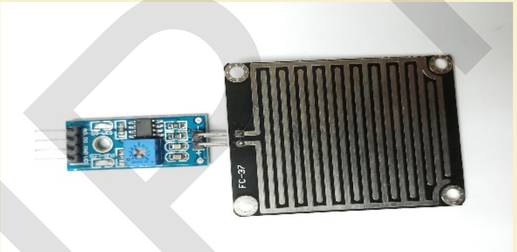
Gas (LPG, CH4, and CO) detector sensor - MQ-5

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 <u>incremental change in the response of the system with respect to incremental change in input parameter</u>.
  - It can be found from slope of output characteristic curve of a sensor
- Linearity
  - The deviation of sensor value curve from a particular <u>straight line</u>

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 <u>no delay</u>
  - <u>Does not include energy-storing</u> elements
  - Example: Potentiometer measures linear and rotary displacements

Dynamic Characteristics (Contd.)

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

Sensor Classification

- Sensor
  - Passive and active
  - Analog and digital
  - Scalar and vector

Passive Sensor

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

Active Sensor

- Independently sense the input
- Example: Radar, sounder, 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)

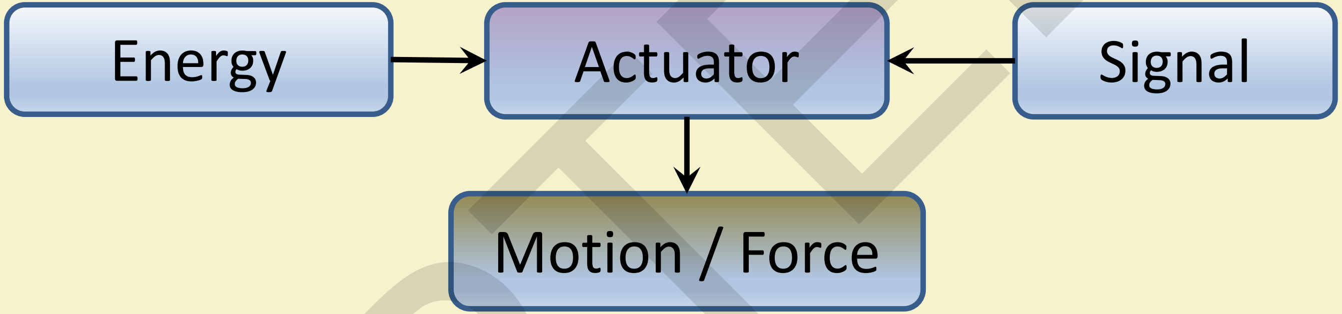
Scalar Sensor

- 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

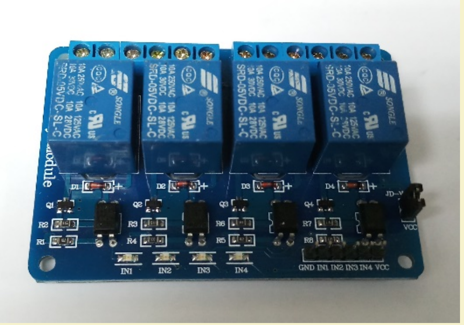


- An actuator is part of the system that deals with the control action required (mechanical action)
- Mechanical or electro-mechanical devices

Actuator (Contd.)

- A <u>control signal</u> is input to an actuator and an <u>energy source</u> 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

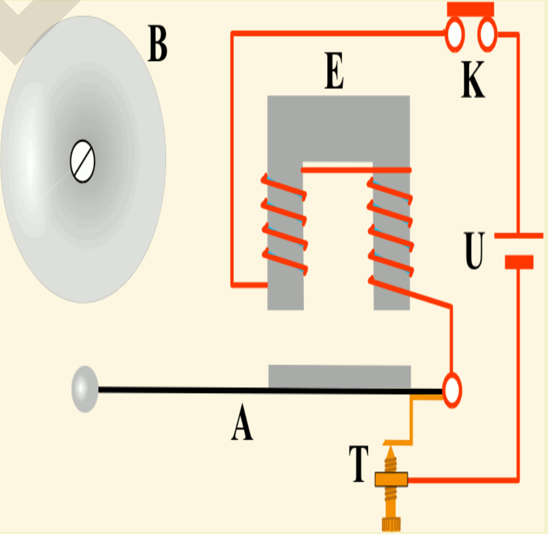
Classification of Actuators

- Electric Linear
- Electric Rotary
- Fluid Power Linear
- Fluid Power Rotary
- Linear Chain Actuators
- Manual Linear
- Manual Rotary

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

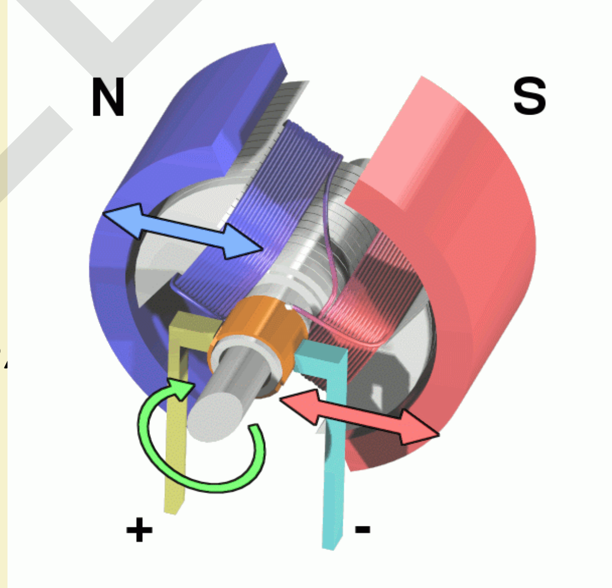


Source: “Electric bell”, ЮК/ Wikimedia Commons/, Published date: 18 February 2008, Online: https://commons.wikimedia.org/wiki/File:Electric_Bell_animation.gif

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

Electric Rotary Actuator

- Powered by electrical signal
- Converts <u>electrical energy</u> into <u>rotational motion</u>
- 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

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

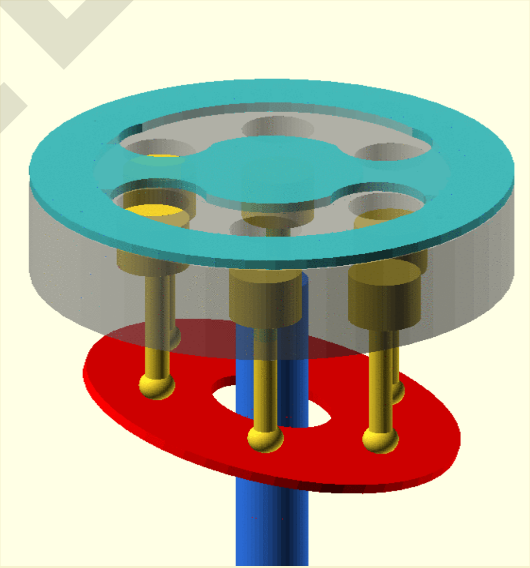
Fluid Power Linear Actuator

- 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

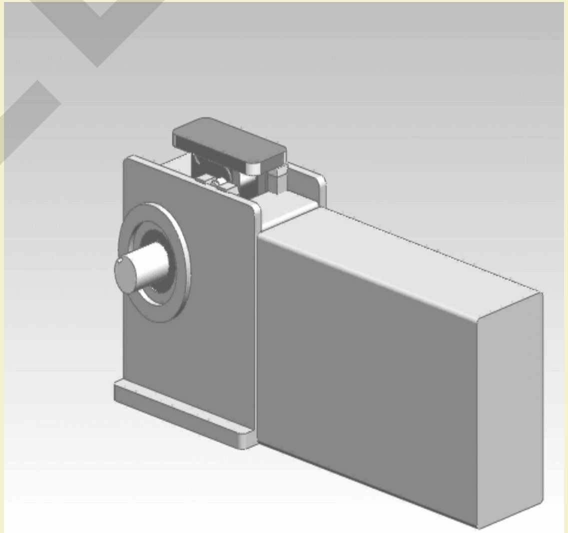


Source: “Axial piston pump”, MichaelFrey / Wikimedia Commons / CC-BY-SA-4.0 International/. Published date: 11 August 2017, Online: https://commons.wikimedia.org/wiki/File:Axialkolbenpumpe_-_einfache_Animation.gif

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

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 higher data rate 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	Increases range 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 China. 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 Japan. 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 ISA SP100.11a application (industrial applications).
802.15.4f	Defines fresh PHYs for 433 MHz frequency band (RFID applications), 2.4 GHz frequency band and UWB.
802.15.4g	Defines fresh PHYs for smart utility networks for 902 - 928 MHz band (smart grid applications, 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.)

- <u>Relaying</u> of packets allow transmission over greater distances.
- Provides <u>low power consumption</u> (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 (> ~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 alloted 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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Introduction: IoT Connectivity – Part 2

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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 then 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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Introduction: IoT Networking- Part I

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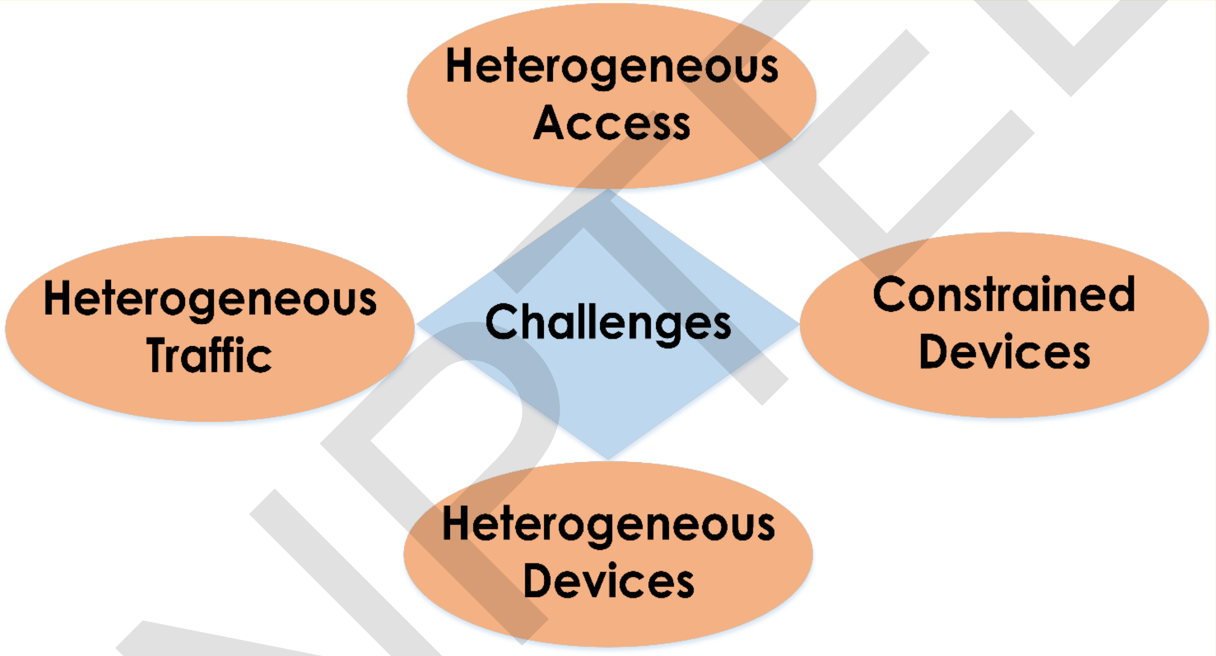
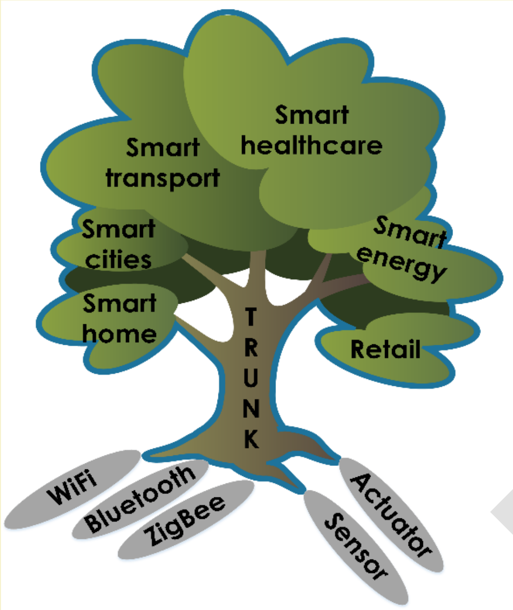
Introduction

- 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."

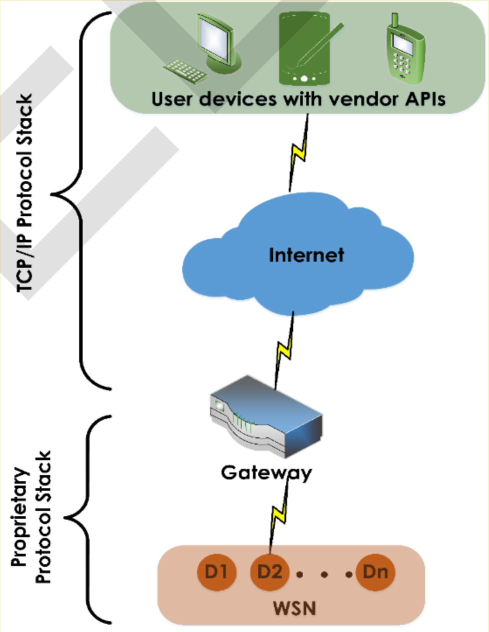
Enabling Classical Internet for IoT Devices

- 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 <u>storage</u> and <u>bandwidth</u> 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

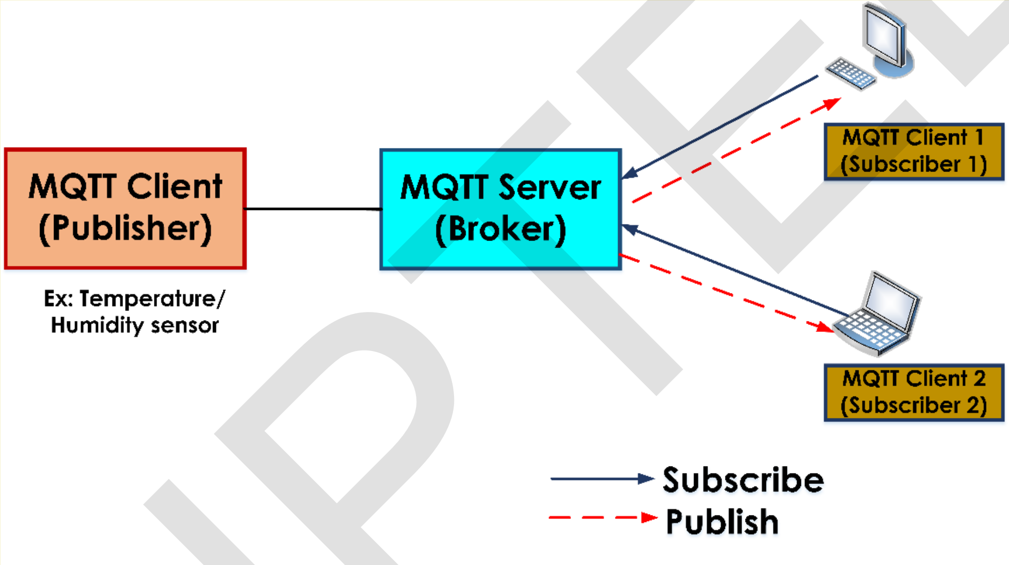
- Coverage
- High throughput
- Low latency
- Ultra reliability
- High power efficiency

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 recieved
- **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!!